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 CO_2 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.

Abstrato

A presente dissertação enfoca o tema do acesso à energia e das ecovilas, como modelo para alcançar uma vida sustentável da comunidade, investigando o tema do desenvolvimento sustentável por meio de um caso real em estudo. A teoria foi posta em prática para alcançar a sustentabilidade da Comunidade Koinonia, localizada em Lusaka, Zâmbia.

A primeira grande proposta diz respeito à otimização e substituição do método de cozimento à base de carvão vegetal do Centro Mthunzi, o orfanato localizado na Comunidade. Três tecnologias são propostas: um microgasificador, um fogão a GLP e uma mistura de biogás e GLP. O microgasificador resultou na tecnologia mais sustentável atingindo um VPL positivo igual a 23.357 € e uma redução equivalente a 94% no CO2 em relação ao carvão vegetal.

A outra avaliação refere-se a um estudo de viabilidade focado no projeto de um sistema de bombeamento solar independente. O duplo objetivo é testar módulos solares flexíveis inovadores e fornecer água à escola de agricultura na Comunidade. Três configurações do sistema são propostas, duas com baterias e uma com armazenamento de água. O último demonstrou ser o mais acessível e escalável para as áreas rurais, com um LCOE igual a 0,103 € / kWh para o caso de autofinanciamento e 0,034 € / kWh para o caso de doação.

Finalmente, para alcançar a sustentabilidade da Comunidade, é desenvolvida a criação de uma empresa local. O projeto tem como objetivo produzir carvão de bambu sólido. O projeto piloto demonstrou a rentabilidade do empreendimento com um lucro de 34 € por dia para o caso analisado.

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

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Acronyms

CF Carbon footprint

EF Ecological footprint

EHV Effective heating value (kJ/kg)

FP Flaming-pyrolysis front

GDP Gross Domestic Product

GEN Global Ecovillage Network

gha global hectares

GHG Green House Gas

GTI Global tilted irradiation

HDI Human Development Index

HHV higher heating value (kJ/ kg)

HRT hydraulic retention time

ICS Improved biomass cookstoves

IEA International Energy Agency

IRR Internal Rate of Return

LCOE Levelized Cost of Energy

LHV lower heating value (kJ/ kg)

LPG Liquefied Petroleum Gas

MC Moisture Content (%)

MPPT Maximum Power Point Tracker

NGO Non-Governmental organization

NPC Net Present Cost

NPV Net Present Value

OLR organic loading rate

PM Particulate Mater

pp per person

PP Payback Period

SDG Sustainable Development Goals

tCO2-e tonnes of CO2 equivalent

TLUD Top Lift Up Draft

UN United Nations

WBT Water Boiling Test

WHO World Health organization

WWF World Wildlife Fund

1.Introduction

1.1. Motivation

In the anthropogenic era and particularly during the last 50 decades, the human being is irreparably damaging the earth. Loss of ozone layer, global warming and climate change, air and water pollution, arable land lost to erosion, salinity and desertification, water scarcities, disappearing forests, extinction of biodiversity, and depletion of mineral resources are the evident consequences of human unsustainable lifestyle. It cannot be permitted a further degradation of the planet earth, the only known location in the Universe that supports an incredible array of diversity of nature that varies in size, shape, colour, movement, and function, and this variety of ecosystems is an immense heritage that is a duty to preserve.

Contrarily, the human being is destroying the earth's biodiversity. It is estimated that in the last decade the rates of species' extinction dramatically rose from 10 to 100 [1]. Moreover, the agriculture sector is one of the main contributors to the destruction of the Earth's ecosystems with the greatest impact on the environment and its biodiversity. During the last 50 years, more than a quarter of the globe have been destroyed through land abuse and overuse. Forests are dramatically attacked by the agriculture sector, it was reported that over the last decade 130 million hectares of forest were cleared, with 40% of them for expansion of agriculture. The same treatment is reserved to the ocean's resources, where on average 70% of world's marine fisheries resources are over-exploited without any possibilities to regenerate. Furthermore, the intensive use of fossil fuels has been producing the dramatic threaten of Global Warming. The former is affecting both the biodiversity and the thermal balance of the earth creating extreme weather condition that contributes to destroying human community and ecosystems. It is now evident that the global carbon pool is altered. Carbon dioxide concentrations in the atmosphere have risen by more than quarter and concentrations of methane, another important greenhouse gas, have doubled in the last decade. An over evidence is represented by an extremely high concentration of air pollutants. As demonstrated by the World Health Organization (WHO), ambient air pollution contributes to 7.6% of all deaths in the world in 2016. Furthermore, 91% of the global population is living in areas where air quality exceeds the health limits fixed by the WHO [2]. It can no longer be denied that human species with his activities is irreversibly damaging the planet earth.

During the exploitation and devastation of forests of the Saxon court in Freiberg, Hans Carl von Carlowitz (1645–1714) expressed for the first time the concept of Sustainability. He realized that deforesting without replanting trees would have destroyed future possibilities of using the wooded resource [3].

By this materialistic intuition, it came from 3 hundred years later the commonly recognised definition of sustainable development. It is expressed as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Therefore, sustainable development recognizes that the growth must be inclusive and respectful of the environment to reduce poverty and inequalities, creating shared prosperity for both today and future populations. The three pillars of sustainable development are economic growth, environmental management and social inclusion that must cooperate harmonically to achieve global goals.

The new frontiers of development today lead directly to the challenges of the millennium, as declined by the United Nations. These challenges represent a set of complex objectives in the individual specificities and multidisciplinary as a whole and constitute the challenge for Humanity and Civil Society in the next decade. The United Nations, during the General Assembly of October 2015, has expressed the 2030 Global Agenda to shift the world onto a sustainable and resilient path [4].

The specific motivation behind this thesis is to investigate the potentiality and the modality for the creation of sustainable communities. The aim is the creation of a new paradigm in which energy is the main engine. Access to energy is crucial for sustainable development. It can bring economic emancipation, through job creation and economic savings to communities.

The aim of this thesis is to investigate 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. The mentioned Community will be used as example to show a potential alternative for rural communities in developing countries.

These two topics, the energy access and the benefits of ecovillages, will be further investigated, to show their importance to create a global development with a lower impact for our Earth. A simplification of the diagram is displayed in Figure 1.

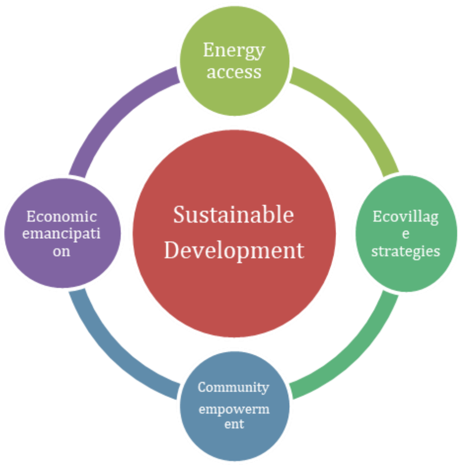


Figure 1: The specific sustainable development paradigm

1.2. Objectives

The case study for this thesis will be the Mthunzi Centre in Lusaka, Zambia. The present thesis has been implemented with the support and collaboration of the Amani Non-Governmental organization (NGO). It is an Italian NGO established in 1995 with the scope of fighting poverty in Africa. The main activity is related to host orphans and street children, living in the biggest cities of Sub-Saharan Africa: Lusaka and Nairobi. Particularly, the present work will be focused on their activities in Lusaka, capital of Zambia. Amani NGO, in Zambia, takes care of the Mthunzi Centre, an orphanage that hosts 50 ex-street children. The Mthunzi centre is located 20 km far from Lusaka, in the Koinonia community. The latest is a rural community, founded by Father Kizito in 1982. Koinonia Community is composed of 10 families that live in an area of 40 hectares.

The Amani NGO, with its holistic view, wanted to create a self-sufficient community, in which, through the synergy between the orphanage and Koinonia, the inhabitants of the community and the children of Mthunzi can live more sustainably, reaching the self-realization and happiness.

The Amani NGO believes in the strengthening of the community through a sustainable development approach and their overall objectives are summarised below, in Figure 2.

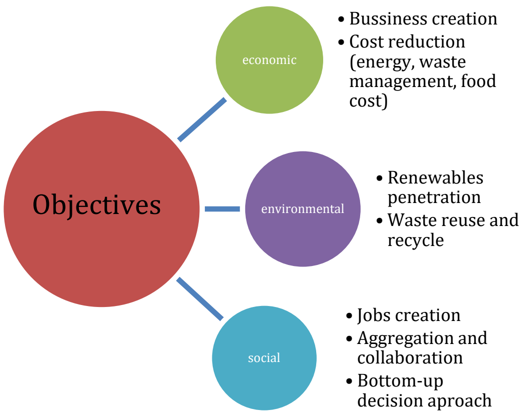


Figure 2: Objectives of Amani NGO

In more detail, these objectives are further explained next.

- Economic objective: currently, the community and the Mthunzi centre do not have an income. The latter survives through national funds and international donations. The NGO aims to reduce the costs associated with energy and food consumption, through the self-production of energy and food.

  Furthermore, it is crucial for the community to find new sources of income, for example by creating a local business.
- Environmental objective: Amani's philosophy is to create a reality that encompasses the principles and practices of the circular economy and environmental sustainability. The purpose is to minimize emissions, using renewable energy, recycle and reuse as much as possible the produced waste, use agricultural practices with low environmental impact and promoting local food production.

  The goal is not only to create an ecovillage that has a low impact on the local and global context but is to create an example of sustainability for Zambia that, hopefully, will be imitated.
- Social objectives: The approach of the thesis and of the association itself is primarily aimed at understanding the needs of the local community, made by its inhabitants. Changes start from them and from them must be created and set in motion. The social goal is to empower the community by giving the tools to better administrate the decision process. The project approach is of a bottom-up type. Every decision and change must be promoted and proposed by the local

community, whoever they are: the inhabitants of Koinonia community, the staff of the orphanage or the children themselves.

By generating local businesses, jobs can be created, which could increase personal well-being. In this context, the main objectives of this thesis are divided into three main topics: electricity access, clean cooking access and business creation.

- Regarding the clean cooking access, the goal is the replacement of the traditional cooking method based on charcoal. The aim is to investigate an alternative able to bring energy and economic savings to the Mthunzi centre, by using low impacts cooking alternatives.
- Regarding electricity access the main goal is to implement a feasibility to size a solar pump system. The aim is to reduce the dependence by the electrical grid in order to test the technology for off-grid rural areas.
- Regarding the business creation, the aim is to investigate the production and supply of charcoal in a sustainable and optimized way. The charcoal will be produced from solid bamboo. The objectives related to this venture are the generation of income on a local scale and the creation of jobs opportunity in local communities.

Consequently, the motivation and the philosophy for the achievement of those goals are further explained in detail.

1.3. Reaching the objectives through a sustainable development

1.3.1. Ecovillages as a model to achieve sustainable development

In recent decades' new modalities of living in communities have experimented all around the world. This alternative is represented by ecovillages. That alternative came from the necessity to experience a different model to the current social, economic and agricultural state of things. Ecovillages are fundamentally built by a group of people that share common objectives that depend on each specific case, but, that usually consider ecological, cultural and socio-economic dimensions.

The most popular definition of an ecovillage is represented by the following: "a human scale, full-featured settlement, in which human activities are harmlessly integrated into the natural world, in a way that is supportive of healthy human development and can be successfully continued into the indefinite future" [5]. The idea behind the ecovillage philosophy is the creation of a life in harmony with the natural ecosystem and through a bottom-up and circular approach present an alternative to the linear society and urban ecosystem.

The ecovillage movement started in 1995 with the foundation by Ross and Hildur Jackson of the global initiative of Gaia Trust, that contributes to the creation of the Global Ecovillage Network (GEN).The main idea was to acquire consciousness of global issues to acting on a local scale.

Three are the main topics that are necessary to understand the ecovillage's figures and goals.

- Social dimension: The inhabitants of the ecovillages are responsible and supported by the group. They share common resources and mutual aid principles. An ecovillage represents an alternative model to consumerism and the institutionalization of social services. The social dimension emphasizes the concept of unending education. Moreover, it centralizes the sense of empowerment within the community as people, leading the community to engage in transparent decision-making. It becomes also crucial encouraging minorities, seniors and marginalized group to take part in community actions.

- Ecological dimension: It is profoundly stimulated the respect for nature. Closeness to the living ecosystems of earth, resilient local food systems and less human pressure on nature are highly prioritized. The circular economy concept is interiorized, using low-impact infrastructure, preservation local ecosystem and ecological business models. The main principles are represented by the holistic and permaculture approach.
- Spirituality dimension: In the ecovillages, values such as creativity, belonging and respect for other culture are a priority. The goal is to reach an inner and community richness through diversity, solidarity, simplicity, respect for the environment, development of one's interiority.

To quantify the benefits of ecovillages and give evidence of the more sustainable lifestyle of these communities, compared to “mainstream” society, it will be considered the environmental aspect of sustainability, considering the ecological footprint (EF) and the carbon footprint (CF) as parameters.

The ecological footprint is defined as “the parameter to measures the ecological assets that a given population requires to produce the natural resources it consumes (including plant-based food and fibre products, livestock and fish products, timber and other forest products, space for urban infrastructure) and to absorb its waste, especially carbon emissions” [6]. It is expressed in terms of equivalent land area (global hectares or gha), that indicate the productive area necessary to supply the renewable resources and absorb the waste for a given human being during a specific period, usually a year. Even if, using the Ecological footprint as a measure can appear limitations and methodological issue, it has been recognised as the most efficient parameter to measure ecological performances. There are two methods to quantify the EF: the compound and the component method. The first is mostly used in regional, national and international levels and take into consideration analysis based on statistical data. The second one is mostly appropriated for a local level. It takes into consideration a "bottom-up” approach that interconnects local consumption data (for example the annual driving distance) with the data that has been pre-computed on a region scale (for instance the impact per passenger-km).

The CF is a parameter that is taken into consideration in the ecological footprint, and its account for more than half of the result of the ecological ones. The CF can be expressed in different ways and units, using tonnes of CO_2 (tCO_2) or tonnes of CO_2 equivalent (tCO_2-e), alternatively in global hectares (gha), to immediately relate it with the overall EF.

In the literature review assessed by Matthew Daly, he reported a systematic and quantitative analysis of the environmental impact of ecovillages, comparing them to relevant “mainstream” communities located in the same region of the ecovillages taken into consideration. Identifying 16 separate scientific studies, with publications dated between 2000 and 2014, he analysed the environmental performance of 23 communities using as measures the EF and the CF [7].

The analysis was performed by using the following boundary conditions and guidelines to rigorously choose the literature data:

- Community purpose: ecovillages that have the environmental impact reduction as a vision, goal, aim or principle.

- Development process: ecovillages that were developed with approaches such as Bottom up, grassroots-initiated communities, formed and created by members.
- Assessment metric: academic papers that based their analysis on EF (gha/pp) and CF (tCO_2/pp/yr or tCO_2-e/pp/yr) parameters.
- Method of publishing: Academic literature, Academic reports, PhD & Masters theses Professional reports, Community reports Detailed summaries of reports on community websites.

The analysed researches were focused on ecovillages based mostly in Europe and the USA, mainly because major researches on the topic were assessed in these regions.

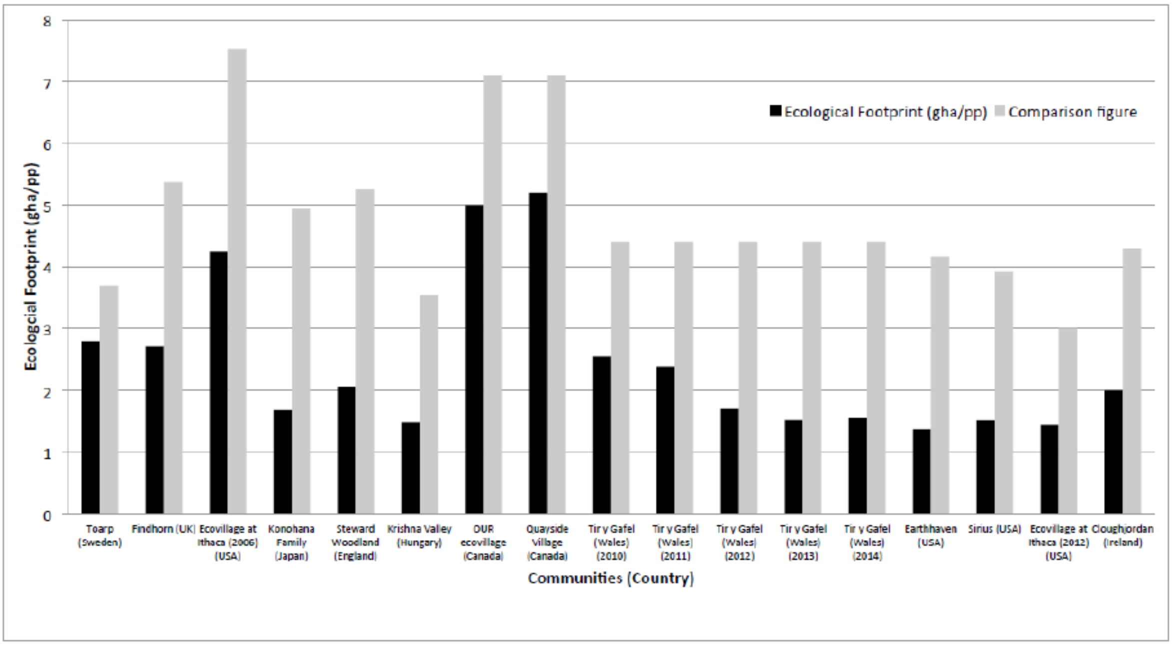


Figure 3: Comparison between EF of ecovillages and regional one [7]

As displayed in Figure 3, it can be affirmed that the analysed ecovillages have achieved a lower footprint compared to the EF for the specific region. On average the ecological footprint in analysed ecovillages was measured to be 50% less than the EF of the comparison figures. There is a great variety between the different communities. For example, the Quayside Village Cohousing, Canada, reached the highest measure of EF of 5.2 gha/pp, around 400% higher than the lowest footprint, represented by the Earthaven Ecovillage, USA., with 1.3 gha/pp.

A relevant example is represented by the Ithaca ecovillage, located in the USA. It was discovered that thanks to the use of a 50-kW solar PV system, installed in the community, it was lowered the EF from 4.3 gha/pp to 1.4 gha/pp.

Even regarding the Carbon footprint, it was noted that ecovillages' practices achieved a lower footprint compared to the "normal" comparison.

Contrarily to the result obtained using only the EF as a measure, it was found that for three communities the carbon footprint for the comparison location was lower than the ecovillages' ones. Higher CO_2 emissions were mainly due to the impact of transport. The reason is that due to the rural locations of that ecovillages, the impact of the fuel-burning for personal transportation resulted in a higher footprint than the compared figures. Overall, the average CF in ecovillages results lower than the "normal" cases, with a reduction on average of 35%.

Consequently, it can be recognised that ecovillages achieve greater environmental performances compared to “mainstream” communities and that is necessary to explore, in detail, how these communities can achieve those sustainable socio-technical systems.

Nevertheless, it needs to be highlighted that not all the ecovillages analysed can achieve the target expressed in the Living Planet Report [7] , which found that the available global bio-capacity, to live in the ecological boundaries of one planet, is 1.7 gha/pp. Actually, only five of the analysed communities had footprints lower than that. However, neither the above communities can achieve the World Wildlife Fund (WWF) targets if the ecological footprint would have been computed using the compound method. The EF for the analysed ecovillages has considered the component method, that is lower than the compound one because gives a lower contribution to the impact of the services, such as health care, legal, government and military services.

Despite the limitations of comparing ecological and carbon footprint studies, it is evident that the ecovillages approach allows achieving a more sustainable human development.

Common practices, used in the analysed ecovillages, were found, that allows achieving a low impact ecosystem. It was noted that most ecovillages had used sustainable design and construction principles and techniques. For example, the use of local construction materials, passive solar designs and high levels of insulation. The use of renewable energy was used in all the communities and has a major role in lowering carbon emissions. The scale of social organisation and high levels of social capital enable residents to play an active role in install and use sustainable technologies for their homes. This consideration explains that is crucial how environmentally friendly technologies are introduced in local communities, and this cannot deny a bottom-up approach. Other practices were found common within the analysed ecovillages: resources reuse, great levels of recycling, composting of waste materials and sharing the use of communal facilities. Another common aspect was the reduction of transport footprints. Many communities encourage cars sharing and a reduction of travels thanks to the use of community co-working spaces.

Sustainable Household food provisioning and procurement, and as well as low impact cooking practices, contributed to achieving lower levels of EF than the "mainstream" communities. The reported ecovillages produced, in their organic farms and gardens, most of the portion of their food consumptions. This allows an environmental impact reduction of packaging, distribution and industrial farming practices. Moreover, the reduction in meat consumption and the use of a vegetarian-based diet guarantee a lower EF than surrounding regions.

1.3.2. Energy access as the engine of sustainable development

The differences between developed and developing of the world will increase if we do not allow and guarantee the necessary access to energy. There cannot be development without energy, and it will not be sustainable without using renewable sources. All production activities and many primary needs need energy in the form of heat or electricity.

The UN General Assembly has set a horizon for 2030, 17 Sustainable Development Goals (SDG). At number 7 we find: "Ensuring access to modern, sustainable and safe energy systems at affordable prices for all" [4].

Energy and development are an inseparable binomial: the economic development of a country cannot take place without adequate access to energy. Energy helps meet basic needs and plays a role fundamental for the industrial and rural development of a country. The correlation between energy and development is highlighted in Figure 4, where are displayed two of the most important parameters about the topic: the Human Development Index (HDI) and the Energy Development Index. The first is the most used indicators to express the development of a country and consider the expectation of life, education and economic development of a country. The second indicator, presented by the International Energy Agency (IEA), express the energy access of a country and as it can be seen it is strictly linked to the HDI parameter.

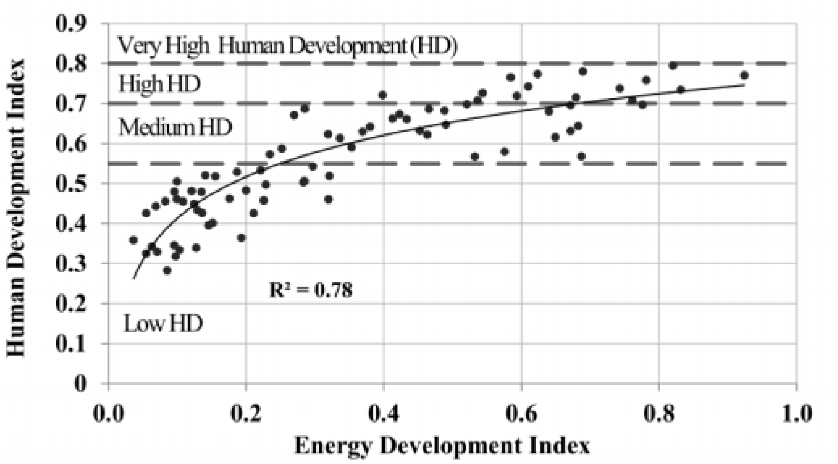


Figure 4: Correlation between the Human Development Index and Energy Development Index [8]

The limit to guaranteeing access to energy is not technical. There are adequate technologies to bring a significant part of humanity to sustainable development. There are also no economic limits as IEA demonstrates, it would take $ 750 billion over 20 years or $ 36 billion a year, equivalent to only 3% of annual global energy investments [9]. Of these, 700 billion would go to investments in the electricity sector and only 50 billion to the clean cooking sector. A suitable approach is lacking, which does not use technocratic methodologies, based on the belief that technology and money are sufficient to dismantle poverty, particularly energy poverty. It is necessary to know people and their needs, to study their cultures and habits.

In the joined energy report of the World Bank and IEA, the surveys about energy access are dramatic. It was estimated that 1.1 billion people, equal to 16% of the world's population, have no access to electricity, while 2.9 billion, 38% of the population, has no access to cooking methods and "clean" heating [10].

The definitions expressed by the IEA is the following: "a household having reliable and affordable access to both clean cooking facilities and to electricity, which is enough to supply a basic bundle of energy services initially, and then an increasing level of electricity over time to reach the regional average".

For the first time in 2015, the Energy was recognised as crucial for the development and prosperity of humanity and this reason was recognised one of the 17 SDGs. The Energy access is even crucial and strictly linked to achieve many of the others SDGs such as poverty reduction (SDG 1), air pollution decrease, increase of the levels of life expectancy and access to essential healthcare services (SDG 3), achieving minimum levels of education (SDG 4), adaptation and mitigation of climate change (SDG 11), food production and security (SDG 2), economic growth and employment (SDG 8), sustainable industrialisation (SDG 9) and gender equality (SDG 5).

Regarding the gender inequality issues, it must be highlighted that women have more disadvantages than men when there is no access to energy. The later have to cook and spend time to collect wood to use in traditional stoves. On average they spend 1.4 hours per day collecting fuel and this has an impact even on their physical well-being, carrying on average 25-50 kg of wood per day per family [11].

Moreover, women and children, using traditional cooking methods are the most affected by air pollution. Women, spend most of the time cooking, in South Asia, they spend four hours per day [12], and to other manual actions, such as clothes washing and cleaning. Saving time, thanks to modern energy access can lead to new economic opportunity to women and even push their education, being one of the most important drivers for poverty reduction. It was discovered that a self-employed woman, with access to electricity, has an income two times higher than one without [13]. In many implemented projects it was seen that women can significantly help to spread modern technologies. This is because they have specific local knowledge about how access to modern energy services could serve household needs, and because of their capacity to influence the community.

As was mentioned, access to modern energy is crucial to guarantee a higher rate of education. Having an electrified school or being able to read during the night is fundamental to achieve global literacy. Over 90 million primary school aged children in sub-Saharan Africa attend schools without electricity.

In Brazil, girls with access to electric power in rural regions are 60% bound to complete primary school by the age of 18 than those without [14].

The Health global development goal is one of the most linked to the lack of energy access. It is estimated that the harmful pollution produced by traditional cooking methods and by traditional lights generate 2.8 million of premature death [15].The principal cause of worldwide premature deaths is the use of highly polluted biomass, such as wood and charcoal produced carbonizing the later. Most of the people find difficulties to switch to other cleaner technologies and fuels mainly because they are not economically affordable.

The link between health and access to energy is not only limited to the clean cooking topic. One of the major challenges is the electrification in a reliable way of hospitals. For example, in sub-Saharan Africa, almost 60% of health facilities have not electricity. Moreover, when there is electricity but supplied on an unreliable way it can extremely increase the cost of the health care system. For example, 50% of vaccines are lost due to the lack of electricity to supply to refrigerators and, moreover, more than 70% of medical devices fail due to poor power quality [16].

To reduce worldwide the poverty is not only important to spread the household energy access but also promote the energy access for productive purposes, guaranteeing a relevant economic growth to local communities.

In low income countries is minimum the energy use for productive uses. Regarding the agriculture sector, in developing countries, the energy is mainly provided by animal and human labour and by the traditional use of biomass or solar energy to process the food. Access to energy can considerably improve this sector. First, irrigation systems can be improved using modern technologies, such as solar water pump. These could efficiently increase the crops' yield. For instance, in India, it was experienced an increase of 35% in the food production since 2000 thanks to modern farming techniques, such as the use of electric pumps [15]. It is not only important to introduce modern technologies, but it is also crucial to use them efficiently.

Moreover, using processing and storage option powered by electricity can decrease food losses and increase the opportunity to commercialized food products. For example, grain dryer introduced in Vietnam allow reducing considerably the time spent to dry a tonne of rice from 46 person-hours to 7 person-hours [17].

Between the modern techniques, it can be highlighted the use of fertilizers. Even their production is energy-intensive and indispensable to increase food production and reduce starvation of many African countries.

Regarding the services sector, in many developing countries the lack of reliable energy supply represents a break to development. In 2015 Sub-Saharan African economics activities had 690 hours of black outs. That were estimated to affect the local economies for a cost equal to 2 % of the GDP [18].

Industrial activities are fundamental to the creation of a reliable electric system. This is justified by the fact that industries are seen by power utilities as creditworthy customers and anchor loads in term of electrical demand. Industries lead largely energy infrastructure economically feasible and consequently, the energy supply can be extended to the nearby communities. With this logic, providing energy to industries can not only create economic growth but also a reduction in the prize of energy for residential customers, that otherwise would not be able to afford the energy cost. For Example, in Zambia was build a solar-hybrid power plant to power a sugarcane plantation and processing industries with the objectives to supply the surplus of energy to surrounding communities [19].

The IEA, to quantify the problem of the lack of access to energy and therefore to provide remedies, expresses two possible scenarios: The "new policies scenario" and the "energy for all case" ones [15]. In the first, to foresee the future development of the energy access goals, it is provided with a quantitative assessment based on existing and announced energy policies. The analysis considers country-by country studies, consideration on population and economic growth, urbanization rate and the cost and availability of primary energy. Moreover, both present and approaching commercialization technologies are considered.

In the Energy for All Case scenario aims to predict possible strategies to reach completely the 7th SDG by 2030. This scenario takes into consideration the possible roads to achieve global access to electricity, highlighting the possible implication in term of energy demand, supply, investment, global and local pollution and thus on health. It has considered that energy access is achieved for rural households when it is supplied at least 250 kilowatt-hours (kWh) and 500 kWh for an urban household. The projections are assessed considering the most cost-effective solution to deliver energy.

Regarding clean cooking access, it is considered achieved when the population can use modern cook-stoves and fuels. Nowadays, it is estimated that more than 38% of the world's population is using solid biomass, for example, wood, charcoal, agricultural waste and manure, with traditional cooking methods [15].

In particular, the most critical situation is in Sub-Saharan Africa, where due to the increase in the population there was a rise in the number of people without access to clean cooking, equal to 240 million people from 2000 to 2015. On the other hand, in China, thanks to energy policies able to spread LPG technologies, the share of the population using solid fuels for cooking decreased of more than 30 % from 2000 to 2015 [15].

The hardest field for the spreading of modern energy technologies is in rural areas, where, due to the abundance of wood, the “three-stone” method is the most spread way to cook.

This consists of the use of three stones that act as a support for the pot, at the base of which wood is burned. The latter is collected by women, the only ones responsible for cooking, in the surrounding areas, covering many kilometres on foot. In this way, they are often unable to devote themselves to other tasks. Also, this traditional way to cook is a method that has a large dispersion of heat, resulting in a quite low efficiency, between 5 and 15 % [20]. Furthermore, this "open" fire is characterized by the bad mixing of fuel and air which leads to incomplete combustion capable of causing multiple pollutants.

Where there are no trees from which to draw, the solid fuel most commonly used in urban areas is the charcoal. This is produced by partially carbonising the wood that is collected in forest areas adjacent to the cities. In particular, the chemical-physical process that occurs is called: slow pyrolysis. The combustion of wood takes place in an oxygen deficiency and from it, two products are obtained: syngas, which is dispersed in the atmosphere and the charcoal that at the end of the process is collected and sold. The process is very slow and lasts several days with a charcoal yield of 35% [21].

The traditional cooking technologies are also directly responsible for two harmful phenomena one on a global scale and one on a local scale:

- Deforestation of large areas of the planet in developing countries, for the retrieval of raw materials. From 1990 to 2010 there was a reduction of forest areas in Africa of 74,819,000 acres or an annual decrease of 0,5% [22]. In Africa, more than 50% of the degradation of wooded areas is caused by the harvesting of wood for cooking purposes. Deforestation involves multiple consequences: the reduction of the number of animal species, regional climatic variations, possible hydrogeological instabilities and the reduction of the absorption of greenhouse gasses.
- The release, by combustion fumes, of dangerous pollutants inside houses. The WHO reports 2.8 million premature deaths annually due to toxic fumes in homes [15]. Indoor toxic fumes are estimated to be the second leading cause of death in the world, children are the most vulnerable target because they are very often alongside mothers who take care of cooking every day [2].

The International Energy Agency has estimated that different technologies are essential for global access to clean cooking by 2030. LPG technologies, electric burners and gas network diffusion are among the technologies that can immediately increase clean cooking access. But very often, they cannot be easily spread to rural areas due to lack of infrastructure. Moreover, at the economic level, they are not affordable for everyone. The graphs in Figure 5 shows the share of the different technologies for worldwide access to clean cooking by 2030. In particular, the new policies scenario cannot guarantee the prefixed goals, around 2.3 billion people will remain without access to cooking energy. Nevertheless, it is foreseen that 900 million people will gain access to modern energy, mainly thanks to the spread of the gas network and the LPG's use in urban areas. It has indeed been seen that since 2000 the number of people relying on LPG, gas and electricity to cook, has increased of 60 %, coherently balanced by a reduction of 50 % in kerosene and charcoal.

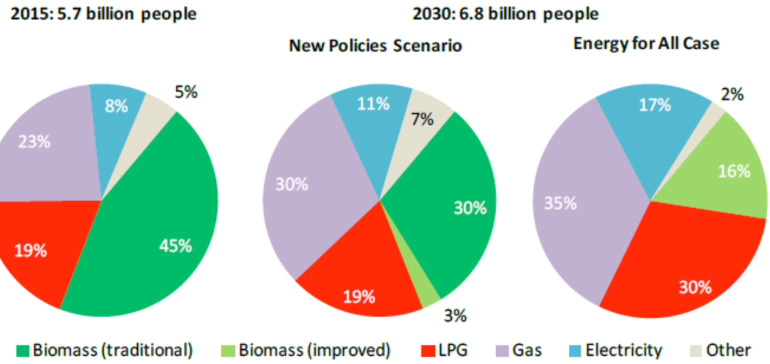


Figure 5: Population relying on fuels for cooking in developing countries (Note: Other includes coal, solar and biogas) [15]

To achieve objectives hoped by the "Energy for All Case" scenario, it becomes crucial the penetration, mostly in rural areas, of Improved biomass cookstoves (ICS) or "clean cooking". ICS can be typically described as a stove which has a higher efficiency or lower level of pollution than a traditional stove. ICSs can have different kinds of designs. The simplest ICS can be a stove that provides an enclosure for the fire to reduce the loss of radiant heat and protect it against the wind. Moreover, ICS can be considered when the upward flow of the combustion gases is controlled, to increase heat transfer to the cooking pot. The less expensive and easy ICSs to build are made of mud or sand, mainly because these materials are free and available. Between the most known ICSs Can be considered rocket stoves and simple micro-gasifiers, which operate a multi-stage burn (also known as wood-gas). ICSs represent in many countries the only alternative with the lowest upfront cost compared to other technologies. Improved and advanced cookstoves can cost less than traditional methods in terms of fuel cost if it has considered the time spend to gathering fuel. In fact, it needs to be considered that the time spent collecting fuelwood can be used to generate income.

The limitation is represented by the upfront cost of ICSs stoves that can be a barrier for poor people.

In rural areas, another alternative is represented by small-scale bio-digesters to produce gas for cooking. Their disadvantages are represented by the higher initial investment required and even by the available resources that not always is available. An example is the case of Bangladesh where the National Domestic Biogas and Manure Programme allows the expansion of biogas technologies in rural areas, and an estimated 80,000 small-scale systems that use animal waste are in operation [15].

As it was mentioned LPG represent a valid alternative in urban areas, but it has many limitations in another context where there are no valid distribution infrastructure and reliable roads. Moreover, both the cost of fuel and of the stoves are not competitive to solid biomass-based fuels. For these reasons in Africa, only 7 % of the population relies on this technology [23]. In term of emission, ICS stoves are not the best solution, but their reliability and affordability are the main characteristics to be considered by the International Energy Agency necessary to minimum energy access. Moreover, as demonstrated by the China National Improved Stove Programme, that distributed around 130 million improved stoves between 1982 and 1992, it was found that ICSs are a technology that can be integrated with local behaviours. From local surveys, in 1993 more than two-thirds of the stoves were still used.

The current status of the electricity access is not as negative as the clean cooking access, in fact, globally there was a decrease in the number of people without access to electricity from 1.7 billion people in 2000 to 1.1 billion in 2016, as shown in Figure 6 [15]. This gain was mainly due to the expansion of the grid in developing countries. There was the highest reduction of people without electricity in developing Asia where from 2000 to 2016 over than half a billion people achieved access to electricity. The major development was experienced by India where there over 40% of the population obtained access to electricity. On the other hand, as it was for the case of the clean cooking access, in Sub-Saharan Africa only 43% of the population has access to electricity and this number it is decreased since 2000 due to the population growth. Globally there are still 14% of the population without access to electricity and 84% of them is in rural areas.

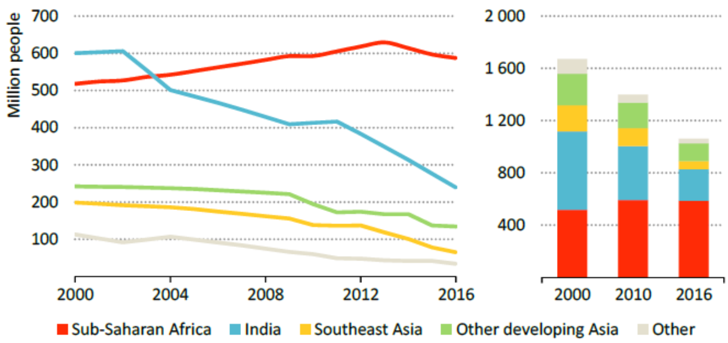


Figure 6: Millions of people without access to electricity by region [15]

A large part of rural areas in developing countries are a long way from the network and are characterized by low energy demand. For this reason, expand the network to these areas to ensure access to electricity, it turns out economically inconvenient. Therefore, governments have concentrated their resources on urban areas, more easily accessible and characterized by more productive economic activities.

The most convenient solution in these contexts is represented by decentralised systems. It provides the generation of electricity close to consumption and a sizing adapted to the demand that leads to a decrease in the investment. The distributed generation is often expressed by the concept of mini-grid. Mini-grids are generation and distribution systems that supply energy to a localised group of customers. Usually, they have a higher levelized cost of energy (LCOE) if compared to transmission and distribution energy supply. These options can make use of conventional (fossil fuel based), unconventional (renewable based) technologies or both. The most common solution adopted in rural areas without connection to the national network consists of the conventional decentralized generation (use of a diesel generator). Diesel generators are very widespread because they have several advantages: availability in developing contexts, simple technology that requires little time for installation, available for small sizes, adapted to the demand, low capital cost. On the other hand, they have many disadvantages: high and unstable fuel costs, also due to difficulty supply, high maintenance, dependence on fossil fuels environmental problems, low yields at partial loads where, moreover, diesel works for most of the time. For these reasons, many project and international organizations' advise push on the use of renewable sources that have many advantages: allows the exploitation of local resources and therefore the increase in diversification and the decrease in dependence on fossil fuels, maintenance is lower, flexibility is greater and long-term prices are low when compared to those of diesel. Renewable sources are, however, characterized by a major drawback, that is the unreliability. For this reason, it is necessary an energy accumulation system (usually batteries) which increases the complexity of the system, the necessary maintenance and the long-term costs. The best solution is a hybrid system that makes use of conventional and unconventional sources, combining the advantages of the two solutions and mitigating its disadvantages.

Mini-grids needs to be sized according to the local demands of energy, the local economic availability, the possibility to be connected to the grid and local natural resources.

An alternative to mini-grids is represented by off-grid systems. They are systems that usually supply energy to single household customers using diesel generators and or solar home systems. The upfront cost is the main barrier to the spread of this solution. However, it is increasing its attractiveness thanks to the decrease in PV and batteries cost.

As expressed by the IEA, access to electricity since 2000 was mainly through the grid extension, with 97 % of the share. This means that the main source of energy is not renewables. In fact, from 2000 to 2012, 72% of those who gained access did so via fossil fuels, with coal accounting for 44%. Sub-Saharan Africa, in this case, has a positive trend, hydropower, geothermal and PV systems were the main source of energy for the energy access, with 70% of the share [15].

The greatest effort to reduce the lack of electricity it needs to be done in rural areas where people are mostly zero income and without current potentiality to set up commercial activities. In these locations, many business models use communication technologies to provide low-cost energy. An example is a pay-as-you-go model, where thanks to mobile phone payments, the customer can pay the energy supplied by an off-grid solar system owned by a private company. These kinds of models have been extensively investigated to replace kerosene lamps and supply a minimum quantity of energy in remote areas. Use of proper software, mobile phones payment, customers friendly business model, efficient devices and national and international incentives are crucial tools to widespread off-grid systems in sparsely populated communities.

The IEA estimated in the New Polices Scenario a fall by 36% by 2030 in the number of people without access to electricity [15]. Half of them will achieve electricity access through the grid extension and 338$ of global investment. However, it still means that 674 million people (8% of the world's population) will be without access to electricity in 2030, because most of them are located in rural areas. In the Energy for All Case scenario are crucial mini-grids, powered by solar sources. As displayed in Figure 6, Mini-grids will be the most used strategy and will account for around 50% of the new energy systems, where the solar PV technologies will be indispensable.

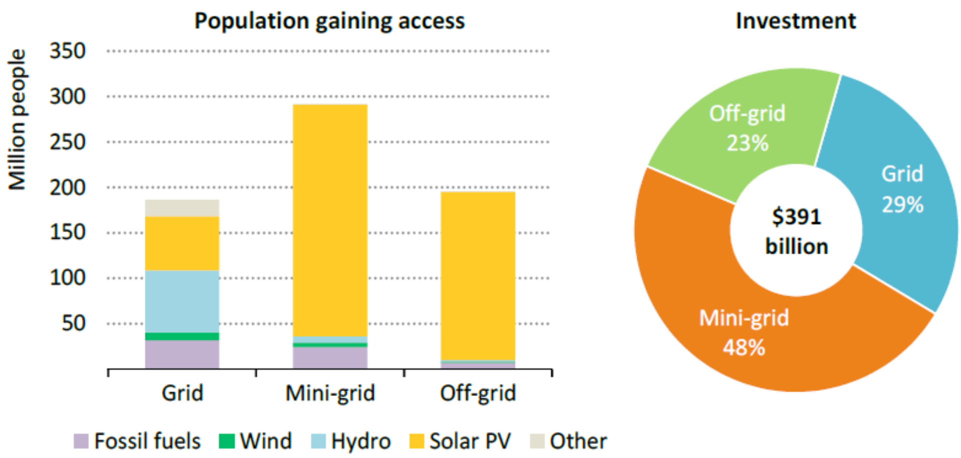


Figure 7: Share of the population gaining access to electricity and relative investments and technologies figures [15]

1.4. Structure of the thesis

To reach the prefixed objectives, it is first of all analysed the specific context of the Koinonia community. The habits of its inhabitants have been deeply understood, with a specific focus on the Mthunzi Centre. The context analysis is displayed in the Chapter 2. In there, both a focus on electrical and water consumption is shown. Moreover, a small analysis of the waste management in the community has been performed.

In the Chapter 2, the core of the analysis is performed. The chapter is mainly focus on the optimization of the cooking system of the Mthunzi centre. First of all, the current cooking method has been analysed, understanding its efficiency and costs. Consequently, three potential alternatives are investigated to replace efficiently the charcoal-based stove:

1. Using a microgasifier. This technology has been practically analysed in the field and its performances tested.
2. Using an LPG stove. The analysis has been performed only theoretically. The final energy consumption of this technology has been computed in comparison to the charcoal stove.
3. Using an Anaerobic Digester system. It has been understood the feasibility on the implementation of a small-scale anaerobic digester for the production of biogas from the available resources in the community.

After having analysed in detail the energy performances of the mentioned technology, an economic and environmental assessment have been developed.

In the Chapter 4 a pilot project focused on electricity and water access is investigated. It is performed a feasibility study aiming to implement a solar pumping system to supply water in the agriculture school of the Koinonia Community. Firstly, the technical aspects of the project have been investigated to size the solar system that uses a flexible solar PV module. Three settings are shown, and their energetic and economic performances are compared.

As it was mentioned in the introduction, it is crucial to generate income in rural areas to let inhabitants achieve a minimum access to electricity. In the Chapter 6, it is shown an example of a sustainable business that can generate an economic development, reducing the impact of human being on forest depletion. During the thesis development, it has started in the Koinonia community the production of charcoal from a local source: the solid bamboo. Future developments of this project will show more in details the benefits and costs of this venture.

2. Case study and methodology

2.1. Case study description

2.1.1. Zambia: Country Profile

The Republic of Zambia is a State (752,614 km², 15,972,000 inhabitants 2005) of central-southern Africa. Zambia is a presidential republic within the Commonwealth, a member of the United Nations and the African Union. The official language is English. Zambia gained independence from the British Empire in 1964. With the election of President Kenneth Kaunda, Zambia immediately proceeded with an interracial social pacification policy rejecting any racist-style government.

Zambia has a population growth rate of 2.93% with a total fertility rate of 5.63 children born / woman. Consequently, most of the population is young, 46 % of the habitants have an age between 0 and 15 years old.

Only 41% of the total population lives in the urban environment. However, what must be highlighted is the very high rate of urbanization, at 4.35%. This is because a lot of people leave rural areas due to food insecurities and extreme poverty, to seek a better quality of life in urban areas.

The economy of Zambia, once compared to that of the average of the African states, suffered in the seventies the collapse of copper prices on the international market. This event triggered a progressive economic decline that today places Zambia among the poorest countries in the world, with 70% of the population below the poverty line and an average annual per capita salary of 395 USD. A strong economic burden also has the plague of HIV/AIDS, with 12% of the adult population affected, which has particularly dramatic proportions in this country, and contributes to placing life expectancy at the birth of the Zambians around the age of 42.

The GDP pro capita of Zambia was in 2017 equal to 1.342 USD. The GDP by sector is divided as follow: agriculture 8.6%, industry 31.3%, services 60%. On the other hand, 48% of the Labour force is employed in the agriculture sector [24].

The economy of Zambia has historically developed around the copper-mining industry. The copper production covers 85 % of the Zambian export.

Regarding the energy situation of Zambia, it has to be highlighted that it has the typical conditions of developing countries. The major share of the primary energy demand is mostly represented by biomass with 78% of the total primary energy supply (Imports and Production), as displayed in Figure 8 [25]. This is not a positive indicator; it means that the major part of the population relies on traditional cooking methods and lights. In Zambia 13.5 million people, 84% of the population use biomass-based fuels to cook, such as wood and charcoal, that is as well produced by wood [26]. For these people, most of the time, those poor fuels are the only energy consumptions. This is proved by the fact that only 31% of the population as access to electricity, of which 67% is urban population and just 4% of the rural population. Those numbers highlight the fact that who doesn't have access to electricity, doesn't have as well access to sustainable cooking methods. Most of the time in urban areas even if there is access to electricity, for an economical reason or culture's ones, the charcoal is still used as the main source of energy for cooking purposes and this explains the small gap in percentage between clean cooking access and electricity access.

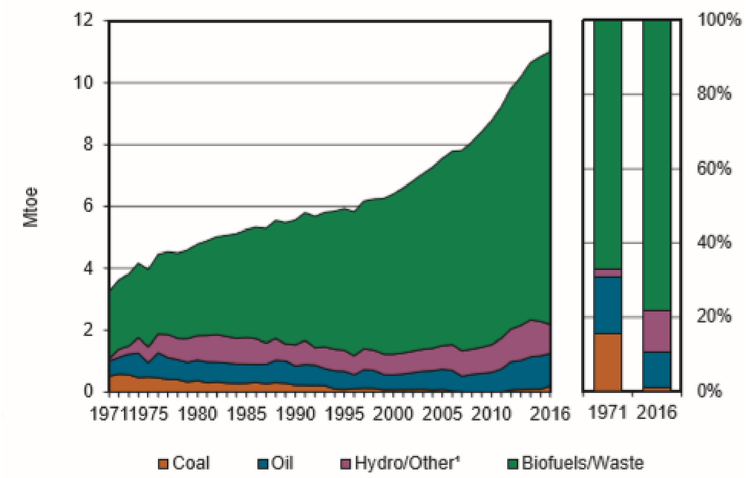


Figure 8: Zambia's primary energy demand [25]

Regarding electricity production, Zambia has 2,800 MW of installed electricity generation capacity. The major part of which 85% is hydropower. The remaining part of the electricity is guaranteed by coal and heavy fuel oil. Due to the hydro's generation dependence, Zambia has a high seasonal fluctuation in the production of energy. This is mainly due to the lack of water in reservoirs during the Dry season. Practically no rains are occurring between June and August [27].

As it was mentioned, the mining industry is the major economic driver in the Zambian economy. Consequently, it is even the major consumer of electricity with a share of 54% of the total electricity consumption. The second major consumer is represented by the residential sector, with 33% of the share. In the 2016 surveys of the IEA, renewables sources, such as wind and solar energy, didn't appear. Nevertheless, the Government of Zambia is currently investigating the opportunity to install micro-grids. 30MW of a mini-grid project is underway.

The overall access to electricity is and hard challenge. The Zambian Government has mandated to increase access to electricity in rural areas from 3.1% as of 2006 to 51% by the year 2030. To achieve this target, it was founded a local department: The Rural Electrification Authority. The former has estimated that to achieve the target, is necessary to invest a total amount of US$1.1 billion, equivalent to US$ 50 million annually. It will be crucial both the extensions of the national grid and projects based on the use of renewable energy sources.

2.1.2. Case study: Koinonia Community and Mthunzi Centre

"Koinonia Community Society" is a charity in the Republic of Zambia and is active since 1982. The company, 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 100 acres, equivalent to 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 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, and for children and young people living in nearby rural areas a program that provides school fees is active and health care, individual and family support. There are currently 40 children. Girls and adolescents refer, instead, to the small centre of Londjezani, which accompanies them with a specific path designed for their needs. In 2015, 123 young people and children are supported in their growth and education.

The future goal is to improve the supply chain of agricultural products as well as optimize the community's water and energy system. These intentions are well explained by the words of the Amani-Zambia project leader Giacomo d'Amelio: "What interests us is the autonomy and the spread of a culture that respects nature. So, a system that can always be improved and that can be a study ground for young Zambian and international students, as well as "demonstration plots" for the whole area and the neighbour communities".

It is currently under construction an agriculture school on the Koinonia land. The Agriculture school will be specifically taken into consideration under the analysis performed in chapter 4.

2.1.2.1. Electrical Energy audit of the Mthunzi Centre

The Mthunzi Centre is connected to the electric grid with a three-phase connection that subsequently divides in mono-phase connection of 220 Volt that goes to supply the different loads inside the centre. A draft of the electrical system is presented APPENDIX A1, showing the meter and switches in Mthunzi. To understand the consumption of electricity in the centre two approaches were used. The first considering the consumption from the demand point of view. The electrical demand has been evaluated considering the overlaps of the real devices utilized in the orphanage in which the consumption periods have been assumed according to the typical habits of the community inhabitants. The typical daily electrical consumption of the centre is shown in Figure 9. In particular, according to the information provided by the community, there is no main seasonal variation in consumption and during the period of studies, there were no electrical black outs. A detailed description regarding the appliances utilized and the usage is available in APPENDIX A2. Indoor and outdoor lighting represents the biggest share of the demand. The fixed load along the load profile is represented by the fridge and freezer.

The total daily consumption of energy, from the demand point of view, is equal to 38.053 kWh per day. It is consequently equal to a monthly consumption of 1,141 kWh per month.

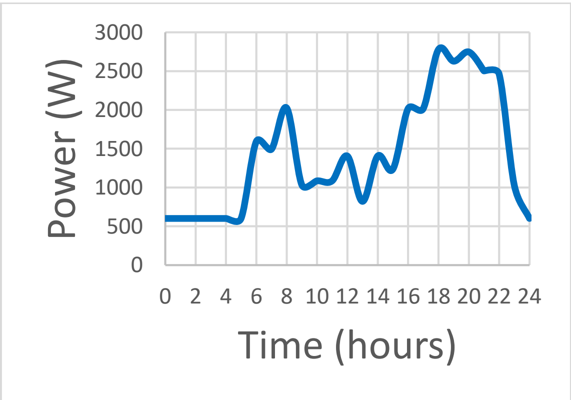


Figure 9: Electrical Load Profile of Mthunzi Centre

Parallel to this analysis, the consumption of energy was estimated from the supply point of view, considering the monthly consumption of energy by analysing the bill of three different months. The results are displayed in Table 1. The centre has a social tariff for the energy of 0.49 ZMW/kWh that is equivalent to around 0.038 €cent per kWh.

Table 1: Monthly Electrical Consumption

Monthly cost (€)	Tariffs (€/kWh)	Monthly consumption (kWh)	Daily consumption (kWh)
36	0.038	959.18	31.97

There is a slight difference between the demand and supply point of views. They differ from around 16 %. This is mainly because the staff of the centre simply estimated the usage of the appliances along the day. Moreover, at the moment some appliances were not correctly working.

2.1.2.2. Water supply in the community

The community water supply takes place through a system of electric pumps that drain water from two different wells located in the community's area. The chemical composition of water abstracted from groundwater is good, free from impurities or debris, low turbidity and with good taste. For these reasons, it is possible to drink it, without the need for additional treatments like filtration and/or disinfection. The water system serves the entire surface of the Koinonia Community and Mthunzi Centre, a draft map of it is displayed in Figure 10.

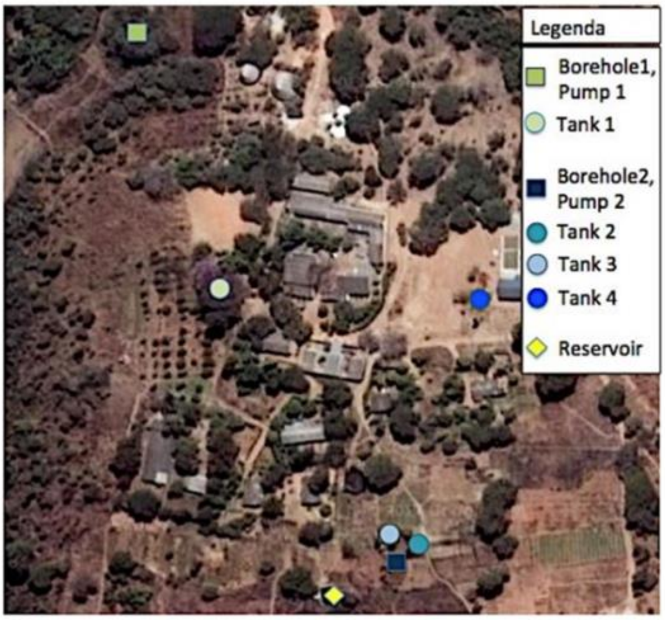


Figure 10: Koinonia's hydraulic map

Currently, the system is composed of the following elements:

- Pumps and wells: three different electric pumping systems handle the extraction of the amount of water required during the day. In the Community, there are two wells, which are associated with the respective pumps. The borehole 1, linked to a 4 kW pump, is located near the entrance road while the borehole 2 is located in the horticultural area and it is connected to a 5.5 kW pump.

- Tank: These are represented by plastic and metallic storage systems positioned on a tower to distribute water by gravity. There are in total of 4 tanks inside the community and the horticultural area. The first tank, with size 10000 L, called tank 1, is located near the Mthunzi and is supplied by the pump 1 of 4 kW, which delivers 4 L/min and fills it in 40 minutes. The second and third tanks, called tank 2 and tank 3 respectively, are in the horticultural area. These have a capacity of 10000 L and 5000 L respectively and they are supplied by pump 2, which draws well water from well number 2 with a power of 5.5 kW. Finally, tank 4, with a size of 10000 L, is located adjacent to the school and supplies this facility, exclusively. It depends on the pump 2 as well but it is filled only when appropriate, thanks to a valve in the tank 2's bottom.
  The tank 1 and 3 have inside a floater that can avoid that water overflowing the tank (because the pumps continued to fill the tanks even when they were flat), turning off the pump.
- Reservoir: it is a 5 x 5 m pond, located nearby borehole 2. It is used exclusively for irrigation and it is filled thanks to meteorological phenomena as well as thanks to the connection to the borehole 1.

2.1.2.3. Waste management in the community

Looking now at the waste management in the community. Initially, the situation was quite critical, there was practically no waste management. The waste was collected inside trash bins. They are consequently disposed inside holes that were dug in the community's ground, as shown in Figure 11.

Figure 11: Waste disposal area in the centre

It was consequently proposed to employee two persons to collect the waste and store that. Overall the community is trying to find a way to recycle as much as possible and for each type of waste, there is specific flow stream.

The undifferentiated waste is disposed of by each inhabitant in bins located in strategic place around the community. These bins are consequently emptied by the operator in the storage area. Each month is rented a truck and all the undifferentiated waste is brought in the landfill.

Regarding the plastic waste, the households dispose of the plastic, mainly bottles and bags, in the same bins of the undifferentiated bins. Subsequently, operators differentiate the plastic by the total waste in the storage area. The collected plastic is subsequently sold when the right amount is reached. Nevertheless, the overall plastic management is cost-intensive, because transport cost is around double than the revenue stream of plastic.

Regarding organic waste, there is a door-to-door collection of it. It is daily collected by the operator and is consequently used to feed pigs. Moreover, part of it is used to produce compost, with the purpose to use that in the soil. Currently, this project is not giving any positive results. The compost is not stored properly, and the organic waste is not able to reach the required quantity to be used in the garden.

The positives of waste management are that the waste is collected with further separation of both organic and plastic waste.

But, the quality of the separation is low. Moreover, some members of the community don't participate in the organic collection, mixing such waste with the other in the undifferentiated bins. Furthermore, some inhabitants even burn the plastic in open fires. The sorting of plastic is performed manually, and this process is not following any security process, having a lack of hygiene.

Overall, waste management in the community is cost-intensive. Each inhabitant pays a monthly fee of 10 ZMW, around 1 €. This amount is used both to pay the operators and for rent the truck to dispose of the waste in the landfills.

Future studies will aim to improve the profitability of the plastic disposal, processing it in order to reach a higher revenue from its recycling.

2.2 Methodology

As it was expressed in the previous subchapter the objectives of the thesis are to optimize and improve the condition of the inhabitants of the Mthunzi centre and Koinonia community. To do so, it will be taken into consideration the economic, environmental and social values previously expressed, that interiorize the sustainable mind-set of the Amani NGO.

Consequently, the methodology of the thesis will be based on display and discuss those crucial points. The thesis has as core three main topics: the clean cooking access, the electricity access and business creation.

The clean cooking topic is developed in chapter 3. Currently, in the Mthunzi Centre, it is used charcoal to cook for the 40 hosted children. The local NGO has explicitly expressed the desire to substitute the current polluted and expensive technology. The present work will look in detail 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 will be compared on an economic and ecologic perspective with the charcoal stove. Overall, the following point will be followed to compare the three cooking methods:

1. The current thermal energy needs of the Mthunzi centre are assessed. It is quantified the amount of charcoal (Final energy consumption) necessary to cook for the 40 children and the related cost.
2. It is consequently performed a resource analysis. The available resources in the context are quantified. For the biogas production, it is analysed the number of feedstock available to feed the biodigester. It is performed a market analysis to understand if nearby the community there

are feedstock (mainly pellet or woodchips) to power the Elsa microgasifier. Moreover, it is assessed the cost of the LPG.

3. Technical analysis of each of the three cooking options is performed
4. The final energy needs from each of the three options are investigated
5. An economic assessment is performed. Two main parameters are used to compare the economic saving from each alternative with the charcoal stove. The Net Present Value (NPV) and the Levelized cost of Energy (LCOE) are computed.
6. An environmental assessment is performed, to quantify the CO2 equivalent emissions from each cooking method

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. Overall, the following point will be followed to size the system and analyse its benefits:

1. The state of the art is firstly investigated regarding solar pumping system
2. The water needs to efficiently supply the agriculture school in the Koinonia community are investigated.
3. The load profile is designed.
4. Using the energy software Homer, the best PV system design is investigated and sized. Three systems are considered: two using a batteries storage and one without it.
5. The energy production for each system is quantified.
6. The NPV and the LCOE of the systems are computed. They are consequently compared on an economic perspective.

The business creation topic is developed in chapter 5. In this part of the thesis, the profitability on the development of a sustainable business is investigated. The aim is to create a business focused on the supply and production of charcoal, obtained out of solid bamboo. This venture could represent both a profitable project for the community and a production of sustainable fuel for households' energy consumptions.

3. Cooking solutions

3.1. Present situation analysis

3.1.1. Consumption and cooking behave analysis

To optimize and lead more sustainable the cooking method of the Mthunzi centre, it is crucial to analyse how is cooked. First of all, it was observed what their diet is and how they cook their meal.

In the Mthunzi centre, 40 ex-street children are hosted. A cook cooks daily for the children three times a day, as it is shown in Figure 12. At lunch, in addition to the boys, there are 10 staff members.

Figure 12: Mthunzi Centre's Kitchen

The cook inserted the pots in the holes made of bricks, in the part below the pot, a metal box filled with charcoal was used. The cook, by varying the amount of coal that inserted in the box, changed the power supplied to the pot. Charcoal consumptions vary from day to day depending on the dishes and the number of people in the canteen.

The main meal cooked was the Nshima, shown in Figure 13. It is the Zambian national food and in the centre is practically eaten every day both for lunch and dinner. The Nshima is made of corn flour. It is cooked in the following way and has on average the following consumption, deducted by asking the cook. At lunch, when there are about 50 people at the table, 30-35 Litres of water are boiled in a pot with a diameter of 50 cm. After about 1 hour the boiling point is reached and then 15 kg of corn flour is added. From a rough estimate, it takes 6-7 kg of coal for the entire cooking cycle.

Figure 13: Nshima preparation

In general, the monthly consumption is equal to around 9 bags per week of around 27 kg of coal and with a price of 70 ZMW per bag equivalent to around 5 €.

The cost of charcoal is completely financed by the NGO that takes care of children in the orphanage. One of their main goals is to replace this traditional method. Mainly because, as previously mentioned, it is highly inefficient and environmentally unsustainable.

They consume on average 1,5 bags of charcoal of around 27 kg each, corresponding to an average of 40.5 kg per day. Considering that the net calorific value of charcoal can be approximated to 8.3 kWh/kg it can be estimated the final energy consumptions for cooking [28]. Their final energy demand of thermal energy per day it is equal to 335.3 kWh per day. Moreover, considering that the cost of a 27 kg bag is equal to 5.4 €, it can be computed the final energy cost of charcoal. It corresponds to 0.024 € per kWh, that on an annual base correspond to a cost of around 2948 €, data are summarised in Table 2.

Table 2: Charcoal consumption data

	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	€/bag	5.4
Cost per Kg	€/kg	0.2
Energy Cost	€/kWh	0.024
Annual cost	€/year	2948.1

It is now crucial to understand which is the efficiency of the current technologies used to cook. That is mandatory to perform optimization measures. To do so the Water Boiling Test (WBT) methodology will be used.

3.1.2. 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 [29].

The WBT aims to test the efficiency of both technologies and fuel using simple equipment, to be assessed everywhere in the world. Its main benefits, as reported by the Global Alliance for Clean Cookstove, are the following:

- Provide initial or laboratory assessments of stove performance in a controlled setting
- Compare the effectiveness of different design's stove at performing similar tasks
- Evaluate stove changes during development
- Select the most promising products for field trials
- Ensure that manufactured stoves meet intended performance based on designs

The test doesn't' strictly represent the efficiency of a specific stove during the cooking condition. This because the test standardizes some conditions. Nevertheless, it is useful to compare various technical aspects of stove design and pre-field evaluations of performance. The WBT is an approximation of the cooking process, but for the present work, it can be a useful tool to compare the charcoal stove with the potential alternatives.

The WBT has been even developed to test the emission of a burner and a specific fuel. But, in the present work, for lacks of instruments, it will not be implemented this part.

The WBT is made of three phases, that are explained below and shown in Figure 14:

1) The cold-start high-power phase, in which the test starts with the stove at ambient temperature. The water reaches the boiling point and the fuel consumed is recorded. After that, when the water is boiled, it is replaced with another pot with water at room temperature, to perform the second phase.
2) The hot-start high-power phase is further performed, with the hot stove. It is used new, pre-weighted fuel and freshwater.
3) The simmer phase shows the quantity of used fuel to simmering a pre-weighted amount of water at just below boiling point for 45 minutes.

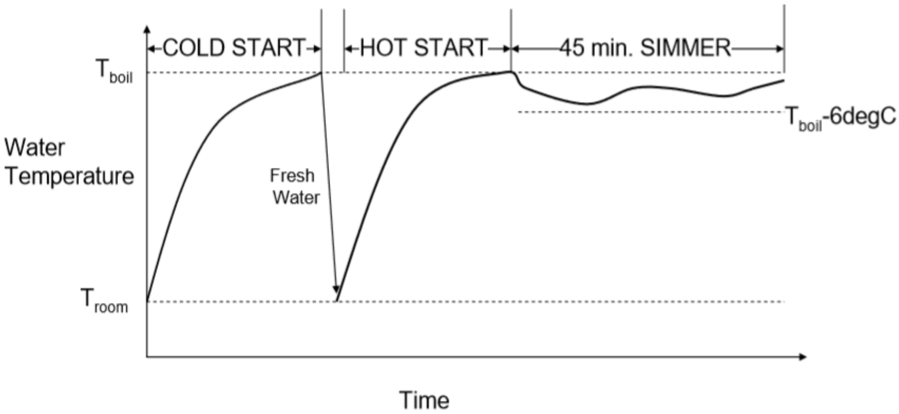


Figure 14: WBT temperature' scheme

For context constraints, in the present work, only the cold-start high power phase will be performed and tested. This is because the charcoal stove, used in the orphanage, needed to be used by the cook and performing the overall test was not possible. Nevertheless, the first phase test can give an overall compression on the efficiency of stoves.

To perform the test, it is first necessary to know the main characteristics of the tested fuel.

- The HHV, higher heating value (kJ/ kg)
- The LHV, lower heating value (kJ/ kg)
- The MC, percentage of humidity (on a wet basis)
- The EHV, actual heating value, which also considers the energy needed to evaporate the wet component

Moreover, it is necessary to know the temperature and the altimetry of the place in which is performed the test. This is necessary to understand the local boiling point temperature. It is obtained by the below equation. The specific boiling point in Lusaka (The altitude for Lusaka is assumed 1,279 m to the sea level) has been found equal to 95 °C. Below is displayed the used equation, where Tb is the boiling temperature and h is the altitude.

$$T_b = \left(100 - \frac{h}{300}\right)^{\circ}C \qquad (1)$$

Secondly, it is necessary to prepare the required instrument to measure all the necessary parameters. The required equipments are:

- Scale
- Digital Thermometer, with thermocouple probe suitable for immersion in liquids
- Timer
- Tape measure for measuring wood and stove (cm)
- Pot
- Small shovel/spatula to remove charcoal from stove
- Tongs for handling charcoal
- Dustpan for transferring charcoal
- Metal tray to hold charcoal for weighing
- Heat resistant gloves

For the specific case in study have been used the following equipment, displayed in Table 3.

Table 3: Equipment details

Equipment	Brand	Model	Uncertainty
Thermometer	Habor Digital Thermometer	022	±1℃
Scale	Fan-Ling	High-Precision Electronic Scale	±5 g
Timer	Sample9	Classic Sports Timer	±0.2 second

By having prepared the laboratory, the cold-start high power test can start following the below steps:

1) Weigh the stove without fuel
2) Weigh the pot together with water
3) Weigh the stove charged with fuel
4) Measured the initial temperature of water in the pot
5) Turns on the stove
6) Place the pot with water on the stove and start the timer.
7) Once the water has reached the boiling point the timer stops
8) Pay attention carefully to extinguish the flame and remove the remaining fuel by the stove and place it in a suitable metal container previously weighed.
9) Unburned fuel is weighed
10) Weigh the water remaining in the pot

Performing the test, the following parameters are obtained:

$\mathbf{f_{ci}}$ Mass of fuel before the test (grams)

$\mathbf{P1_{ci}}$ Mass of the pot of water before the test (grams)

$\mathbf{T1_{ci}}$ Water temperature at the start of the test (ºC)

$\mathbf{t_{c,i}}$ Time at the start of the test (min)

$\mathbf{f_{cf}}$ Mass of fuel after the test (grams)

$\mathbf{c_c}$ Mass char with dish after the test (grams)

$P1_{cf}$ Mass of the pot of water after the test (grams)

$T1_{cf}$ Water temperature at end of the test (ºC)

t_{cf} Time at end of the test (mins)

This data can be processed in the equation presented in the APPENDIX B. The Global Alliance For Clean Cookstove has developed a specific excel sheet that includes the mentioned equations. It has been used during performed tests.

By processing the value obtained during testes the following parameters can be obtained:

- Burning Rate – Represent the average grams of fuel burned per minute during the test. This parameter can be used to compare tests, indicating how consistently the tester has operated the stove. Moreover, comparing different stoves, this measure shows how rapidly the stove consumes fuel.
- Firepower – It is the parameter that indicate how quickly fuel was burning, expressed in Watts. It depends on the stove size and design and fuel supply.
- Turn-Down Ratio – It shows how much the tester regulates the heat between high power and low power phases. This represents the variability in power that can be obtained in a stove. A high value represents a higher ratio between high and low power.
- Time to Boil – it is the time necessary to reach the boiling point.
- Temperature Corrected Time to Boil – It is the time necessary to reach the boiling temperature, corrected to reflect an increase in temperature of 75 ºC from start to boil. This parameter can be useful to compare tests and stoves.
- Thermal Efficiency (International Workshop Agreement Metric for High Power) – This last parameter is the measure of the fraction of the heat produced by the fuel that is released to the pot to let the water boil. The thermal efficiency is the parameter that will be used to have technical and economic comparisons between the potential cooking solutions.

3.1.3 Test on the charcoal stove

Together with the cook, a set of three tests has been performed in the kitchen of the Mthunzi centre. The procedure previously explained was followed. Table 4 displays the initial test condition and the characteristics of the charcoal. The used value was suggested by the guidelines reported by the Global Cooking Alliance to effectively perform the test [29].

Table 4: Initial test condition

Initial test condition	Units	Test 1	Test 2	Test 3
Air temperature	ºC	29	29.5	29
Fuel moisture content (wet basis)	%	2	2	2
Gross calorific value (dry fuel)	kJ/kg	31,000	31,000	31,000
Net calorific value (dry fuel)	kJ/kg	29,800	29,800	29,800
Dry weight of Pot	g	2,000	2,000	2,000
Local boiling point	ºC	95	95	95

The test was consequently performed, and the data below were obtained, shown in Table 5.

Table 5: Measured parameters

TEST		Test 1		Test 2		Test 3	
Measurements	Units	Start	Finish	Start	Finish	Start	Finish
Time (in 24 hour form)	h:min:s	15:30:00	17:23:00	15:30:00	17:26:00	15:30:00	17:28:00
Weight of fuel	g	3,000	1,010	3,000	1,012	3,000	1,013
Water temperature	ºC	15	95	15	95	15	95
Weight of Pot with water	g	22,000	21,230	22,000	21,234	22,000	21,200

The data was consequently used to obtain the results of the test, in Table 6.

Table 6: Test Results

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	Standard Deviation
Time to boil Pot # 1 (B5)	Min	113.0	116.0	118.0	115.7	2.5
Temp-corrected time to boil Pot # 1 (B6)	Min	105.9	108.8	110.6	108.4	2.4
Burning rate (B20)	g/min	17.2	16.8	16.5	16.8	0.4
Thermal efficiency (B15)	%	14.5	14.5	14.7	14.6	0.1
Specific fuel consumption (B21)	g/Litre	101.2	101.1	101.2	101.2	0.1
Temp-corrected specific consumption (B22)	g/Litre	94.9	94.8	94.9	94.9	0.1
Temp-corrected specific energy cons (B23)	kJ/Litre	2,828.4	2,824.9	2,828.5	2,827.3	2.0
Firepower (B24)	Watts	8,556.8	8,327.1	8,181.9	8,355.3	189.0

The stove has an average power of 8.35 kW. The efficiency can be estimated equal to 14.6 %. By this data can be obtained the useful energy consumption necessary to cook every day. Considering that the daily consumption of final energy per day is equal to 335 kWh per day, the daily useful energy consumption is on average equal to 48.96 kWh per day. This data is mandatory to optimize the overall cooking system of the centre and compare the current technology with other cooking alternatives.

3.2. Cooking Alternatives

Three main plausible solutions will be taken into consideration: using a micro gasifier, a gas stove fuelled by LPG and a local biogas production. For each of them, a feasibility study will be performed taking into consideration economic, technological and sociocultural factors.

3.2.1. The Microgasifier alternative

3.2.1.1. General overview

The first alternatives that it is presented is the use of the micro-gasifier Elsa, presented in Figure 15. 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 [30].

Figure 15: Elsa Microgasifier [30]

This microgasifiers can be identified as a Top Lift Up Draft (TLUD) burner and it is a specific type of improved biomass cookstove. The term Improved biomass cookstove describes a stove which has a higher efficiency or lower level of pollution than a traditional stove, through improvements including a chimney or closed combustion chamber. Typical types of improved cookstoves include rocket stoves or simple micro-gasifiers, which operates a multi-stage burn (also known as wood-gas) [15].

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. This process is what differentiates micro-gasification from normal burners, where combustion takes place with a chaotic mix of phases.

Combustion is an exothermic process consisting of different chemical reactions, which take place sequentially or in parallel until the substance is thermally decomposed. Combustion consists of 4 processes:

- DRYING: the water contained in the biomass evaporates and becomes volatile. It already occurs at temperatures below 100 °C. The lower the degree of humidity of the biomass, the more the combustion will sustain itself.
- GASIFICATION: the process of transformation of solid fuel into a gaseous part (wood-gas), which will consequently burn, and a solid component will remain. Gasification is characterized by two processes:
    - PYROLYSIS (OR CARBONIZATION): consists in the degradation of the biomass exclusively by thermal degradation, without the presence of external oxidizing agents. The process produces free radicals (unstable ions) that produce a chain reaction capable of breaking down chemical bonds, thus producing other radicals. From the

reaction of the radicals produced, low molecular weight gases are produced, such as carbon monoxide, carbon dioxide, methane, butane, ethane and ethylene. It is an endothermic reaction that occurs at temperatures above 150 °C at atm pressure. The products of the reaction in addition to the gas are a char (solid) and a small quantity of tar (liquid).

    - CHAR gasification: the reaction that takes place in the presence of oxygen and consists of the thermal-oxidative degradation of the char previously produced in the pyrolysis phase. It is an endothermic reaction that occurs at temperatures around 600 °C and leads to the production of volatile gases (carbon monoxide and dioxide). The product of the reaction is ash.

- COMBUSTION: it consists in the complete oxidation of the gases previously produced, with the emission of carbon dioxide, unburdened gases and water vapour.

Two types of pyrolysis can be distinguished:

- Fast pyrolysis: medium-high reaction temperatures (500-1000 °C) and short reaction times (seconds). In the reaction products, 75% tar is obtained.
- Slow pyrolysis: long times (minutes, hours) and low temperatures (300-600 °C). The results are 75% of gaseous products and the remaining solid residue such as char.

Thus, by varying the two fundamental parameters, temperature and time, the desired products are obtained. For the interests of the project, the characteristics of the burner should favour slow pyrolysis, with long times and low temperatures to produce wood-gas and char. Consequently, the char produced by the micro-gasifier will have to be cooled to avoid oxidation and therefore transformation into ash. The char or biochar is a porous agglomerate with very high carbon content, more than 95%.

The mentioned microgasifier is defined as a TLUD stove. This acronymic stand for Top-Lit Up-Draft, that expresses two intrinsic concepts of the type of burner: ignition occurs in the upper surface of the biomass column, placed in the cylinder (Top-Lit) and the flow of gas proceeds from the base of the cylinder up to the top (Up- Draft) where it then mixes with the external oxygen [31].

In general, gasifier stoves have the following main component:

- A cylindrical reaction chamber, where the biomass is inserted
- An air inlet at the base (primary air)
- An air inlet at the top (secondary air)
- "flame-cap" system at the top of the cylinder

The latter is necessary both to prevent the air from entering the reaction chamber, where the gasification is carried out and to guarantee a suitable shape for the flame to increase the heat exchange between the flame and the pot.

The operation foresees that after filling the cylinder with the proper biomass, it is necessary to trigger the reaction. This is done by simply creating a small flame at the top of the fuel column, using paraffin or straw. The upper part of the column will begin to burn through classic combustion. After few minutes, from 2 to 10 minutes, depending on the type of biomass and the boundary conditions [32], the regime condition is reached, so the flame rises from the upper surface of the biomass to reach the top of the burner. At this point, the cap is created, it prevents the oxygen from entering from the upper hole, which therefore will enter only from the two inputs: primary and secondary air.

By focusing on the inside of the cylinder, during operation, there will be three different localized chemical-physical configurations, corresponding to the three phases of combustion.

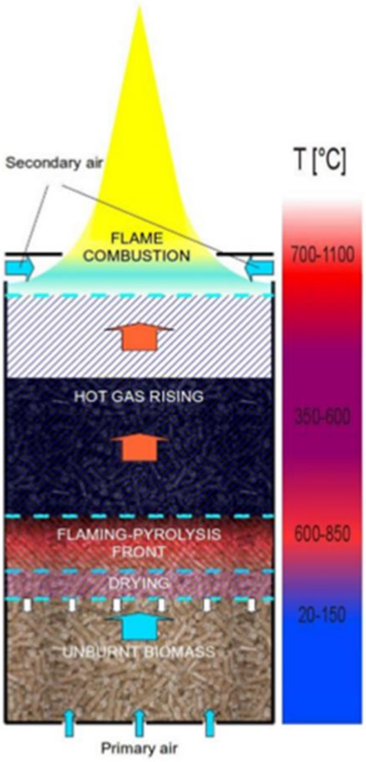


Figure 16: Thermo-Physical detail of the microgasifier [30]

As explained in Figure 16 [30], at a time t, corresponding to about half the burner usage time, there is a portion of unburnt biomass, in the bottom, where between its cavities, through natural convection, a flow of air, that enters from the cylinder base (primary air), passes upwards.

Proceeding upwards, it can be noted the first phase of the combustion process, corresponding to the drying of the biomass. This phase will have a duration proportional to the quantity of moisture in the reacting biomass portion. In this area, temperatures between 20 ° C, in the base of the cylinder, up to 150 ° C, in the drying area, are reached [31].

Continuing upwards, it can be noted the so-called "Flaming-pyrolysis front" (front of F-P) which occupies the horizontal surface of the cylinder for a thickness of few centimetres. Here there are temperatures between 600 and 850 °C. The biomass is incandescent and takes on a bright red colour. in this area pyrolysis occurs, releasing the gases that in small part burn when mixing with the oxygen that enters from the bottom (primary air). This combustion guarantees the heat necessary to carry out the endothermic pyrolysis reaction. The gases produced are not burned immediately but they proceed upwards. The F-P front then proceeds slowly downwards, gradually pyrolyzing new biomass. The reaction speed and the front height are constant since the amount of primary air does not change.

In the area superior to the front of F-P, there is a total absence of oxygen. This is because the air coming from the bottom is exhausted by reacting in the F-P area, and in the top does not enter oxygen due to the presence of the flame cap, which prevents the entrance.

Finally, in the upper part of the burner occurs the last phase, the combustion itself, generated by mixing the gases coming from the underlying area and the air (secondary air). Consequently, heat exchange between the flame and the pot is performed.

The microgasifier represents just the burner, and it needs to be provided with an opportune structure to maintain the pot on the top of it and to reduce the heat losses between the pot and the external ambient. Even the proper structure is crucial to increase the efficiency of the global system.

During the pyrolysis reaction is produced both gas (syngas), that it goes on the top of the burner, and the char, that remains inside the chamber. The char being in an area of absence of oxygen, between the front FP and the flame cap, is not oxidized and therefore does not turn into ash, because, the gasification of the char does not occur.

The micro-gasifiers represent an important improvement if compared to traditional ways of cooking. Improved cookstove, in term of emissions, are by far less polluted than both the three-stone methods and charcoal stoves. As it is displayed in Figure 17, they reduce drastically CO and Particulate mater (PM) emission. Specifically, fan gasifier stove can achieve even better performance using a forced-air system, creating a better mix of air and fuel.

Nevertheless, they are not comparable to LPG stoves. From a future perspective, by 2030, micro-gasifier technologies will achieve the WHO targets, and then they will be comparable to LPG burners [15].

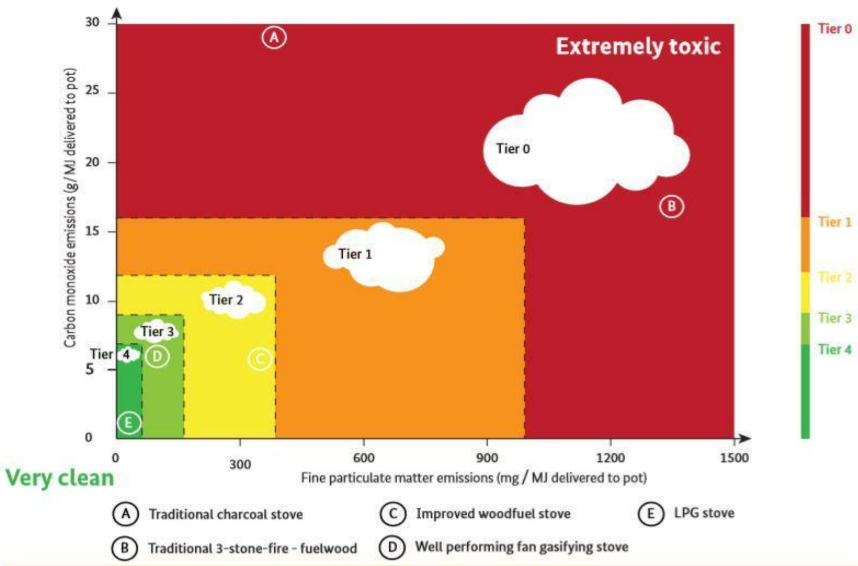


Figure 17: CO and PM emissions per cooking methods [31]

The microgasifier needs to be provided with suitable biomass, enabling the pyrolysis process to be performed efficiently. For optimal use of the burner it is necessary to choose the proper biomass that follows the following requirements [31]:

- Moisture content less than 20%. Biomass must be dry. Moisture reduces the net usable energy component of the fuel.

- Dimensions not less than 4 mm. For example, sawdust or rice husk is not good because they can obstruct the passage of air and gas. If these types of biomass are used, the burner must be equipped with forced ventilation. The suitable size of the biomass depends on the characteristics of the reactor: diameter and height.
- Easy to load the reactor.
- Homogeneous dimension, to avoid that the front of F-P does not maintain a uniform distribution during the journey in the reactor, creating compact zones and areas where voids are created.
- Have an adequate energy density. This is essential to have a burner operating time suitable for completing cooking.
- Easily retrieval. Obtaining it should not harm the biodiversity of the area
- It must not contain or release toxic agents

This makes it clear that not all biomasses can be used immediately, because, they may not meet the characteristics listed above. For example, some biomasses need to be processed to obtain a dense, dry product of the right size.

From the tests and the experience with Elsa, the project promoters saw that different types of woody and dry biomass are suitable. Biomasses that must not be processed as kernels, nutshells, hazelnuts, almonds, calibrated wood chips, elephant grass, while other biomasses that must be processed through shredding, drying and pelletizing, such as sawdust produced from agro-industrial or woodworking waste. To ensure the natural flow of gas reaches the top of the burner, the range in which the dimensions must fall is the length of 1-3 cm, diameter 0.5-1 cm [31].

Remembering that what is needed is a sufficient porosity of the fuel matrix and a sufficient calorific value, in concrete, only by observing the flame it can be understood if the biomass is suitable. For it to be, it must not produce smoke puffs. It is necessary to look for a suitable fuel, based on each geographical area where the technology is exported.

As previously explained the by-product of the gasification process in a microgasifier is the biochar, of whom a microscopic picture is shown in Figure 18. By definition, the term "biochar" refers to a material rich in carbon obtained from the combustion of biomass in an environment free of oxygen (pyrolysis), to be applied in soils for both agronomic and environmental management purposes [33].

The properties of the biochar depend on the type of starting biomass and thermal conditions (temperature and residence time) of the synthesis process. Biochar is a highly heterogeneous material characterized by stable components and many labile components. It is mainly characterized by a high content of organic carbon (up to 90%) with a prevalent aromatic structure [34].

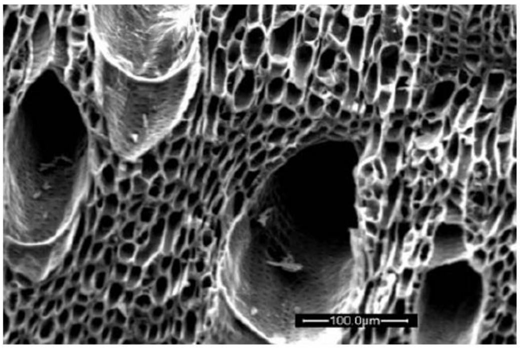


Figure 18: Microscope picture of the biochar [30]

In addition to carbon, biochar is characterized by hydrogen, oxygen and in a lower percentage by nitrogen, sulphur and different minerals. The content of nitrogen, sulphur and other minerals depends on the starting biomass.

The applications associated with the biochar are many, often complementary and synergistic: the improvement of the soil (increase in agricultural productivity, reduction of pollutants); waste management; mitigation of climate change and energy production.

The application of biochar in the soil could prove to be a winning strategy because the carbon components in the biochar are highly recalcitrant in the soil, with residence times in the soil estimated between 100 and 1000 years (approximately 10 times longer than the residence time of the substance organic soil). This is why the biochar added to the soil can turn out to be a potential carbon sink. However, nowadays, the techniques of applying biochar in soil have been poorly investigated.

The main factors determining the improvement of agricultural yields include the reduction of soil acidity, the improvement of cation exchange capacity (CEC) and soil pH, and the capacity of water retention [35].

Moreover, in low PH soil, the biochar increases plant growth. This happens because it alleviates the Al toxicity and the P deficiency [36].

Furthermore, biochar can be a proper alternative to use mineral fertilizer. In the specific, it was discovered that a mix of biochar and compost can jointly feed the crop with vital nutrients. In particular, Biochar can provide C and P, whilst compost recycles C, N, P and K. This was proved by an LCA assessed in three different countries: Italy, Belgium and Spain [37]. In each of the different climate, the condition was discovered that the biochar-compost blend is environmentally less impacting than mineral fertilizer, contributing to a reduction of global warming, acidification and eutrophication of agriculture practices.

Furthermore, in a real case of biochar application on Canadian soil, some interesting results were demonstrated: improvement of 18% of the ecosystem quality, a 15 % of climate change mitigation, finally, and a reduction of 13 % of resources use [38].

Specifically, this technology has been proved to be carbon negative. The fixed carbon present in the biomass, instead of been spread in the environment during his combustion, is saved and stored in the biochar and then in the soil. Consequently, the use of biochar has a double advantage: as it was said, the carbon is sequestrated and it is even saved the consumption of minerals fertilizers, that is recognized as being highly carbon intensive.

Nevertheless, some limitations of biochar applications have been found. For example, biochar stored for a long time in the soil can be negative effects for fungi growth [39]. Finally, it was observed that biochar application can result in delays of plant flowering [40].

The biochar technology, from its production to its use in the ground, can represent the foundation for the development of new business based on a circular economy philosophy.

The two products (syngas and biochar) can be included in a circular economy and energy system. The biochar system must necessarily take into consideration three fundamental objects to be efficient, coherent and complete: the stove, the biomass and the biochar. A schematic project plan is presented in Figure 19.

Before any action, it is necessary to know the needs of people, for good cooperation with local populations. For example:

• Need to increase crop yields

• Need to guarantee women better cooking technology that is well suited to their traditional uses.

Figure 19: Elsa's project plan [30]

Taking into consideration the different needs or objectives to act on, a targeted plan can be set. Training lessons are crucial, to let the beneficiaries understand the benefits of using the Elsa stove and biochar.

Key to the realization of the project are the women, who in the communities take care of the cooking. To proceed with the introduction of technology, three fundamental phases are expected:

A preliminary study on the possibility and adaptability of technology in women's habits. Studying the cooking methods, the type of dishes, the need for biomass and their availability, therefore, the adaptation of the technology to the environmental conditions.

It is crucial to involve women in improving the burner according to their uses, and then testing it in the different operating conditions in their presence. The ultimate goal is to make the technology familiar to the users dynamically able to spread it to make the project go on and the knowledge inherent in it.

The use of biochar in agriculture is not immediate but prelaminar tests of the soil needs to be done.

3.2.1.2 Microgasifier's water boiling test

Zambia has abundant quantities of biomass available from the wood and farm industries. For example, wood chips and pelletized sawdust can be used. In the rural area, on the other hand, the convenience of raw materials could be less, it would be convenient to use agricultural biomasses, such as corn cobs, or shells of various kinds, which don't need to be processed.

It is crucial to have a reliable supply of biomass, to consistently provide the required energy needs of the centre. It was consequently performed a market analysis in the Lusaka province to find a proper source of biomass. In Lusaka, various projects promoting pyrolysis stoves are dynamically developing. It has been possible to meet and converse with three companies' producers of microgasifiers, pellets and wood chips. Their projects are similar in intent to those promoted by the University of Udine but with diversity in the methods of approaching problems and solving solutions. Moreover, they supply the microgasifier Peko-Pe. The way in which it works is similar to Elsa, the only difference is on the design

It has been consequently compared the cost of fuels in Lusaka. Data are shown in Table 7.

Table 7: Fuels cost in Lusaka

SUPPLIER	PRODUCT	LHV (kWh/kg)	€/kWh	€/kg
Supamoto	Pellet	4.8	0.05	0.25
Vitalitè	Woodchips	3.6	0.027	0.11
Home energy ltd	Pellet	4.8	0.027	0.13
/	Charcoal	8.13	0.024	0.2

As can be seen, the cheapest price in term of final energy is the one of charcoal but it is not necessarily the most advantageous to burn if the efficiency of the stove is lower than that of the stove used for biomasses.

Only the Vitalitè and Home energy products are more suitable with the objective of reducing the cost of energy for the centre. It has been chosen to use for the test the pellet produced by Home Energy Ltd. This because, the pellet performs better in microgasifier, having a lower moisture content and producing less smoke than woodchips. The chosen pellet has an energy content of 4.8 kWh/kg, moisture content below 5 % and average size in diameter of 8 mm. The pellet is produced by sawdust of pine wood. These parameters are leading this product a valid fuel for the microgasifier. The pellet that has been used is produced from sawdust, by product of industrial carpentries in Lusaka, and further pelletized in Lusaka by the company, owner of the plant.

Having chosen a proper biomass for the test, the thermal efficiency of the Elsa microgasifier can be found using the water boiling test.

As it was performed for the case of the charcoal stove, the initial test condition can be identified. They are displayed in Table 8.

Table 8: Initial test condition

Initial test condition	Units	Test 1	Test 2	Test 3
Air temperature	ºC	29	28.5	29
Fuel moisture content (wet basis)	%	5	5	5
Gross calorific value (dry fuel)	kJ/kg	18684.05	18684.05	18684.05
Net calorific value (dry fuel)	kJ/kg	17364.05	17364.05	17364.05
Dry weight of Pot	g	1500	1500	1500
Local boiling point	ºC	95	95	95

Three tests were consequently performed. The tests were undertaken using three different power settings of the stove. For test 1, the Elsa was used with a maximum power setting. In test 3, the stove has operated at minimum power and in test 2 it was used intermediate power supply. The measured parameters are displayed in Table 9.

Table 9: Measured parameters

TEST		Test 1		Test 2		Test 3	
Measurements	Units	Start	Finish	Start	Finish	Start	Finish
Time (in 24 hour form)	h:mins	10:52	11:02	11:20	11:55	12:30	12:45
Weight of fuel	G	1,900	900	1,900	800	1,900	1,000
Water temperature	ºC	26	95	26	95	26	95
Weight of Pot with water	G	5,500	5,300	5,500	5,200	5,500	5,300
Weight of charcoal+container	G		380		400		370

Consequently, the acquired measures were used to compute the test results, presented in Table 10. The results were obtained using the equation presented in APPENDIX B. The data was processed using the Excel software, in the excel sheet developed by the Global Alliance for Clean Cookstove [29].

Table 10: Test results

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	Standard Deviation
Time to boil Pot # 1 (B5)	min	10.0	35.0	15.0	20.0	13.2
Temp-corrected time to boil Pot # 1 (B6)	min	10.9	38.0	16.3	21.7	14.4
Burning rate (B20)	g/min	29.7	10.2	14.7	18.2	10.2
Thermal efficiency (B15)	%	31	30	42	34	0.1
Specific fuel consumption (B21)	g/Litre	78.2	96.6	57.9	77.5	19.4
Temp-corrected specific consumption (B22)	g/Litre	85.0	105.0	62.9	84.3	21.1
Temp-corrected specific energy cons (B23)	kJ/Litre	1,475.7	1,823.1	1,091.9	1,463.6	365.8
Firepower (B24)	watts	8,598.6	2,955.2	4,241.4	5,265.1	2,957.7

At maximum power, the microgasifier has a similar power of the charcoal stove, equal to 8.6 kW power. The maximum efficiency of the stove is obtained for test 3, using the stove with an intermediate power supply. On average the overall efficiency of the process is equal to 34 %, more than the double respect to the charcoal stove. This is a considerable improvement that will be further addressed in an economical point of view.

3.2.1.3. Microgasifier tests with local persons

After having performed the Water Boiling Test, to understand the performance of the microgasifier, it has been crucial to explain to the cook how the technology works and understand the performance in the real working condition.

Figure 20: Test with the cooks of the Centre

Specifically, it has been trained the cook on how adjust the burner power, load the pellet into the burner, empty the biochar and turn it off. After having built a suitable support for the pot, the nshima was prepared for the 40 children of the Mthunzi Centre. The experience has been also useful to understand the energy consumption to cook their typical dish, the nshima.

The burner was used at maximum power, loading the reactor with about 2 kg of pellets, per 20 Litres of water. After less than 50 minutes the boiling was reached and then 15 kg of maize flour was added into the pot.

After 5 minutes all the charge was exhausted, then the burner turned off. After removing the biochar and cooling it down with sand, to prevent oxidation reactions from starting, the reactor was recharged with 1 kg of pellets. After 40 minutes the cooking of the dish was completed.

Overall, 3 kgs of pellets were consumed in 2 charges. For a total time of 95 minutes. 0.6 kg of biochar were produced.

What has been noticed is a reduction in cooking time compared to traditional cooking methods. With the charcoal, around 2 hours were necessary. The test with the microgasifier has shown a reduction of almost 0.5 hour in the cooking time, for the same amount of maize flour prepared. The cook was overall satisfied to learn a new and faster cooking method.

3.2.2. The LPG technology's alternative

LPG is a technology globally used by around 3 billion people [41]. It can potentially transform the household's energy consumptions in developing countries. It is recognised as a technology that can provide important benefits in terms of emission reduction, health, forest protection and economic development. It is recognised as a crucial technology to achieve energy access for urban people that still cooks with polluted biomass sources.

Households that will switch from biomass to LPG will have many advantages that would result in:

1. Relevant health benefits from the reduction of household air pollutants produced by the burning of solid fuels and kerosene;
2. Using LPG technology contribute to a reduction in emissions of other greenhouse gasses such as methane, black carbon and organic carbon that are released by solid fuel stoves;
3. Reduction on depletion of forests;
4. LPG technologies can contribute in terms of timesaving. Women and children spend most of their time collecting and using firewood to cook. A proper LPG supply can considerably reduce their time and effort.

To spread this technology and consequently benefits from it on a small and global level, it is necessary a proper national planning to well enable the access and the supply of this technology to people.

50% of urban consumers of biomass in Sub-Saharan Africa can afford to buy LPG for daily cooking, not being more expensive than solid fuel.

Nevertheless, the limitation of this technology is that is considered having and higher relative cost respect to solid fuels. The reason is that charcoal and kerosene are bought on a daily base in a small quantity. On the other hand, LPG is refilled every few weeks. To overcome this challenge, on a national level, smaller cylinders can be introduced in the market. This can contribute even to a reduction in weight, being easier to transport.

For rural people, the introduction of LPG is more difficult for two main reasons. First of all, they don't purchase their used biomass, they collect it on the forest in the form of firewood. Secondly, the transport and the supply of LPG becomes difficult in remote areas without proper infrastructural facilities. Financial and fiscal subsidies are necessary to assist this energy transition to this part of the population.

From the technical point of view, the LPG is a by-product of oil and natural gas production and petroleum refining. It is composed by light hydrocarbon compounds. It is mainly made of two main components: propane (C_3H_8) and butane (C_4H_{10}). LPG can be produced by other energy sources that combine portability with convenience, high energy and low sulphur content, and its clean-burning nature. LPG is non-toxic, colourless and odourless.

40% of the globally produced LPG comes from oil refineries. LPG can be easily transported and stored being easier to liquefied at moderate pressure. Where there is a reliable electrical and gas grid, the LPG doesn't result in a valuable alternative. Nevertheless, it results in the most feasible solution for peri-urban and rural areas.

An LPG system consists of the following parts:

- An LPG cylinder
- A valve connector
- A pressure regulator
- A rubber pipe
- A cookstove (single or multi burner)

The lifespan of LPG cookstoves is between 5 to 10 years depending on the type of stove, quality of materials and design. A simple and reliable alternative, to reduce the initial investment cost, is represented by a stove directly fit onto the top of the cylinder. This system option is usually using small LPG cylinders.

The LPG has a Net Calorific Value of 12.20 kWh/kg. LPG technology has an overall thermal efficiency of around 60 % [42]. This value considers both the combustion efficiency and the efficiency of the heat transfer.

Many LPG suppliers are present in the Lusaka market. They deliver for free cylinders to household customers. From local market analysis, it was found that the cost of LPG depends on the size of the cylinder. Considering to use a 45 kg cylinder, the cost of the final energy has been estimated and shown in Table 11.

Table 11: LPG cost

Cylinder cost (€/45 kg)	Unit cost (€/kg)	Net Calorific Value (kWh/kg)	Final energy cost (€/kWh)
61.5	1.4	12.2	0.112

Even if the final energy cost is considerably higher than the one of the other potential sources in the Lusaka market, the LPG can represent a valid alternative for its efficient performances. This part will be further covered at the end of the chapter.

3.2.3. The Anaerobic digestion's alternative

3.2.3.1. State of Art of anaerobic digestion plans

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 digestion process is divided into 4 main stages: hydrolysis and abiogenesis, acetogenesis and methanogens.

In this first phase, by the intervention of different bacterial groups, there is the degradation of complex organic substrates (polymers), such as proteins, fats and carbohydrates, with the formation of simple compounds (monomers), such as amino acids, fatty acids and monosaccharides in soluble form.

Simultaneous to the hydrolysis of complex organic material, particulate or soluble, the acidogenesis fermentation process takes place, in which the bacteria degrade fatty acids and amino acids, producing volatile fatty acids, mostly short chain.

Starting from the substrates formed during the hydrolysis and acidification phase, the acetogenic bacteria produce acetic acid (CH_3COOH), formic acid, CO_2 and H_2.

The last phase is the methanogenesis, where the CH_4 is formed. It is the slowest phase and consequently conditions the whole process. The production of methane takes place mainly in two different ways. From the oxidation of hydrogen, contributes to about 30% of the total production of methane, or through the degradation of acetic acid that produces methane and carbon dioxide, this last reaction contributes to about 70% of the methane produced [43].

4 main process parameters determine the conditions and performance of anaerobic digestion: temperature, pH, hydraulic retention time (HRT), organic loading rate (OLR).

All the degradation processes that take place inside the reactor are operated by different types of bacterial colonies that are strongly affected by temperature variations, both regards the speed of their metabolic processes and their existence, as presented in Figure 21. Each temperature condition favourite's specific bacteria formation. The thermophiles bacteria have the highest methane production. It is favourites for a range of temperatures higher than 35°C. This means that the efficiency of the biodigester is strongly dependent by the fact that the reactor is heated up or not and by the weather conditions.

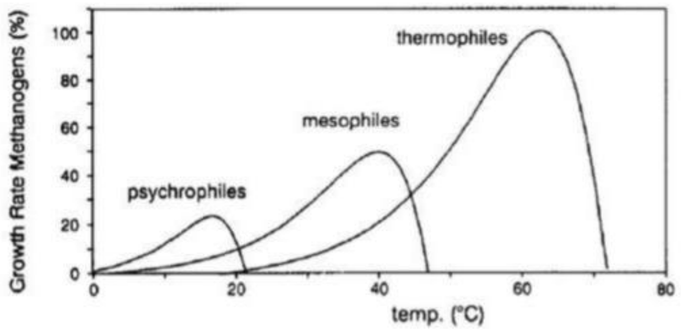


Figure 21: Bacteria growth rate related to operating temperature

The pH is an important parameter that must be detected to maintain constant the methanogenic bacteria population. The anaerobic digestion process is considered stable for pH's values between 6.5 and 7.5. Within the digester, the pH is mainly determined by the presence of CO_2 in the liquid medium, and therefore by its partial pressure in the biogas and by the concentration values of volatile fatty acids and ammonia.

Another important parameter is the hydraulic retention time (HRT). It is given by the ratio between the volume of liquid present inside the reactor and the volumetric flow rate leaving the system.

It can be expressed as the ratio between the volume of the reactor (V) and the outlet flow of the substrate (Q).

$$HRT = \frac{V}{Q} \ [t] \tag{2}$$

The variation of this parameter influences the yields as it determines the duration of the stay of the biomass in the reactor and therefore the degree of degradation of the organic substance.

It is even crucial to obtain an optimum organic load rate (OLR). It is defined as the amount of substrate entering the digester referred to the reactor volume unit and time. The kinetics of the process and the production of biogas depend on this parameter.

Analytically it is expressed by the following equation, where Q is the inlet flow rate, S is the substrate concentration in the influent flow, and finally, V is the reactor volume.

$$OLR = \frac{Q \times S}{V} \left[\frac{Kg}{m3\ day}\right] \quad (3)$$

In the implementation of a digester plant is important to analyse the quantity and the quality of the available biomass.

The biomass can be classified in the following macro groups:

- Dedicated crops;
- Waste from the agro-industry;
- The organic fraction of municipal solid waste;
- Sewage sludge from the civil treatment plants;
- Zoo-technical waste.

The available biomass can be classified by the following parameters:

- Total Solids: It is the overall measurement of the solid matter. it is given by the total residue by evaporation of the liquid phase at 105 °C for about one hour; these represent the sum of the organic substance and the inert substance.
- Organic Substance (% on dry matter): it includes both the volatile organic substance, which is transformed into gas and the non-volatile organic substance which cannot be gasified.
- Inert Substance (% on dry matter): it is the residual fraction (ash) after combustion at 650 °C in a muffle. It is assumed to be equal to the inorganic content.
- Volatile Substance (% on total solids): it is the fraction of organic substance that can be volatilized and is about 70 - 80% of the total organic. Operationally it is assumed that the volatile substance is equal to the organic substance.

As previously mentioned, from the digestion of the biomass is obtained the biogas and the digestate.

The biogas consists mainly of methane and carbon dioxide in ratios that depend mainly on the biomass composition and the completeness of the reaction. There is also the presence of other components that are not relevant in terms of energy, but which can greatly influence the process kinetics and the methods of use of the biogas, as water, oxygen, nitrogen, hydrogen sulphide and hydrogen. The Methane can range between 40 to 70 % of the total biogas volume, while the CO_2 range between 25 to 45 % [43].

Due to the presence of hydrogen sulphide, corrosion can occur in the system. Also, the condensation steam can also block the biogas transport pipes. It is important to treat these products with accurate filtering measures.

The biogas can be used for different scopes. The biogas previously treated can be used to produce heat in combustion engines with mechanical energy. This mechanical engine can consequently power an electric motor to produce electricity. Otherwise, it can be used directly for cooking in gas burners.

The by-product of the anaerobic digestion is the digestate, even called bio-slurry, that can be placed in the ground as fertilizer. This represents the natural closure of a cycle that, starting from the plant organisms, passes or not through animal breeding, it is carried to the biogas plant, and then returns to the ground.

Moreover, it can be used as a soil improver. For this purpose, the digestate helps to keep the quantity of organic substance constant on the ground and releases the nutrients more gradually.

In developing countries, many projects are growing with the purpose to bring clean cooking access to many people that are nowadays cooking with inefficient and pollutant cooking methods. As highlighted by the International Energy Agency the biogas production by Anaerobic Digestion can be a suitable alternative to achieve global energy access by 2030 [15].
To achieve this target, specific anaerobic digesters need to be used depending on the specific working context.
The principle of operation at the base of an anaerobic digestion plant is the following: the substrates are placed in a watertight reactor, in which, through a digestion process operated by suitable bacteria, the biogas is produced. This is collected in a tank to guarantee a constant supply.
A biogas production plant generally consists of:

- Implant accumulation tank.
- Reactor;
- Gasometer;
- Instrumentation and accessories.

In the specific, three main designs are suitable with rural areas in developing countries. This is because they have these main characteristics: they are scalable, they have a low investment and maintenance cost, construction materials easily available, simple plant management.
It is possible to classify the digesters according to the scheme of the plant.

1. Fixed-dome digester is composed of a dome-shaped reactor, a gasometer, and another displacement tank also called compensation tank. When the biogas starts to form, there is a lowering of the level of the gas - mud interface: at the same time part of the digestate goes up through a tube that leads it to the compensation tank and the biogas flows through a second pipe to be then stored in the gasometer.

   The plant is built under the ground level both to provide thermal insulation, and therefore to avoid temperature fluctuations between day and night which negatively affect the process, and as protection from atmospheric events. The location below the ground level allows the reactor to be adapted to regions with mild climates and the possible predisposition of heating sources (for more complex digesters).

   The materials used in construction are generally bricks, cement and reinforced concrete that are not impermeable to the biogas created at the top of the digester. For this reason, it is necessary to treat the dome internally and externally with synthetic paints or to cover it with latex. The choice of materials depends on the costs, the local availability, and the ability to work, the efficiency and finally the duration. The plant is shown in Figure 22.

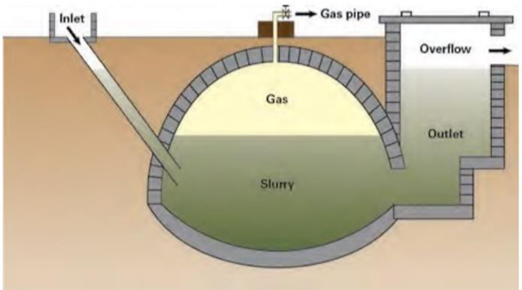


Figure 22: Fixed dome digester

2. The floating-Drum digester is composed of a cylindrical reactor and a mobile gasometer, called drum, which floats directly on the sludge or in an impermeable bag connected to a guide frame to the digester walls which gives it stability and keeps it in the vertical position. When the biogas production process begins, the drum rises and when it is consumed it returns to the starting point. The plant is displayed in Figure 23.

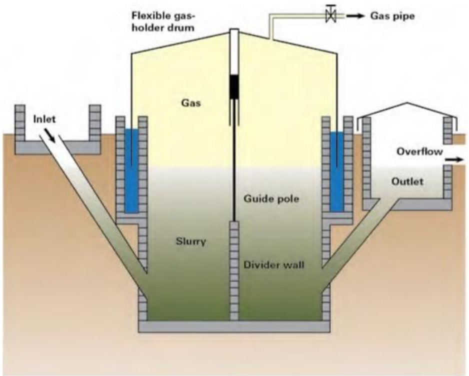


Figure 23: Floating-Drum digester

3. The tubular digester consists of a plastic bag (polyethylene or PVC) at the ends of which there are two tubes: one for the entry of the substrate and one for the exit of the digestate. In the central part, there is a pipe that allows the biogas to be transported to the gasometer, where it is stored.
   The digester, if installed in regions with a high nocturnal temperature range, is usually placed in a pit and protected by a greenhouse. This structure, built-in brick or wood and covered with a layer of synthetic material, allows thermal insulation so that the anaerobic digestion is not negatively influenced by the lowering of the temperature. Otherwise, if the region of interest is tropical, it is still necessary to provide the reactor with a structure that can repair it from the high direct solar radiation, from the bad weather and the animals.
   Since construction and installation costs are reduced, this technology is appropriate for applications in poor households, in rural areas in countries where there has been no support and subsidies in the biogas sector. The plant scheme is presented in Figure 24.

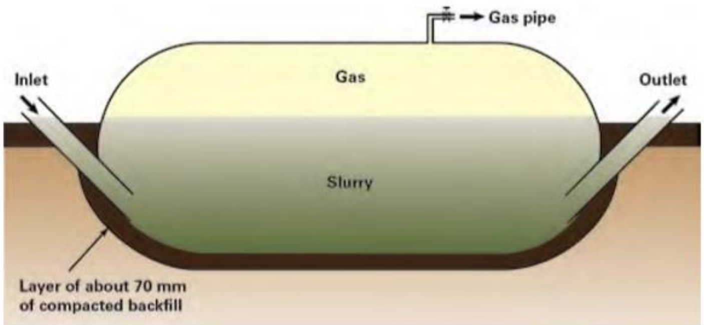


Figure 24: Tubular digester

The typologies of anaerobic digesters can be equipped with a gas conditioning unit. According to the feedstock used when biogas leaves the digester, it usually contains some hydrogen sulphide, which is toxic, water and high amounts of energy-deficient CO_2, depending on the use that is going to be given to the biogas, it needs to be cleaned to remove the H_2S, water vapour and CO_2.

3.2.3.2. Biogas potential for Mthunzi Centre

After having understood the possible benefits of anaerobic digestion technologies, their working condition and design's characteristics, it will be investigated the potentiality to size a bioreactor in the community. First of all, to understand the potential biogas production, it is essential to estimate the available feedstocks in the community. It has been found that there are three main organic resources produced locally: the households' organic waste, garden and agriculture residues and pigs' manure.

For the specific case in the study, two main organic sources of biogas will be evaluated: pig manure and human excreta. In the community of Koinonia, there is a piggery with 20 pigs. Moreover, in the Mthunzi centre, 50 people are residents in it. They discharge their excreta in two soakaways, that are periodically discharged.

Both the pigs' manure and human excrete are not used as energy resource either as agriculture fertiliser, in the form of compost. Thus, they are available biomass, that can be suitably converted in biogas.

To understand the potential biogas yields' production from each feedstock, it is initially crucial to quantify the daily availability of the resources. The results found are displayed in Table 12. In there, it is even reported the biogas yield by each source. That value was found considering by literature the total solid, the volatile solid and the biogas yield per volatile solid, respectively for each organic feedstock. It was found a biogas yield per kg of volatile solid of pig manure equal to 0.34 m^3 [43]. Moreover, it has been considered a potential biogas yield of human excreta equal to 0.3 m^3 per kg of volatile solid [44].

Table 12: Available Resources

Biomasses	Production per head (kg/day) (19)	Volatile Solid (kg/ day)	Biogas yield (m^3/kg of VS)	Methane content %
pig's manure	5	1	0.34	75
human's excreta	0.2	0.03	0.3	60

Consequently, considering that there are 20 pigs and an average of 40 people, it can be estimated the potential biogas production per day, displayed in Table 13.

Table 13: Potential biogas production

Biomasses	Production(kg/day)	Volatile solids (kg/day)	Biogas production (m^3/day)
Pig's manure	100.0	20	6.74
Human's excreta	8.0	1.2	0.36
Total	108.0	21.2	7.10

From this stage, it can be computed the size of the anaerobic digester to produce the desired biogas production from the available biomasses.

As previously mentioned, three main types of digester are usually used in rural areas in developing countries: Fixed dome, Floating-Drum and the tubular digester. To understand which of them better fit with our purposes, they have been compared on economic and technical bases.
Only the fixed dome and the floating dome can supply the required biogas. A tubular digester is usually used for small-scale plant and is not able to feed more than 15 m^3 of biogas.
In term of lifespan, fixed dome digesters have a longer lifetime, on average between 15-20 years. This is because the materials are more resistant and there are no moving mechanical parts as in the floating drum biodigester, leading the fixed dome to more durable working conditions [45].
From the economic point of view, two main factors are affecting the feasibility of a digester's project: the initial investment cost and the maintenance operations' frequency and cost. In the Table 14 the three digesters are compared.

Table 14: Digesters comparison

Technology	Cost voice		Initial Investment Cost
	Labour	*Material*	
Tubular Digester	Not relevant, could be self-built.	PVC digester bag.	Low
Fixed Dome Digester	Very relevant, specialized worker are needed.	Bricks and concrete.	Quite High
Floating Drum Digester	Very relevant, specialized worker are needed.	Steel drum, bricks and concrete.	High

On one hand, can be noted that the fixed dome has higher initial investment and it needs to be built by expert companies. On the other hand, it needs almost no maintenance during its lifetime, subsequently, the operation and maintenance costs are practically nulls.
Overall, it can be assumed that the best option is the fixed dome digester. It can produce the amount of biogas required and even for longer life. Compared to the floating Drum digester, it presents on average lower investment cost and nulls maintenance costs.
At this point of the feasibility study is crucial to understand the size of the fixed dome bioreactor. The total digester volume is represented by the sum of the digester volume and the gas volume. The digester volume is the maximum quantity of slurry that the digester can store. The gas volume is the amount of gas that the plant can store when it is full of digestate. The first is usually expressed as a portion of the second. The volume of the plant can even include a safety volume, that usually prevents the slurry overflow when there is an overproduction of biogas. The volume of an anaerobic digestion plant is expressed in m^3.
To compute that is used the following formulas [46].

$$V = S \times HRT \quad \text{And} \quad S = B + W \tag{4}$$

- V is the digester volume (m^3)
- S is the amount of substrate (L)
- HRT is the hydraulic retention time (days), it was found to be equal to 40 days in Zambia [46]

- B is the amount of biomass (L)
- W is the amount of water (L)

It has been considered a density for the human excreta equal to 1.06 kg/L [47] and the density of pig manure equal to 0.9 kg/L [48].
It has been considered to add as much water as the quantity of biomass on a volume base [49].

Table 15: Resource assessment

Biomass	Biomass quantity (kg)	Biomass density (kg/L)	Biomass quantity (L)	Water quantity (L)	HRT (days)
Pig's manure	100.0	0.9	90	90	40
Human's excreta	8.0	1.06	8.48	8.48	40
Total	108.0		98.48	98.48	40

From the values displayed in Table 15, it can be estimated that is necessary a fixed dome digester of at least 7.8 m^3. Looking into the local market, it was found that the NGO, named SNV, produce fixed dome digester of 10 m^3. It has consequently considered installing that type of system plant with that size.
Then, it has been considered to estimate the real daily production of biogas from a fixed dome digester of 10 m^3 of volume. It has been used the following equation. The daily production depends both on the type of biomass, on the ambient conditions (Temperature) and the HRT. These factors have been considered in the yield factor (Y). That for the specific case it has been taken a Y equal to 5.53. Moreover, daily production depends on the Volume (V) of the plant and the quantity of biomass (S) added every day.

$$G = \frac{Y \times V \times S}{1000} \quad (5)$$

From the equation and the considered parameters, expressed in Table 16, it is estimated to obtain a daily production equal to 6 m^3 per day.

Table 16: Biogas production

AD Volume (m3)	Total Feedstock Volume (m^3/day)	Feedstock Retention Time (days)	Initial concentration of volatile solids (kg/m^3)	Yield factor	Biogas production (m3/day)
10.0	0.197	51	107.6	5.53	6.0

From the obtained results it can be consequently analysed if the biogas production can provide the required energy needs to cook every day in the Mthunzi Centre.
Knowing that the overall thermal efficiency in cooking with biogas can be assumed equal to 55 % [45], and that it can be considered a net calorific value of 5.42 kWh/kg and a specific density of the gas equal to 1.2 kg/m^3, it can be obtained the total useful energy produced per day, equal to 21.3 kWh. The results are summarised in Table 17.

Table 17: Useful energy production by biogas per day

Net Calorific Value (kWh/kg)	Biogas production (m3/day)	Biogas Density (kg/m3)	Thermal Efficiency (%)	Final Energy (kWh/day)	Useful Energy (kWh/day)
5.42	6.0	1.2	55	38.69	21.279

It can be noticed, that the useful energy supplied by the biogas plant, is not enough to cover the cooking energy needs. As it was highlighted in the chapter 3.1.3 the useful energy to cover the energy needs is equal to 48.96 kWh per day of thermal energy.
Consequently, it is considered to supply the remaining energy with the LPG stove. Referring to the consideration done before for the LPG, 3.73 kg of LPG on a daily base is necessary. The considered value are displayed in Table 18.

Table 18: Useful energy consumption by LPG per day

Useful Energy (kWh/day)	Thermal Efficiency (%)	Final Energy (kWh/day)	Net Calorific Value LPG (kWh/kg)	LPG amount (kg/day)
27.321	60	45.53	12.2	3.73

Summarizing 45.53 kWh of final energy from LPG and 38.69 kWh from the biogas plant are necessary.

3.3. Comparison of the cooking methods

Summarizing, three potential alternatives were presented. They were selected because of valid technology for developing countries and specifically for the context into consideration.
For the microgasifier, it has been seen to be easy to build and to use. The fuel used in it is easy to transport in the Mthunzi centre, being produced in Lusaka. Moreover, in terms of indoor air pollution, it has been proved to considerably reduce the emissions respect to charcoal. The microgasifier has an efficiency more than double respect the charcoal stove, equal on average to 34%. It will contribute to a final energy saving equal to 57 %.
The LPG technology has been proved to be the best solution in terms of reduction of indoor air pollutants. It can be supplied easily to the centre. It has an overall thermal efficiency of 60 %, being the most efficient technology. It will contribute to a considerable energy saving equal to 76 % respect to charcoal.
The energy mix of LPG and biogas is a suitable solution to use the local resource of the community. This solution could in the future turn to a complete renewable energy solution. With the expected future development of the community, it will be possible to use more agriculture by-products suitable for the

production of biogas. From the present analysis, this mix presents an average thermal efficiency of 58 %, contributing to an energy-saving equal to 75 %. The results are presented in Table 19.

Table 19: Cooking option 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

Having an overall understanding of the energy alternatives, it can be consequently taken into account the energy cost for each alternative. This is a fundamental aspect to lead the community fully sustainable.

3.4. Economic Analysis

To evaluate the economic savings from the three different energy alternatives respect to the charcoal stove, the NPV has been computed for a lifetime of 20 years. Moreover, it has been computed the LCOE of the thermal energy produced from each technology.

First of all, the operational and maintenance cost and the initial investment per each technology has been investigated.

Regarding the microgasifier technology, the initial investment is equal to 60 € for each of it, it will be considered to buy two of them. It has a lifespan of around 10 years and doesn't have any maintenance cost related to its operation. These specifications were suggested by the manufacturer company.

The operational cost is related to fuel cost. As it was mentioned, this technology is fuelled with pellet. It is produced in Lusaka and has a cost per unit of energy equal to 0.027 €/kWh.

The LPG alternative has as initial investment the cost of the burner, valve and pipe to connect to the cylinder. The overall cost to have two operative gas burners is equal to 100 € with a lifespan of 10 years. Even for this solution are not necessary costs related to maintenance. In Lusaka, the LPG has found to cost 1.4 €/kg. Considering an LHV of LPG equal to 12.2 kWh/kg, it can be consequently estimated a final cost of energy equal to 0.112 €/kWh.

The biogas alternative is the solution with the higher initial investment cost. The fixed dome digester can be built by a local company. They can build the 10 m^3 for 1400 €. Moreover, from their experience, they estimate a yearly maintenance cost equal to 1% of the initial investment. This cost is related to the cost of employing a person in charge to feed the biogas plant with the proper biomass. The plant has a lifespan of 20 years and no operational cost are related to this solution. It must be remembered, that for the biogas solution needs to be taken into consideration the investment and the operational cost related to the LPG technology.

Consequently, the operational and maintenance cost and the initial investment cost are expressed for each of the three-potential solution. To compute the daily operational cost, it has taken into consideration the final energy demand expressed in the 3.3. subchapter. The overall cost analysis is displayed in Table 20.

Table 20: Cost analysis

	Initial investment (€)	Maintenance cost (€)	Operational Cost (€)	Annual cost
Microgasifier	120	0.0	1,419.1	1,419.1
LPG	100	0.0	3,335.8	3,335.8
Biogas and LPG	1500	14.0	1,861.3	1,875.3

From this analysis, it can be noticed that the operational cost of the microgasifier is more than half of the one of the LPG.

The economic savings respect the current situation can be consequently estimated. The annual cost related to the charcoal demand of energy is equal to 2948.1 €. By having an overall estimation of the costs, the NPV can be computed. The NPV allows assessing the profitability of a project. The NPV, by definition [50], is the difference between the present value of cash inflows (Inc) and the present value of cash outflows (Outc) over the project lifetime.

The NPV formula is displayed below. In the equation 8, r represents the discount rate and n is the project lifetime.

$$\text{NPV}= \sum_{j=1}^{n} \frac{Incj}{(1+r)^j} - \sum_{j=1}^{n} \frac{Outcj}{(1+r)^j} \qquad (6)$$

The income of this project is related to the cost-saving of using the other energy alternatives. The outcomes of the project include investment, operation and maintenance costs for each specific alternative.

The discount rate allows to explicit the following economic concept: the money available today has a greater value than money received in the future. The practical objective of the discount rate theory is to bring future monetary value to the present time and vice versa.

In the present project, it will be considered the real discount rate. It is a more specific value that takes into consideration the inflation rate. It is used the following formula to obtain it.

$$\boldsymbol{r} = \frac{r'-f}{1+f} \qquad (7)$$

Where r' is the nominal discount rate, f is the inflation rate. In the specific, the following values were found.

- The inflation rate in Zambia is forecasted to reach 6.5% in 2020 [51].

- The interest (discount) rate in Zambia is projected to reach 10% in 2020 [52].

Consequently, it is considered a real discount rate equal to 3.3%.

If the value of the NPV is greater than 0, the project is economically profitable, it means that the investment is recovered, the minimum rate of return of capital is achieved and a surplus is obtained. In the case of NPV = 0, the project is feasible, meaning that the investment is recovered and the minimum rate of return of capital is achieved. Alternatively, If NPV < 0 the project is not economically profitable.

Considering the specific cost analysis, the NPVs, shown in Table 21, are obtained, for a lifetime project of 20 years. Moreover, the Internal Rate of Return (IRR) and the payback period (PP) have been computed using the Excel software. The IRR represent the rate of return that turn the NPV=0. The payback period represents the period necessary to recover the initial investment.

Table 21: NPV, IRR and Payback time

	NPV (€)	IRR (%)	PP (year)
Microgasifier	23,357	1,274	0.078
LPG	-7,112	-	-
Biogas and LPG	17,921	77	1,3

For the microgasifier alternative is obtained a positive NPV and a PP of less than one month, being the most convenient cooking option. On the other hand, LPG technology doesn't bring any economic advantages to the Mthunzi Centre. The mix of biogas and LPG is obtained a positive NPV. This solution results conveniently compared to charcoal but not respect the first alternative. It takes more one year and 4 months to recover the initial investment.

In Figure 25, the cash-flow along the project lifetime is displayed.

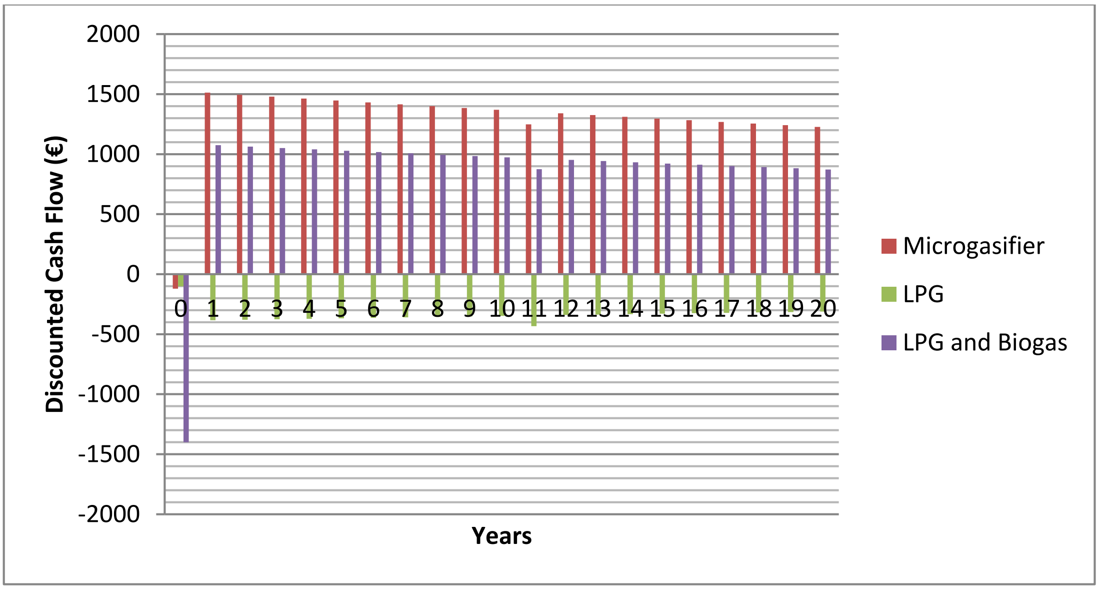


Figure 25: Net Cash-Flow

Another relevant parameter in energy projects is the Levelized Cost of Energy (LCOE). The LCOE, or discounted average cost, has been computed to compare the cost of the thermal energy produced for each different energy solution, including the current cooking method in the Mthunzi Centre.
The LCOE can be expressed as:

$$\boldsymbol{LCOE} = \frac{\boldsymbol{Life\ Cycle\ Cost}}{\boldsymbol{Lifetime\ Energy\ Production}} \qquad (8)$$

The life cycle cost represents the discounted investment cost plus the discounted operation and maintenance (O&M) cost. The lifetime energy production is the energy produced by each cooking alternative in the project lifetime, considered equal to 20 years.
The above equation can be better expressed in the following way:

$$LCOE = \frac{IT + \sum_{j=1}^{n} \frac{Cinvj}{(1+r)^j} + \sum_{j=1}^{n} \frac{comj}{(1+r)^j}}{Ed} \qquad (9)$$

Where IT is the total investment cost, n is the number of years of lifetime, j is the year in which the expenses occurred, $comj$ is the O&M cost incurred in the year j, $Cinvj$ is the replacement costs incurred in the year j and Ed is the discounted energy produced that is expressed as follow:

$$Ed = \sum_{j=1}^{n} \frac{Eaj}{(1+r)^j} \qquad (10)$$

Eaj represent the annual thermal energy produced in the year j.
To compute the LCOE has been considered the same discount rate of the NPV, equal to 3.3 %. The Eaj is considered constant for the 4 cooking solutions: charcoal, microgasifier, LPG and LPG mixed with biogas. The value corresponds to the thermal energy delivered to the pot to cook for a year. The value is equal to 17.9 MWh/year.
Considering the initial investment cost, the O&M cost and the replacement cost expressed in the computation of the NPV, the following value of the LCOE for each cooking method are reported in Table 22.

Table 22: LCOE for the different options

	Charcoal	**Microgasifier**	**LPG**	**LPG and Biogas**
LCOE (€/MWh)	165	80	187	110

As it was seen is the NPV computations, the microgasifier alternative is the most convenient, having more than half of the cost respect to the charcoal method. The mix of LPG is more convenient than charcoal but is less convenient respect the microgasifier solution.

3.5. Environmental Impact assessment

To have an overall feasibility analysis regarding the different cooking options, it is crucial to understand the environmental impact of them.

During the combustion process, theoretically, only carbon dioxide (CO_2) and water (H_2O) are produced. Those products are not harmful but, the first is a Green House Gas (GHG) that contribute in major part to global warming. Carbon dioxide and all the other GHGs can absorb long-wave infrared radiation emitted by the sun. Subsequently, they interfere with the dissipation of terrestrial infrared radiation, involving the accumulation of thermal energy in the atmosphere and therefore the increase in surface temperature. If the concentration of these gases increases, due to anthropogenic activities, the phenomenon of the greenhouse effect undergoes non-natural alterations, leading to the so-called global warming.

Most of the time, the combustion process doesn't occur completely thus, more combustion products are produced, that are both harmful and a global risk, being important Green-House Gases. Between them can be recognised: carbon monoxide (CO), nitrous oxide (N_2O), methane (CH_4), and polycyclic aromatic hydrocarbons (PAHs).

Emission of pollutants from cooking activities depends on many factors, mainly from the type of used fuel and from the technology used to combust it. The indoor air pollutants released by the combustion with traditional cooking methods, biomasses based, are an important cause of death in developing countries. Moreover, due to their incomplete combustion process, they realised important GHGs in the atmosphere, such as CH4 and N_2O. Those GHGs have a Global Warming Potential, computed for a 100 years' time horizon, quite more relevant than CO_2, as presented in Table 23. Consequently, even if the traditional methods are using renewables sources, such as firewood and carbonized timber, they contribute relevantly to global warming, due to their inefficient combustion process.

Table 23: Global Warming Potential of GHGs [53]

	Greenhouse Gas	Global Warming Potential (GWP)
1.	Carbon dioxide (CO_2)	1
2.	Methane (CH_4)	25
3.	Nitrous oxide(N_2O)	298
4.	Hydrofluorocarbons (HFCs)	124 – 14,800
5.	Perfluorocarbons (PFCs)	7,390 – 12,200
6.	Sulfur hexafluoride (SF_6)	22,800
7.	Nitrogen trifluoride (NF_3)[3]	17,200

To estimate the emissions from the different cooking system, it is first crucial to define the emission factor for each fuel. The quantity of pollutants emitted from a cooking system is found multiplying the quantity of fuel used by the emission factor of each pollutant. The obtained value represents the mass of the pollutants emitted per unit mass of the fuel consumed. It can be even expressed as the mass emitted per unit energy content of the fuel consumed. To compare different technologies and fuel, it is used an emission factor expressed as the mass of the pollutant emitted per unit of useful energy delivered.

For a cooking system, lower is the efficiency higher will be the quantity of fuel used. Consequently, even the total emissions, will be dependent on the efficiency of the system. Moreover, the emission factors depend not only on the type of fuel but also on the type and design of the burner, by his operating condition and by the ambient condition.

Consequently, the CO_2 equivalent emitted by each cooking options is estimated, including the current charcoal-based way of cooking. To do so, the emission factor expressed in Table 24 are used, they have been computed for a 100 years' time horizon. In there, it is visible the efficiency for different cooking methods, the emission factor for three main GHGs, CO_2, CH_4 and N_20, and consequently the estimated CO_2 equivalent. This parameter is expressed on a two-unit basis: per final energy and useful energy. The last is taken into consideration to estimate the overall CO_2 equivalent emissions for one year. As can be seen in the table, CO_2 emission for biomass sources are not considered. This why the CO_2 emitted is the one absorbed during the photosynthesis process of the tree [54].

Table 24: Emission factors for different cooking options [54]

CO_2 equivalent emission from different cooking options*

Cooking options	Efficiency values selected (%)	Emission factor values selected			Estimated CO_2 equivalent	
		CO_2 (kg TJ^{-1})	CH_4 (kg TJ^{-1})	N_2O (kg TJ^{-1})	g CO_2-e MJ^{-1}	g CO_2-e MJ^{-1}_{useful}
Traditional stoves (wood)	11	—	519.6	3.74	12.1	109.7
Traditional stoves (residues)	10.2	—	300	4	7.5	73.9
Traditional stoves (charcoal)	19	—	253.6	1	5.6	29.7
Traditional stoves (dung)	10.6	—	300	4	7.5	71.1
Improved stoves (wood)	24	—	408	4.83	10.1	41.9
Improved stoves (residues)	21	—	131.8	4	4.0	19.1
Improved stoves (charcoal)	27	—	200	1	4.5	16.7
Improved stoves (dung)	19	—	300	4	7.5	39.7
Biogas stoves	55	—	57.8	5.2	2.8	5.1
Gasifier stoves	27	—	—	1.48	0.46	1.7
Natural Gas	55	90402	20.65	1.84	91.4	166.2
LPG	55	106900	21.11	1.88	107.9	196.2
Kerosene	45	155500	28.05	4.18	157.4	349.7

*CO_2-e: CO_2 equivalent for 100 yr time horizon.

Knowing that the useful energy required to cook in the centre per year is equal to 17.9 MJ, it can be obtained the annual emission for each cooking option. In the specific, it is considered for the energy mix of biogas and LPG, that the first can cover 7.76 MJ of the required useful energy and the LPG the remaining one.

Table 25: 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)	531	30	3,506	1,996
Emission Savings	-	94%	-561%	-276%

It can be noticed in Table 25 that even for the environmental analysis, the microgasifier is by far the best option, bringing to an emission saving equal to 94 % respect to charcoal.

The other two options are not environmentally convenient respect to charcoal. This is mainly due to the contribution of the LPG, that is much more polluted respect to charcoal and biogas. The biogas is potentially 6 times less polluted than charcoal.

4. Development of a Solar pump system in the Koinonia Community

In the present chapter a feasibility study to size a solar pumping system will be performed. The present project will be developed and donated by 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.

The other objective of this project is to provide a reliable water supply to the agriculture school, under construction in the Koinonia community.

In the first part of the studies, an overview of solar pumping systems and a context analysis will be displayed. Consequently, both the hydraulic and electrical system will be sized. Then, an economic analysis of the systems will be done.

4.1. Overview of Solar pump systems

For both the agricultural sector and household consumptions in developing countries, access to a reliable water supply is an important step in improving people livelihoods and farmers' productivity. In many developing countries, and specifically in Zambia, the value of irrigation is strictly dependent on rainfall patterns. For instance, in the rural areas of Zambia, where the access to electricity is practically null, the farmers can cultivate their lands just in the rainy season. This reduces the potentiality to reach the necessary food supply, limiting the production of crops just on the rainy seasons. Irrigation can significantly improve the agriculture yields, providing a higher variety of crop options, thus reducing the land depletion. The crucial technology to obtain a reliable irrigation system is a water pumping system. Different pumps can be seen in the market and used for developing countries. The most used are hand pumps, diesel pumps, grid-tied electric pumps, and solar pumps. In areas where there is no grid connection has been seen that solar pump systems are more economically viable than diesel systems. The average upfront cost, operation and maintenance cost and replacement of a diesel pump are 2–4 times higher than solar pump systems. Solar pumping systems are environmentally friendly and require low maintenance with no fuel cost [55]. The limitation of the formers is that they need a higher initial investment than the diesel systems [56]. Nevertheless, this challenge can be overcome with subsidies or microcredit financing aids.

The solar water pump system is fundamentally a combination of the photovoltaic and pumping systems which consist of different parts. The PV panel converts the solar energy into electricity and consequently this energy power the motor allowing the pump to work. Other components can be added to the system, for example, storage components: batteries to store the electrical energy or tanks to store the water.

The photovoltaic array consists of different PV modules and the setting depends on the voltage and the power that they need to deliver to the pump.

The simplest system that can be used is a direct coupled (DC) solar pump. It doesn't need the use of an inverter or MPPT controller, thus the investment cost is reduced. Being the simplest solution possible, it has some drawbacks. For example, it cannot operate at the maximum power point as the solar radiation varies during the day from morning till evening. The performance can be improved adding an MPPT and controls/protections. The first generation of solar pump systems was using centrifugal pumps, driven by DC motors and AC motors with a hydraulic efficiency between 25 and 35%. The second generation of solar pumps has considerably increased its performance, using positive displacement pumps. This allows relevant progress, permitting a lower PV input power, thus, requiring a lower capital cost. Moreover, hydraulic efficiency increased dramatically, reaching around 70% [55]. The current state of the art of solar pumping system has considerable being improved thanks to the introduction of electronics systems. The use of efficient power electronics equipment, controllers to monitor the water level in the tank and the pump speed and the use of solar tracking have considerably increased the overall efficiency of the system, reducing the levelized cost of energy for the water supply. The solar pump is selected according to the Head of the site and the flow rate required. In particular, the submersible pumps offer high discharge and heads. However, they have a shorter life because is located inside the well. The centrifugal ones work on the low head and high discharge conditions. Positive displacement pumps have good suction power but low discharge.

In the present project, two different system settings will be taken into consideration. Each of them will be analysed from a techno-economical perspective.

The first, that will be indicated with case 1 and case 3, is a stand-alone solar pumping system consist of the following elements:

- AC submersible pump
- Solar panels
- Inverter/controller and MPPT
- Batteries storage

In Figure 26 is displayed a simplification of the system. This system allows a more reliable water supply than a system with just a storage tank. The water can be pumped even during the night; in case the water tank will empty.

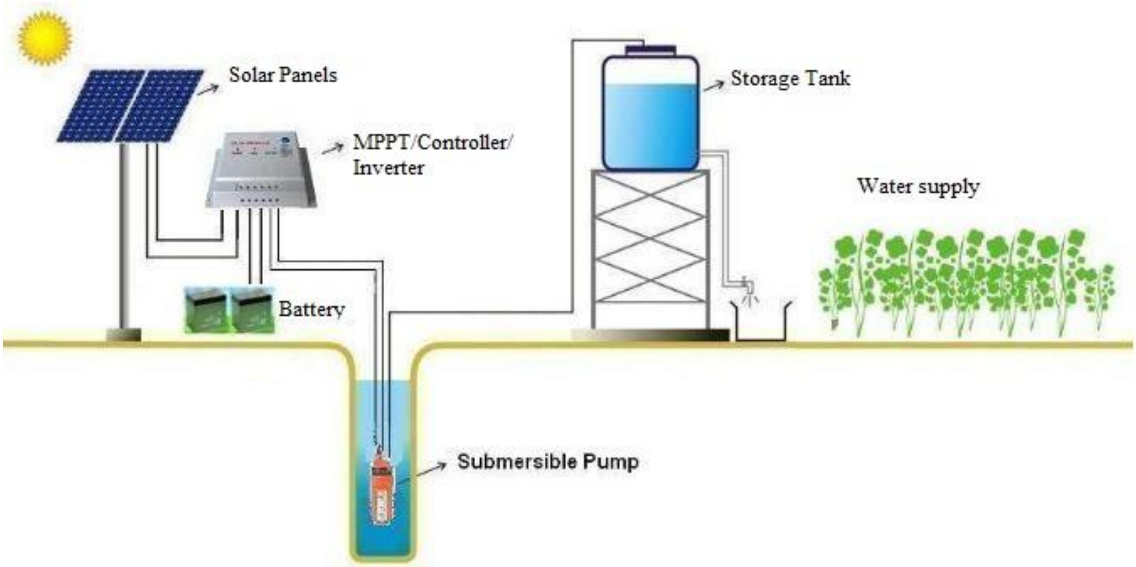


Figure 26: Solar Pumping system with batteries

The second system will be similar to the first, but, with simply the water storage, avoiding to use a batteries storage. This will be more sensitive to solar irradiation along the day. The initial investment and replacement cost are lower than the two previous cases. This system will be indicated with the name, case 2.

4.2. Context Analysis: The Agriculture school

The scope of this project is to supply water to the agriculture school that is under construction in the Koinonia community. Moreover, to supply water to a demonstration plot of solid bamboo. To do so will be used and off-grid solar pump system. Currently, in the area, there is no water supply. The Italian company Caprari is going to donate the overall system, enabling the agriculture school to cover the water needs. At the moment, it has been drilled a well and a water tank of 5000 Litres of water has been provided to the school. The overall water system presented in Figure 27 has been designed using the software Scribble Maps. The system will consist of the following parts:

- Well
- Submergible water pump
- Water storage. A tank of 5000 Litres
- Pipe system
- Irrigation system

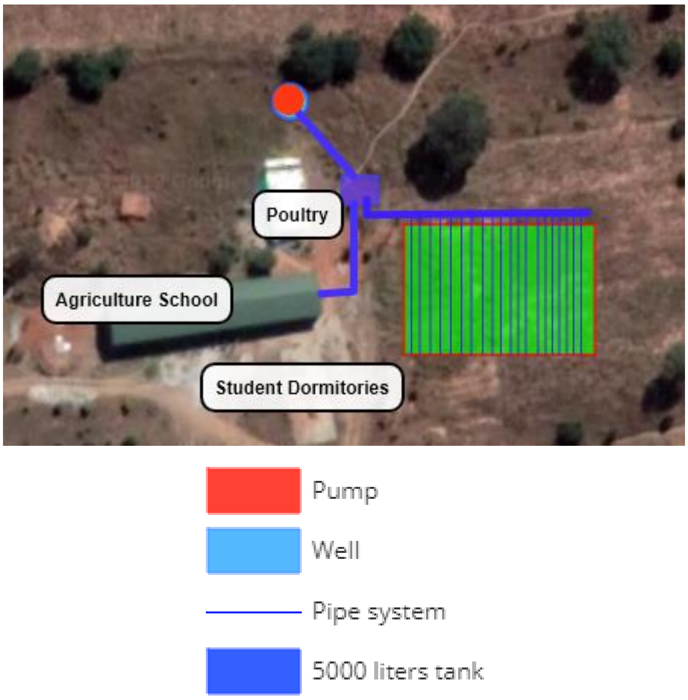


Figure 27: Hydraulic system of the agriculture school

The hydraulic system will be implemented by a local company. To size, a submergible water system is crucial to know two main data: the head of the site and the required water flow rate. The head (H) represents the amount of pressure that the water must win to flow at a certain flow rate (Q).

To analyse a pump system must be studied the H-Q curve, that allows understanding how much is the flow referred to a specific Head of the site. The Head specifically is dependent by two factors: the static Head, that considers the difference of gravity between the lower and the higher water surface and the dynamic Head that is depended by the flow rate and take into account the shape of the pipe, the viscosity and its length.

From the analysis done by a local company on the specific site, it was found that the Head is equal to 52.5 m. This represents the hydraulic pressure that the pump needs to overcome to fill the 5000 Litres tank.

Consequently, it has been chosen the pump E4XP15/13+MC405M-1, manufactured by the Caprari company. The details of the pump are displayed in Table 26 [57].

Table 26: Pump details

Rated Power (kW)	**0.37**
Rated Frequency (Hz)	50
Rated Voltage (V)	230
Full Load Current (A)	3.6
Phases	1

It is a single-phase pump of 0.37 kW of peak power. The curve of the pump is displayed in APPENDIX C.

Analysing the pump curve, it can be noticed that, for a dynamic head of 52,5 m can be obtained a flow rate equal to 0.3 l/s, that will represent the water input into the tank. The overall efficiency of the pump for the considered value of Head and flow rate is equal to 42.5 %. It is the maximum efficiency that can be obtained by that specific pump.

It is consequently needed to analyse the water consumption of the agriculture school. They will be divided into two main consumptions, the ones strictly connected to the agriculture school and the ones related to the bamboo plantation.

- The water demand for the school is computed considering that 30 people will be residents into the school. From an analysis of the demand for water per person in the Koinonia community, 50 Litres per person can be estimated to be the consumption per day. Consequently, the daily residential demand will be equal to 1500 Litres per day. It will be assumed that will not have a seasonal variation.
- The water necessary for the bamboo plantation has been estimated by our partners, Plantamillion, that is currently cultivating the plot. They need to supply water to 1728 plants of bamboo for an area of 900 m^2. They estimate a fluctuation on the water demand. They estimated the demand for water of 3500 Litres during the hot months: September, October and November. During the other months, they considered half of that value, equivalent to 1750 Litres per day. They will use drip irrigation. It is a technology with the higher efficiency on the water supply, almost 90 % of the water reaches the roots of the plant [58]. In Figure 28 the water demand per month is displayed.

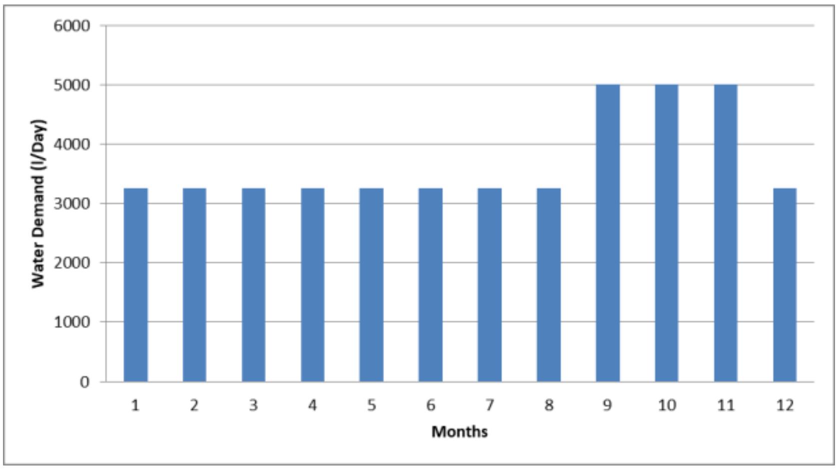


Figure 28: Daily Water Demand in several months.

From the estimated data, the pump will need 5 hours to fill the tank during the hot season. Instead, it will take 3 hours during the rainy and winter season. The bamboo plantation will be irrigated twice per day, during the hot season, from 6 to 8 and from 18 to 20. On the other hand, just one time per day will be necessary during the other months, late in the evening. Consequently, the energy consumptions will depend on the season. The demand for energy will be around 1.11 kWh per day during the rainy and winter season and 1.85 during the hot season.

Consequently, in the APPENDIX D, the water demand and the energy consumption of the pump are displayed. This data is necessary to size the solar.

4.3 System sizing

Once it has been identified the hydraulic system, the solar system can be sized. As it was mentioned, three different system will be compared for performances and costs. Case 1 and case 3 are the systems proposed by the company Caprari and Keyfuture, partners in the implementation of the project and donors of it.

Moreover, in the present thesis will be analysed an alternative, named Case 2. It will be considered a system that doesn't use the batteries system, thus will use as storage, the water tank, that is already in place. It will be analysed if this alternative can lower the initial investment cost and the operational and maintenance cost.

To size the two systems, it is first crucial to understand the potential load profile of the pump.

4.3.1. Load Profile of the pump

The energy consumption will depend on the water demand.

For case 1, the one using batteries, will be assumed that workers at the agriculture school switch on the pump from 6 in the morning. In the Koinonia community, residents turn on the pump around that time. Consequently, we assume that they will similarly operate in the agriculture school.

The demand for water has variability along the year, subsequently, there will be two different load profile. During the hot season, the pump will run for 5 hours to pump the 5000 Litres required in that period. On the other hand, the pump will run for 3 hours during the winter and rainy season.

The load profiles are respectively displayed in Figure 29 and figure Figure 30. It can be noticed that the peak power is the power required by the pump and equal to 0.37 kWh.

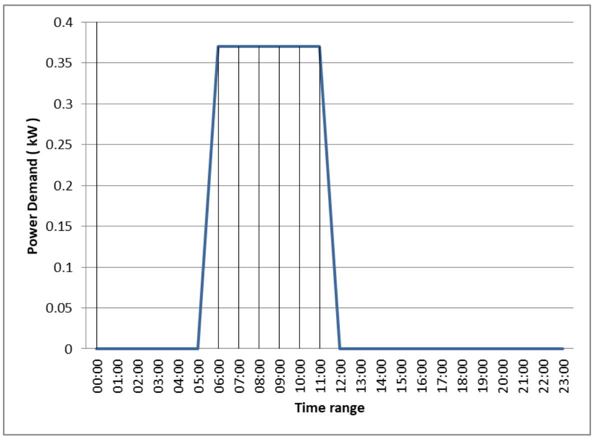


Figure 29: Load Profile case 1, hot season

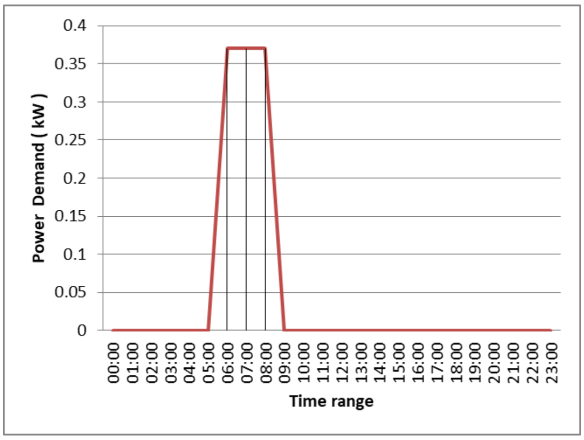


Figure 30: Load Profile case 1, winter and rainy season

For case 2 and case 3, it is assumed to run the pump during the best solar time, around solar noon. This alternative is crucial to the case 2 since there will not be a battery system. Consequently, it is necessary to absorb the maximum solar energy during the daytime to store the necessary water and subsequently supply during the day.

From Figure 31, it can be noticed that solar noon is almost constant along the year and around 12 a.m., civil time [59]. This consideration is strictly dependant by the specific location that is taken into consideration, Lusaka, Zambia (Latitude:15 degrees 23.25 minutes South and Longitude: 28 degrees 19.37 minutes East).

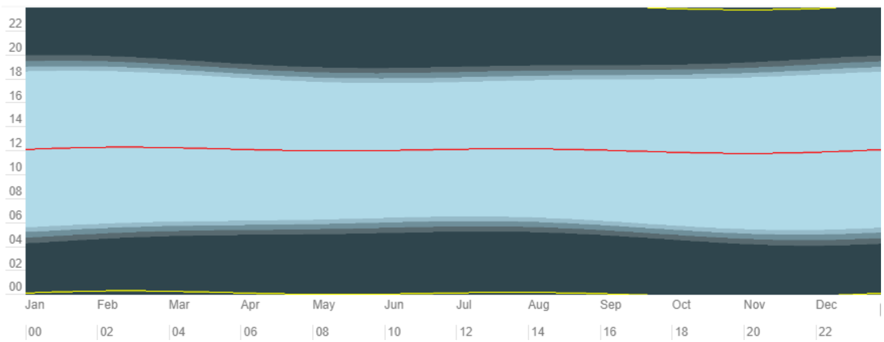


Figure 31: Lusaka's daily solar time

It will be consequently proposed to the workers to switch on the pump at 9:30 a.m. during the hot season. Even in this case, the pump needs to operate for 5 hours to fill the water tank. On the other hand, it will be asked to switch on the pump at 10:30 during the winter and rainy seasons. In this case, the pump will operate for 3 hours to supply the 3500 Litres of water into the tank.

These specific periods to operate the pump have been considered as results of a normal distribution of the energy demand around 12 a.m., the hour in which is expected the maximum tilted irradiance.

In Figure 32 and Figure 33, the load profiles are displayed for the two different periods.

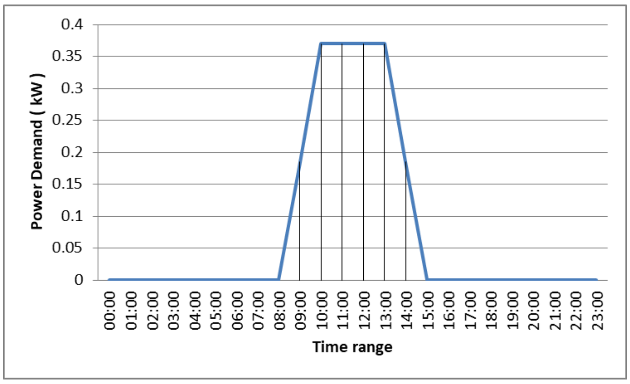


Figure 32: Load Profile case 2 and 3, hot season

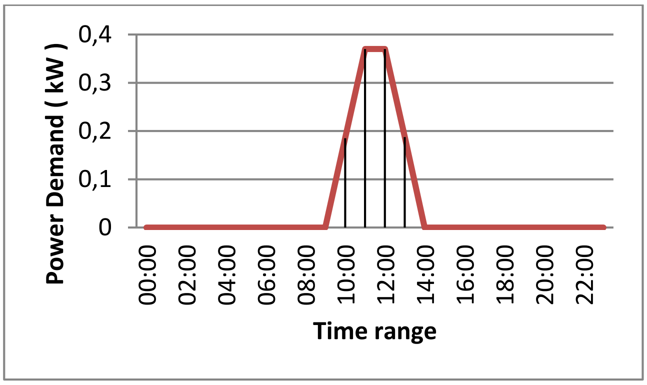


Figure 33: Load Profile case 2 and 3, winter and rainy season

4.3.2. System components

The Caprari and Keyfuture company would test in this project the performance of flexible solar panels. The purpose of the development of this system is to understand the potentiality of flexible solar panels for rural and emergency applications in the stand-alone system.

The use of low weight off-grid system is crucial to reduce the transport cost to remote areas. In specific situations, such as remote hospitals, temporary camps and conflicted areas the use of these technologies becomes fundamental. Moreover, low-weight systems become fundamental for populations that use to migrate on a seasonal base. This happens for example, in the central-west province of Zambia. The local population migrates from the dry area to wet areas to properly feed their animals and grow their crops. As explained in the research performed by Iván Cristóbal-Monreal and Rodolfo Dufo-López, the mobile system cannot disserve of the use of flexible crystalline silicon panels to reduce weight and consequently the transport cost of the system, that becomes a crucial variable on the emergency [60].

Figure 34: Flexible solar panels

In Table 27, the electrical and physical characteristics of the module are displayed [61]. The name of the module is FWAVE, is a 92 W module and is produced by Fuji Electric.

Table 27: Technical characteristics of the PV module

Item	Symbol	unit	Rating (After stabilization)
Rated Maximum Power Output	Pmax	W	92
Minimum Power Output	Pmax(min)	W	82.8
Maximum Power Voltage	Vpm	V	319
Maximum Power Current	Ipm	A	0.288
Open Circuit Voltage	Voc	V	429
Short Circuit Current	Isc	A	0.390
Maximum reverse current	Ir(max)	mA	30 (*2)

For the solar modules, a 25 years' lifespan has been considered, as suggested by manufacturer.

Moreover, below are reported two fundamentals data, tested by manufacture under Standard Test Conditions:

- Temperature coefficient of short circuit current (Isc) equal to +0.008 %/°C
- Temperature coefficient of open circuit Voltage (Voc) equal to -0.35 %/°C. Consequently, equal to -150.15 V/°C

Can be consequently computed the temperature coefficient of power using the Equation 11 [62].

$$\alpha_p = \frac{\mu_{Voc}}{V_{mp}} \tag{11}$$

Where:

μ_{Voc} = the temperature coefficient of the open-circuit voltage [V/°C]

V_{mp} = the voltage at the maximum power point under standard test condition [V]

Consequently, it can be obtained a temperature coefficient of P_{max} equal to -0.23 %/°C.

It has been suggested to use by the Keyfuture company the Covenergy inverter. It has been developed by the company specifically to be used with flexible solar panels. It works as a battery controller and a maximum power point tracker.

The technical characteristics of the inverter are displayed in Table 28.

Table 28: Inverter's technical details

Maximum Power Input (kW)	**3**
Maximum input voltage (V)	400
Maximum input current (A)	15
Maximum Power output (kW)	2
Efficiency (%)	92
Life-span	10

Moreover, the Hoppecke 10 OPZS lead-acid batteries are considered. They have a nominal capacity of 1500 Ah, a rated voltage of 2 V and a lifetime of 8 years, with a round-trip efficiency of 86% [63].

4.3.3. Homer Simulation

Hybrid Optimization Model for Electric Renewables (HOMER) is a software developed by the National Renewable Energy Laboratory (NREL) to facilitate the design of distributed generation (DG) systems - both on and off-grid [64]. HOMER allows performing optimization and sensitivity analysis to evaluate the economic and technical feasibility of many technology options taking into consideration the potential variations in technology costs and energy resource availability.

The software allows to simplify the operation of a system by making energy balance calculations in the chosen time step of the year. For each time step, it compares electric and thermal energy loads in that time step to the energy that the system can generate. It consequently computes the energy flow for each component of the system. Subsequently, the software analyses if the chosen configuration is feasible, matching or not the energy needs. Then, HOMER computes the installation and operation cost of the system along its lifetime. The software sort all the feasible configurations base on the Net Present Cost (NPC) of the system. The software

can perform sensitivity analysis of the system. The sensitivity analysis allows quantifying the effects of the variation of parameters not controllable, such as wind speed or fuel price.
Specifically referring to the present case in study, it has been first inserted the potential load profile of the system, shown in chapter 4.3.. The yearly load has been inserted as a series of 8760 values, representing the energy demand per hour along the year.
Consequently, it has been selected the location of the project. The programme can reveal the solar resource and the thermal data corresponding to the specific project site, Lusaka. The respective resources data are taken by the software from "NASA surface meteorology and Solar energy database" as monthly averaged values over 22 years (July 1983 – June 2005). In Figure 35, the average temperatures in Lusaka are displayed.

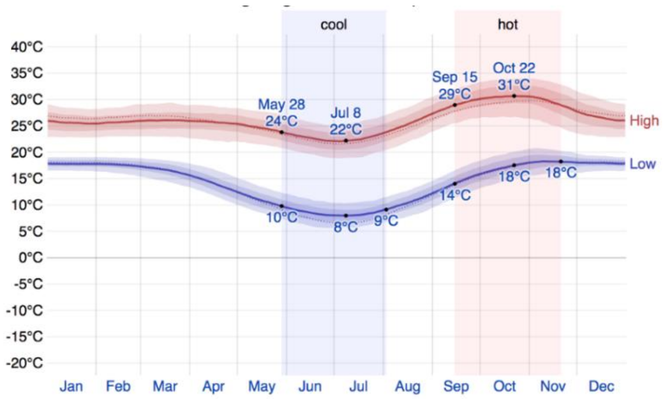


Figure 35: Average high and low temperature for Lusaka

It has been used an optimum tilt angle equal to 15°, towards the north. It is displayed, in Figure 36 the average global tilted irradiation (GTI), along the years.

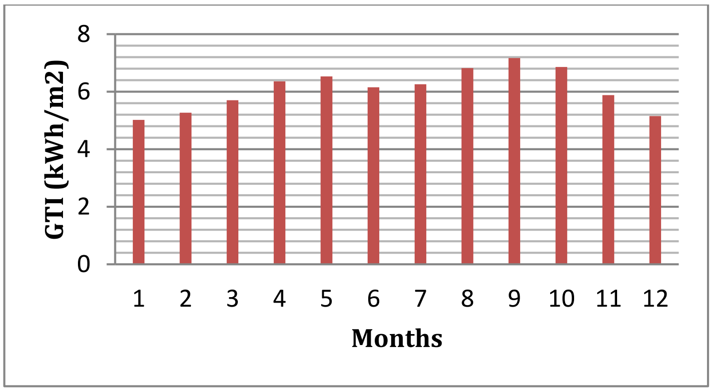


Figure 36: Average global tilted irradiation (GTI) in Lusaka

After having considered the available resource and the load profile of the system, the details of the specific components, shown in the previous chapter, have been inserted in the software for each specific case. The design setting of each case is summarised below:

- Case 1: The system consists of solar modules, inverter and battery system. For this case, it has been taken into consideration the load profile 1, the one that sees the pump work from 6 a.m.

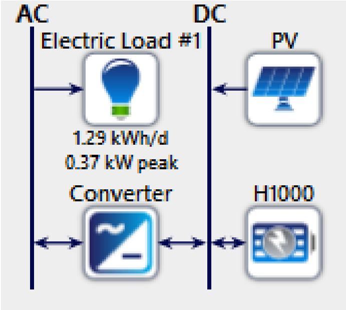


Figure 37: System design, case 1

- Case 2: The system consists of solar modules and inverter. For this case, it has been taken into consideration the load profile 2, the one that uses a normal distribution of the demand of energy around the solar noon.

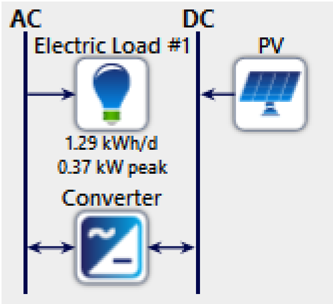


Figure 38: System design, case 2

- Case 3: The system as a similar setting of case 1, solar modules, batteries and inverter/controller, and use the load profile of the case 2, load profile 2.

Finally, specifics constraints have been set in the software. The unmet load has been limited to 10% per year, to provide high system reliability. The flexibility of the load profile has been set to 5%. Consequently, the software has been run and the results analysed.

4.3.4. Results

To firstly size the system, it has been used the optimization strategy used by the software Homer. The results obtained for each case are displayed in Table 29. As can be seen in case 2, the one without electrochemical storage, the necessary PV power is higher than the other two cases.

Table 29: System setting, using the Homer Optimization Strategy

Components	Units	Case 1	Case 2	Case 3
Pv modules	kW	0.375	0.692	0.333
Batteries	Numbers	1	-	1
Inverter/controller	kW	0.368	0.37	0.375

Consequently, the system has been sized considering the real components that will be used. In the specific, the 2 kW inverter and the 92 W flexible modules were considered to consequently run the software and obtain the potential energy production along the year. The final setting for each case is displayed in Table 30. There is just one PV module of difference between t the case 1 and 3.

Table 30: Final systems settings

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 31.

Table 31: 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.

It is consequently necessary to understand the economic feasibility of the three systems.

4.4. Economic Analysis

In energy projects, to analyse the profitability and the cost related to the system during its lifetime is crucial. 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 will be 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.

To implement the economic assessment, it is, first, analysed the cost for each component.

The cost and lifespans of the flexible solar panels and inverter have been given by the partners of the project: Caprari and Keyfuture. They suggested to refer for a maintenance cost of the solar panels equal to 1 % of the initial investment cost. The cost of the Hoppecke 10 OPzV battery has been given by a local supplier.
The overall costs are displayed in Table 32. They specifically take into consideration the cost of shipping and transport to the community and the current VAT in Zambia equal to 16 % of the cost.

Table 32: Systems Costs

Component	Initial cost	Replacement cost	Unit	Operational cost (€/year)	Life span (year)
PV module	630.0	630.0	€ per kWh	6.3	20
	58.0	58.0	Module cost	0.58	20
Batteries	762.0	762.0	€ per unit	0	8
Inverter/Controller	767.0	767.0	€ per unit	0	10

As well as for chapter 3, the same economic parameters will be taken into consideration:

- Inflation rate for Zambia equal to 6.5 % [51].
- Nominal interest rate for Zambia equal to 10% [52].
- The project lifetime is considered 20 years.

By the inflation rate and the nominal interest rate, the real discount rate is obtained. It can be assumed equal to 3.3%.
Consequently, the NPV can be computed. In the specific, it is considered the Net Present Cost (NPC), that is simply the NPV without the revenues, not being present in this specific project. Consequently, below is displayed the formula of the NPC:

$$\text{NPC}= \sum_{j=1}^{n} \frac{Outcj}{(1+r)^{j}} \quad (12)$$

Where $Outcj$ represent the total outcome in the year j, n represent the project lifetime and r the real discount rate. In particular, the initial investment is considered to occur at the starting point of the project. The replacement of the inverter occurs in year 11 and of the battery in year 9 and 19. Consequently are computed the six NPCs, one for each of the three systems and the two-financing method, with and without the donation, provided to overcome the initial investment. They are displayed in Table 33.

Table 33: NPCs for the three cases

	Units	NPC Case 1	NPC Case 2	NPC Case 3
Sel-financing	€	3,380.0	1,835.3	3,313.7
Donation	€	1,561.2	604.6	1,552.8

The most affordable solar system is the one arranged for case 2. This is mainly because there is no energy storage. The replacement cost for batteries and inverter is quite relevant. This can be noticed in the NPC for the case with the initial investment covered by the donation. The NPC results in more than double between the case 2 and the other two cases.

It can be consequently computed with the same logic the LCOE. Resuming, the formula of the LCOE is the following:

$$LCOE = \frac{IT + \sum_{j=1}^{n} \frac{\text{Cinvj}}{(1+r)^j} + \sum_{j=1}^{n} \frac{\text{comj}}{(1+r)^j}}{Ed} \tag{13}$$

Where Ed is expressed as:

$$Ed = \sum_{j=1}^{n} \frac{\text{Eaj}}{(1+r)^j} \tag{14}$$

It will be taken into consideration the energy produced by each system as expressed in the previous subchapter. Moreover, it will be considered a degradation of the system that produces a yearly reduction in the production of energy equal to 0.4 %.

The results of the computation are displayed in Table 34, considering the two different case to cover the initial investment: with and without a donation.

Table 34: levelized cost of energy of the three cases (LCOE)

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

Even in this case, the most convenient system is the one of the case 2, not only because the initial investment is much lower than the other two but even because the energy produced is almost the double.

The energy tariffs in Zambia depend on the type of costumers. The main ones are displayed in Table 35.

Table 35: Electrical Tariffs in Zambia [65]

	Below 200 kWh month	Above 200 kWh month	Social tariff
Tariffs (€)	0.012	0.055	0.038

Comparing them with the LCOEs computed, there is no type of system and financial aid able to compete with the tariff for energy consumers below 200 kWh per month. Only the LCOE referred to the system of case 2, financed throughout donation, can compete with the other national tariffs.

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

5. Sustainable Business creation

5.1. Motivation

After the small experience on the context analysed, it has been found that is not easy to replace the cooking methods of people with less polluted technology. The charcoal is currently the most used source of energy in urban areas of Zambia and even the first cause of deforestation of the country. Consequently, on a macroscale level, the business has as main objective the reduction of the deforestation process produced by the harvesting of wood for cooking purposes. To do so, the creation of a sustainable value chain to produce a more sustainable source of energy is investigated.

Timber and charcoal trade is one of the major responsible for the 0.3 % forest loss in Zambia. On the other hand, this market contributes considerably to the income of the country. It contributes to 3.7 % of the GDPs of the country [21].

The charcoal is produced in the rural areas of the country. Trees are chopped down, and from their timber is produced the charcoal. It is produced traditionally, using earth kiln. The carbonization yield of these methods is considerable low, of around 12% [21]. Consequently, it is transported in the main cities and sold in informal ways. It is estimated that in Lusaka, 85 % of the population uses charcoal to cook on a daily base. These numbers are expected to increase without valid alternative energy sources, because the urbanisation rate is expected to increase by 3.2 % per annum [21].

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, will be developed a pilot project to understand the feasibility of this venture. Once it will be proved the reliability and the profitability, the business will be scaled up, to understand the validity on a country level.

In this thesis, only some details of the project are shown. The project partners have expressly mentioned their intention to keep certain project specifications secret, to keep their intellectual property intact.

5.2. Defining the methodology: The Sustainable Canvas model

In this part of the project, it will be dealt with defining, step by step, one of the most used tools by the Start-up business, to describe and design new business models, the Canvas scheme and in the specific the Sustainable Canvas Model.

The "Canvas" model offers a visual and easier representation of the business model, in a comprehensible description that allows to design strategic alternatives. This model is a preliminary description of the business that allows the enterprise to make assessments both in organizational and strategic terms.

By establishing a new product or service, the first thing to do is to define what is offered to whom and how to produce it. It has been decided to use the canvas model for four main reasons. First, it allows undertaking an exercise of constant reflection, gradually developing the business model. Second, it ensures that entrepreneurs, customers, employees, managers, and even competitors understand how the company articulates its various components. Therefore, with this tool, communication with the various stakeholders is facilitated. This makes possible to be a starting point for the creative discussion of new business opportunities. It also allows to always have the focus and vision of the company and facilitates the identification of risks and possible failures. Third, it allows the business creator to consider each of the elements of the business simultaneously, individually but also as a whole. Finally, the use of a graphics tool helps to increase the creativity and the degree of innovation of companies. The canvas integrates the design thinking methodology, being easier to allow the stakeholders to the discussion and brainstorming sessions, which encourage creative developments based on the needs and desires of customers

The original Canvas model can greatly simplify the representation of the business through the identification of nine key elements that represent the company. They are arranged in blocks and interlocked on a single scheme that needs to be filled using a specific logic. The nine blocks are customer segments (1), value proposition (2), channels (3), customer relationships (4), revenue streams (5), key resources (6), key activities (7), key partnerships (8), and cost structure (9). Each block contains a series of questions to validate the model and its internal strength.

For the specific study case, it will be followed the sustainable Canvas model. Much No-profit associations are nowadays following the triple-bottom-line business model. It is the expression of the sustainable development approach where the three main topic, environment, social inclusion and economy, are strictly interconnected. The triple bottom line business model wants to achieve social and environmental goals at the same time as revenue generation. To design a business model that matches the triple objectives of a sustainable model, the Canvas model must include two additional blocks, namely, "Social and Environment Benefit" and "Social and Environment Cost" [66]. The model is presented in APPENDIX E.

The focus on the social impact include monitoring and management of the social impact of the business and of the possible social change processes triggered by itself. The creation of a new business, in the creation of a product or service, can have both intentional and involuntary repercussions, both positive and negative, both on people and environment. For these reasons, it is crucial to include the two blocks that take environmental and social aspect into account.

5.3. Business model development and enterprise creation

5.3.1. Customer Segment

The project will start focusing on a specific market and area. The customers will be initially households of a specific compound, called Chikondano, located in Lusaka. It has been decided to start in this area because is nearby of the community and some of the community staff are living there. In this area, the only available fuel to cook is the charcoal. It is produced illegally and has a monopoly because there are no other local technologies and fuel. The electricity in this compound is not reliable and the LPG is too expensive and the transport of it in the compound is not so facilitated.

In this area, people cook using the Mbawula, a locally manufactured stove, shown in Figure 39. It has an efficiency of around 19 %. It is used charcoal in there [21].

Figure 39: Mbawula stove

The cost of charcoal is one of the main expenditures for the residents in this compound. In Table 36 are expressed the cost of it for the different bag's size.

Table 36: Charcoal cost analysis

Kg per bag	Cost (€)	Cost per Kg (€)
5	0.8	0.15
10	1.2	0.12
25	4.6	0.18
50	6.9	0.14
90	10.8	0.12

5.3.2.Value Proposition

The objective of this business is to produce and sell a different type of charcoal, made from solid bamboo. The solid bamboo has found to be a local tree, that grows in the north part of Zambia. The properties of this tree are that once is chopped down can easily regrowth. Laboratories test needs still to be performed, to have an overall figure of its chemical properties.

Figure 40: Sample of solid bamboo and the obtained charcoal

The present business aims to sell the charcoal shown on the right of Figure 40. It has a length that can vary from 20 to 30 cm for a 3 cm of diameter.

5.3.3.Distribution Channel

Initially, the product will be sold door-by-door. First, promotions of the product will be performed, to show its potentiality and advantages. With the increase of the business will be created a distribution system of the charcoal that will mainly target the women, since, in the targeted compound they are the ones that sells and buy the charcoal.

5.3.4.Key activities (production of charcoal, in details)

The main activity of the business is the production and sale of charcoal. The charcoal is produced using a drum that has been opportunely cut to produce a device like the one used in chapter 3. It is substantially a gasifier that carbonizing the solid bamboo produce the charcoal.

The drum was locally manufactured following the design proposed by the University of Udine. Local people were trained to produce it, using specific templates, produced by the author of the thesis, as presented in Figure 41.

Figure 41: Manufacturing of gasifier

The drum is filled with around 50 Kg of dry solid bamboo. After an average of 1 hour and a half, the biomass is fully turned into charcoal. It has been found a carbonization yield of around 40 %. This means that from 50 kg of biomass is possible to obtain 20 kg of charcoal. Consequently, the charcoal needs to be cooled down, to avoid that transforms into ash. To do so, it is added water into the drum. Finally, the charcoal is dried into a metal sheet.

Then, the charcoal needs to be packed and transported into the nearby compound.

5.3.5.Key resource (supply of biomass and drums)

In each bioenergy project and business, it is first crucial to estimate the available biomass. This needs still to be done. Nevertheless, the key resource of this project is solid bamboo. It is fundamental to understand its availability and its supply.

Moreover, another important resource is the supply of the drums to carbonise the bamboo. It can be estimated a lifespan of the drum equal to 100 loads of bamboo. This assumption will be taken into consideration to understand the production cost of the charcoal.

5.3.6.Key Partners

In the order, 6 main partners can be identified:

1. Plantamillion: it is a company that deals with tree economy. They aim to create an economic scheme based on tree planting. It is the main developer of the project. It is currently financing the pilot project and planting solid bamboo in different areas of Zambia.
2. Koinonia community: as it was explained in the previous chapters, it is a rural community in the suburban area of Lusaka. The pilot project is developed on its land and its residents will be the first beneficiaries of the project.

3. Rural workers and communities: to collect the solid bamboo in the rural areas, the participation of villages and communities is crucial. They are engaged for them to learn a new charcoal production method and the opportunity to be employed for the bamboo cutting and planting.
4. Women in the compound: to sell the produced charcoal in the compound it is important to build a strong collaboration with the women that are already selling the charcoal in there.
5. Drums supplier: the drums used to produce charcoal will be supplied by a nearby company that produce jams and other food products. The project aims to reuse their drums and to give another life and use to them.

All the 5 partners will positively beneficiary throughout this potential collaboration, mainly through a monetary contribution for their services and products.

5.3.7. Customer Relationship (Questionnaires)

To understand the wiliness to pay off the product, it will be initially provided for free the charcoal. Consequently, interviews with the potential customers will be performed.

5.3.8. Cost and revenue stream

To have an idea on the profitability of the business, it is crucial to estimate the cost related to the production of charcoal. It has been initially considered to estimate the cost related to a 50 kg bag. For its production were considered the following operational cost:

1. Cost related to biomass cutting
2. Cost related to biomass transport
3. Cost related to the charcoal production (labour cost and other costs necessary to perform the process)
4. Equipment cost (Drums, packaging, metal sheet etc.)
5. Production license

In details the costs are shown in table 1 of the APPENDIX F. It can be noticed that the overall cost for a 50 kg bag is 4.9 €. The most relevant cost is related to the production license cost. It contributes to 42.5 % of the overall cost of a 50 kg bag.

As it was previously shown in the customer segment analysis, a 50 kg bag of charcoal is sold for 6.9 € in the targeted compound. Considering selling it for 6.8 €, the estimated profit is 1.7 € per bag.

The production capacity is for the moment of 20 bags per day, so the daily profit is equal to 34 €. That profit corresponds to the average monthly income in Zambia. Increasing the production capacity can considerably bring an income to all the stakeholders.

5.3.9. Eco-social Cost and benefits

The potential eco-social benefits and drawbacks of the project are displayed in Table 37. A future study will better quantify the impact of the business.

Table 37: Eco-social benefits and drawbacks

	Environmental	Social
Benefits	• Potential reduction of local deforestation • Local fuel production	• Job creation • Income generation • Local fuel production
Drawbacks	• Local indoor pollution due to charcoal combustion	• Unexpected

6.Conclusions 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. Moreover, it will be interesting to compute the cost of water (€/litres) to assess and compare different sizes of water storage and electrical systems.

In the last chapter, the last work of the author of the thesis has been presented. 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 8 months 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.

References

[1] M. Shah, "Sustainable Development," International Institute for Applied Systems Analysis, 2008.

[2] WHO, "WHO guidelines for indoor air quality: Houseold fuel combustion," 2012.

[3] "Hans Carl von Carlowitz and “Sustainability”," [Online]. Available: http://www.environmentandsociety.org/tools/keywords/hans-carl-von-carlowitz-and-sustainability. [Accessed March 2019].

[4] G. A. UN, "Resolution adopted by the General Assembly on 25 September 2015," 2018.

[5] D. Gilman and R. Gilman, "Eco-villages and Sustainable Communities: A Report for Gaia Trust by Context Institute," Context Institute , 1991.

[6] Footprint Network, "Global Footprint Network," [Online]. Available: https://www.footprintnetwork.org/our-work/ecological-footprint/. [Accessed March 2019].

[7] M. Daly, "Quantifying the environmental impact of ecovillages and co-housing communities: a systematic literature review," Local Environment, 2017.

[8] S. Mandelli, "STRATEGIES FOR ACCESS TO ENERGY IN DEVELOPING COUNTRIES: METHODS AND MODELS FOR OFF-GRID DESIGN," Politecnico Di Milano, Milan, 2014.

[9] IEA (International Energy Agency), "Energy for all. Financing Access for the poor, World Energy Outlook," 2011.

[10] WB-IEA (World Bank - International Energy Agency), "Progress towards Sustainable Energy 2015 - Global Tracking Framework Report," 2015.

[11] UNEP (United Nations Environment Programme), "Atlas of Africa Energy Resources," UNEP , Nairobi, 2017.

[12] Practical Action, "Gender and Livelihoods Impacts of Clean Cookstoves in South Asia," Practical Action Publishing Ltd, 2014.

[13] K. O’Dell, "Women, Energy, and Economic Empowerment," Deloitte University Press, 2014.

[14] T. Dinkelman, "“The effects of rural electrification on employment: new evidence from South Africa"," The American Economic Review, 2011.

[15] IEA, “Energy Access Outlook,” 2017.

[16] WHO, "Medical Devices: Managing the Mismatch," 2010.

[17] R. Hodges, "“Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use," Journal of Agricultural Science, 2011.

[18] Worl Bank, "Getting Electricity: Factors Affecting the Reliability of Electricity Supply, Doing Business 2017," 2017.

[19] ESI Africa, "BBOXX: solar innovation to light up Togo," 2019. [Online]. [Accessed February 2019].

[20] S. Agabu, H. G. Shabbir and P. Seveliano, "Rural domestic biogas supply model for Zambia," Renewable and sustainable energy reviews, 2017.

[21] D. Gumbo, K. Moombe and M. Kandulu, "Dynamics of the charcoal and indigenous timber trade in Zambia," 2013.

[22] FAO, "Forest global resources," 2015.

[23] N. Bruce, "Liquefied Petroleum Gas as a Clean Cooking Fuel for Developing Countries: Implications for Climate, Forests, and Affordability, Materials on Development Financing," KFW Development Bank, 2017.

[24] World Bank, "ZAMBIA ECONOMIC BRIEF," 2017.

[25] IEA, "World energy balances," 2018.

[26] M. Jürisoo, F. Lambe and O. Matwee, "Beyond buying: The application of service design methodology to understand adoption of clean cookstoves in Kenya and Zambia," Energy Research & Social Science, 2018.

[27] World Bank , "Climate Data Zambia," [Online]. Available: https://climateknowledgeportal.worldbank.org/country/zambia/climate-data-historical#. [Accessed August 2019].

[28] F. Research, "Typical calorific values of fuels," [Online]. Available: https://www.forestresearch.gov.uk/tools-and-resources/biomass-energy-resources/reference-biomass/facts-figures/typical-calorific-values-of-fuels/. [Accessed August 2019].

[29] Global Alliance For Clean Cookstove, "The Water Boiling Test Version 4.2.3," 2014.

[30] Department of Agricultural, Food, Environmental and Animal Sciences - University of Udine, "Biocharplus project," [Online]. Available: https://sites.google.com/site/biocharplusproject/home. [Accessed August 2019].

[31] GIZ, Gesellschaft für Internationale Zusammenarbeit GmbH, "Micro-gasification: cooking with gas from dry biomass," 2013.

[32] F. O. Okey, L. E. Sunday and C. O. Ifeanyichukwu, "Energetic performance of a top-lit updraft (TLUD) cookstove," Renewable Energy, 2016.

[33] J. Lehmann, J. Gaunt and M. Rondon, "Bio-char sequestration in terrestrial ecosystems," Mitigation and Adaptation Strategies for Global Changes, 2006.

[34] L. Lijian and H. Huajun, "An overview of the effect of pyrolysis process parameters on biochar stability," Bioresources Technology , 2018.

[35] P. Blackwell, G. Riethuller and M. Collins, "Biochar application to soil," Biochar for Environmental Management, 2009.

[36] Z. Qiaohong and P. Xinhua, "Effect of Biochar Addition on Maize Growth and Nitrogen Use Efficiency in Acidic Red Soils," Pedosphere, 2014.

[37] T. Oldfield and N. Sikirica, "Biochar, compost and biochar-compost blend as options to recover," Journal of Environmental Management , 2018.

[38] K. Homagain and C. Shahi, "Life cycle cost and economic assessment of biochar-based bioenergy production and biochar land application in Northwestern Ontario, Canada," Forest Ecosystem, 2016.

[39] I. N. Anyanwu, M. N. Alo and A. M. Onyekwere, "Data on heavy metals content and biochar toxicity in a pristine tropical agricultural soil," Data in Brief, 2018.

[40] G. W. H. G. Hol, M. Vestergård and F. C. Ten Hooven, "Transient negative biochar effects on plant growth are strongest after microbial species loss," Soil Biology & Biochemistry, 2017.

[41] KfW Development Bank, "Liquefied Petroleum Gas as a Clean Cooking Fuel for Developing Countries: Implications for Climate, Forest and Affordability," 2017.

[42] Center for Energy Studies , "Efficiency Measurement of Biogas, Kerosene and LPG Stoves," 2001.

[43] Swiss Agency for Development and Cooperation, "Anaerobic Digestion of Biowaste in Developing Countries," 2014.

[44] J. Colón, A. Forbis-Stokes and M. Deshusses, "Anaerobic digestion of undiluted simulant human excreta for sanitation and energy recovery in less-developed countries," Energy for Sustainable Development, 2015.

[45] SDC, Swiss agency for development and cooperation, "Anaerobic Digestion of Biowaste in Developing Countries," 2014.

[46] S. Agabu, H. Shabbir and P. Seveliano, "Rural domestic biogas supply model for Zambia," Renewable and Sustaiable Energy Reviews, 2017.

[47] R. Penn and B. Ward, "Review of synthetic human faeces and faecal sludge for sanitation and," Water Research, 2017.

[48] Z. Kowalski, M. A. and K. Fijorek, "Changes in the properties of pig manure slurry," Actabp, 2013.

[49] International Renewable Energy Agency, "Measuring small-scale biogas capacity and production," Abu Dhabi, 2016.

[50] J. Santana and R. Castro, "Economics and energy markets,Basics on the Economic Assessment of the Power System," 2016.

[51] Trading Ecomincs, "Zambia inflaction rate," August 2019. [Online]. Available: https://tradingeconomics.com/zambia/inflation-cpi. [Accessed August 2019]

[52] Trading Ecomomics, "Zambia Interest Rate," August 2019. [Online]. Available: https://tradingeconomics.com/zambia/interest-rate. [Accessed August 2019]

[53] Ecometrica, "Greenhouse Gases, CO2, CO2e, and Carbon: What Do All These Terms Mean?," [Online]. Available: https://ecometrica.com/assets/GHGs-CO2-CO2e-and-Carbon-What-Do-These-Mean-v2.1.pdf. [Accessed August 2019].

[54] S. Bhattacharya and A. P. Salam, "Low greenhouse gas biomass options for cooking in developing countries," Biomass & Bioenergy, 2002.

[55] S. Chandel, N. Naik and R. Chandel, "Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies," Renewable and Sustainable Energy Reviews, 2015.

[56] B. Damasceno, M. Pinto and D. Alves, "Cost Analysis of Pumping Water Using Solar Energy and Diesel in Drip Irrigation," IRRIGA, 2014.

[57] CAPRARI, "E4XP15," [Online]. Available: http://www.perfoitalia.com/public/file/el_so_caprari.pdf. [Accessed August 2019]

[58] FAO, "Irrigation Techniques for Small-scale Farmers: Key Practices for DRR Implementers," 2014.

[59] "2019 Sun Graph for Lusaka," [Online]. Available: https://www.timeanddate.com/sun/zambia/lusaka. [Accessed august 2019].

[60] I. Cristóbal-Monreal and R. Dufo-López, "Optimisation of photovoltaic–diesel–battery stand-alone systems minimising system weight," Energy Conversion and Management, 2016.

[61] " Modules Solar FWAVE," Fuji Electric, [Online]. Available: http://calculationsolar.com/pdfs/Calculationsolar_module_FUJI_FPV1092COM2843.pdf. [Accessed august 2019].

[62] "PV Temperature Coefficient of Power," Homerenergy , [Online]. Available: https://www.homerenergy.com/products/pro/docs/3.13/pv_temperature_coefficient_of_power.html. [Accessed august 2019].

[63] Hoppecke, [Online]. Available: https://www.hoppecke.com/fileadmin/Redakteur/Hoppecke-Main/Products/Downloads/OPzS_en.pdf. [Accessed august 2019].

[64] H. energy, "HOMER® Pro Version 3.7 User Manual," [Online]. Available: https://www.homerenergy.com/pdf/HOMERHelpManual.pdf. [Accessed august 2019].

[65] Zesco, [Online]. Available: http://www.zesco.co.zm/customerCare/tariffs. [Accessed September 2019].

[66] R. Ledda, IMPRENDITORIALITA’ E POSIZIONAMENTI STRATEGICI NELLE START-UP INNOVATIVE: IL CASO ENKI STOVE, 2015.

[67] Practical Action, "Energy Access and Urban Poverty," 2015.

[68] G. Alberti, "Environmental benefits from biochar technology," Università di Udine, 2015.

[69] WHO, "www.who.int," 03 2019. [Online]. [Accessed August 2019]

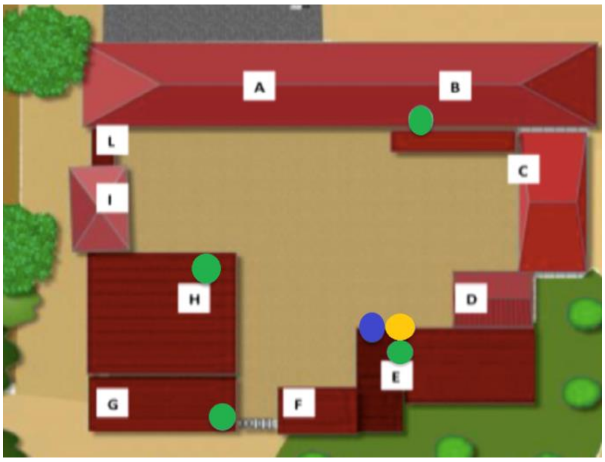
[70] Wikipedia, "Zambia," [Online]. Available: https://en.wikipedia.org/wiki/Zambia. [Accessed August 2019].

[71] WWF, "Living Planet Report 2014," 2014.

[72] G. Lia, Y. Jinb, M. Akramb and X. Chenc, "Research and current status of the solar photovoltaic water pumping system – A review," Renewable and Sustainable Energy Reviews, 2017.

[73] S. H. G. S. P. Agabu Shanea, "Rural domestic biogas supply model for Zambia," Renewable and Sustainable Energy Reviews, 2017.

Appendix A1: Mthunzi's Simplified Electrical system



A-I	Dormitories
B	Kitchen and living room
C	Offices
D	Garage
E	Theatre
F	Warehouse
H-G	Offices and Guest House
L	Empty room

(yellow)	Electrical Meter
(blue)	Three-Phase switch
(green)	Single-Phase switch

Figure 42:Mthunzi's semplified Electrical system

Appendix A2: Mthunzi energy consumptions

Area	appliances	power consumption (W)	quantiy	usage(h/day)	period (h)
A-I	Light 1	40	10	8	6-8 and 16-22
	Light 2	18	4	8	6-8 and 16-23
	Philips neon	36	3	4	18-22
B	Light 1	40	5	10	6-8 ; 16-22 and 12-14
	Philips neon	36	6	4	18-22
	TV	150	1	2	18-22
	Projector	40	1	2	20-22
	computer	150	1	3	15-18
C	Light 1	40	1	9	8-12 14-19
	Philips neon	36	5	9	8-12 14-20
	Laptop	40	3	9	8-12 14-21
E	Philips neon	36	2	4	18-22
	spothlight	50	2	10	20-6
F	Philips neon	36	3	7	18-22
	frezeer 530L	300	1	24	24-00
	fridge 220L	200	1	24	24-01
G	Light 1	40	8	7	6-8 ; 12-14 and 20-23
	Light 3	85	1	10	8-12 14-20
	Philips neon	36	2	4	18-22
	laptop	40	4	6	10-12 14-20
H	Philips neon	36	4	4	18-22
	Light 2	18	6	8	16-23

Appendix B: Water Boiling Test Computations

Measured Variables:

f_{ci} Mass of fuel before the test (grams)

$P1_{ci}$ Mass of the pot of water before the test (grams)

$T1_{ci}$ Water temperature at the start of the test (ºC)

$t_{c,i}$ Time at the start of the test (min)

f_{cf} Mass of fuel after the test (grams)

c_c Mass char with dish after the test (grams)

$P1_{cf}$ Mass of the pot of water after the test (grams)

$T1_{cf}$ Water temperature at end of the test (ºC)

t_{cf} Time at end of the test (mins)

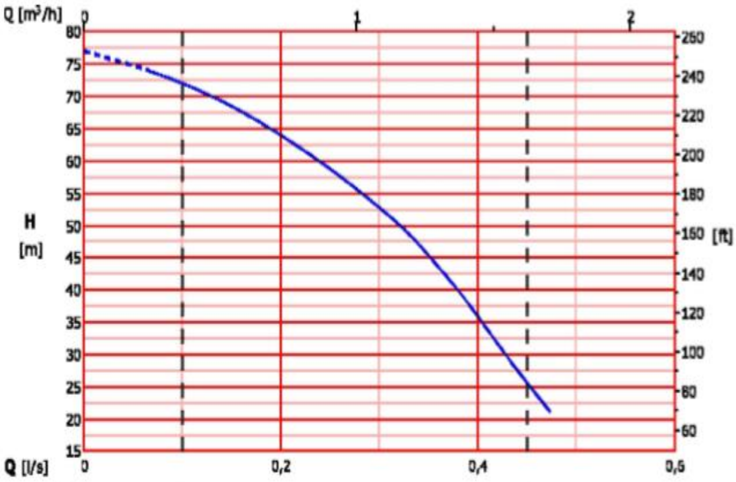
Equations [29]:

Equation B1: Consumed Fuel	$f_{cm} = f_{ci} - f_{cf}$
Equation B2: Net change in char	$\Delta c_c = c_c - k$
Equation B3: Mass of water vaporised	$w_{cv} = P1_{ci} - P1_{cf}$
Equation B4: Effective mass of water boiled	$w_{cr} = P1_{cf} - P1$
Equation B5: Time to boil	$\Delta t_c = t_{c,f} - t_{c,i}$
Equation B6: Temperature corrected time to boil	$\Delta t_c^T = \Delta t_c \cdot \frac{75}{T1_{cf} - T1_{ci}}$
Equation B7: Equivalent dry fuel consumed	$dry\, fuel = f_{cm} \cdot (1 - MC)$
Equation B8: Energy to evaporate water	$\Delta E_{H_2O,c} = m_{H_20,c}\left(C_p\left(T_b - T_{fuel,i}\right) + \Delta h_{H_2O,fg}\right)$ $C_p \approx 4.186 \left[\frac{kJ}{kgK}\right]$ $\Delta h_{H_2O,fg} \approx 2{,}257 \left[\frac{kJ}{kg}\right]$ $T_{fuel,i} \approx T_a$
Equation B9: mass of water in the fuel	$m_{H_20,c} = f_{cm} \cdot MC$

Equation B10: Energy to evaporate water (extended)	$\Delta E_{H_2O,c} = f_{cm} \cdot MC(4.186(T_b - T_a) + 2{,}257)$
Equation B11: Quantity of fuel to evaporate water	$fuel\ to\ evap\ water = \frac{\Delta E_{H_2O,c}}{LHV}$
Equation B12: Energy stored in the remaining char	$\Delta E_{char,c} = \Delta c_c \cdot LHV_{char}$
Equation B13: Equivalent amount of fuel remaining in form of char	$fuel\ in\ char = \frac{\Delta E_{char,c}}{LHV}$
Equation B14: Equivalent dry fuel consumed (extended)	$f_{cd} = dry\ fuel - fuel\ to\ evap\ water - fuel\ in\ char$ $f_{cd} = f_{cm} \cdot (1 - MC) - \frac{f_{cm} \cdot MC(4.186(T_b - T_a) + 2{,}257)}{LHV} - \frac{\Delta c_c \cdot LHV_{char}}{LHV}$ $f_{cd} = \frac{f_{cm}(LHV(1 - MC) - MC(4.186(T_b - T_a) + 2{,}257)) - \Delta c_c \cdot LHV_{char}}{LHV}$
Equation B15: Thermal efficiency	$h_c = \frac{\Delta E_{H_2O,heat} + \Delta E_{H_2O,evap}}{E_{released,c}}$
Equation B16: Energy to heat water	$\Delta E_{H_2O,heat} = m_{H_2O} \cdot C_p \cdot \Delta T$
Equation B17: Energy to evaporate water	$\Delta E_{H_2O,evap} = w_{cv} \cdot \Delta h_{H_2O,fg}$
Equation B18: Consumed energy	$E_{released,c} = f_{cd} \cdot LHV$
Equation B19: Thermal efficiency (extended)	$h_c = \frac{4.186(T1_{cf} - T1_{ci})(P1_{ci} - P1) + 2260 \cdot w_{cv}}{f_{cd} \cdot LHV}$
Equation B20: Burning Rate	$r_{cb} = \frac{f_{cd}}{\Delta t_c}$
Equation B21: Specific fuel consumed	$SC_c = \frac{f_{cd}}{W_{cr}}$

Equation B22: Temperature corrected specific fuel consumed	$SC_c^T = SC_c \cdot \frac{75}{T1_{cf} - T1_{ci}}$
Equation B23: Temperature corrected specific energy consumption	$SE_c^T = SC_c^T \cdot \frac{LHV}{1000}$
Equation B24: Firepower	$FP_c = \frac{f_{cd} \cdot LHV}{\Delta t_c \cdot 60}$

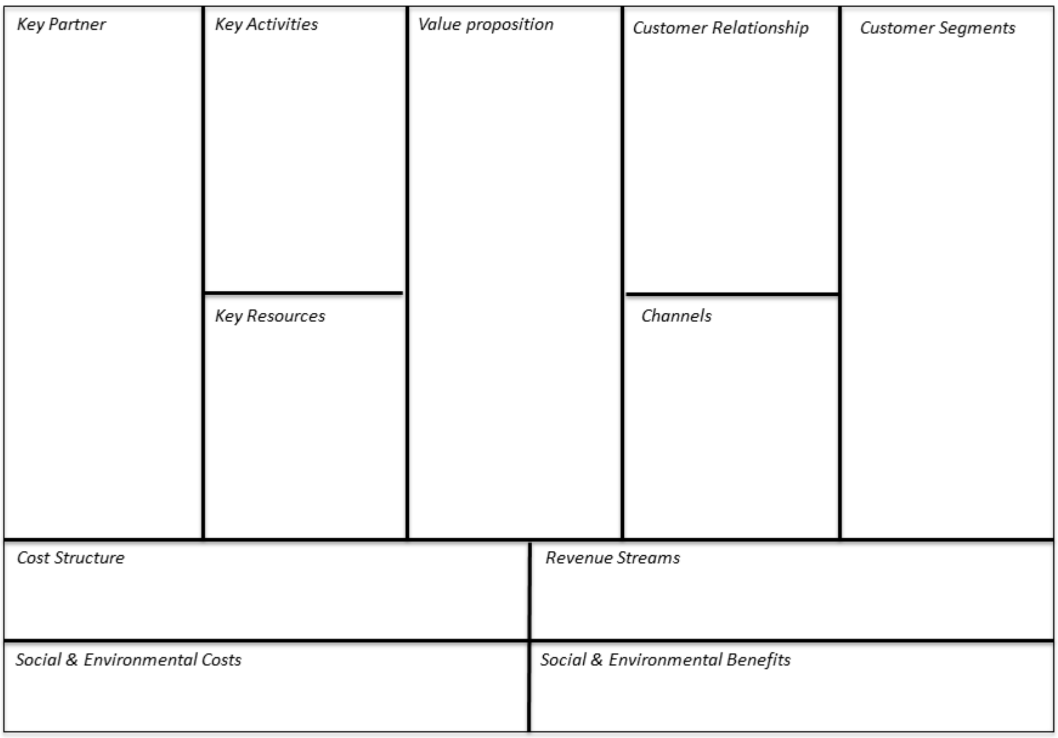
Appendix C: Pump curve



Appendix D: Water and energy consumption of the solar pumping system

Month	Energy demand (kWh/day)	Water Demand (l/day)	Irrigation Schedule	Irrigation time (h)
January	1.11	3,250	from 6 to 8	2
February	1.11	3,250	from 6 to 8	2
March	1.11	3,250	from 6 to 8	2
April	1.11	3,250	from 6 to 8	2
May	1.11	3,250	from 6 to 8	2
June	1.11	3,250	from 6 to 8	2
July	1.11	3,250	from 6 to 8	2
August	1.11	3,250	from 6 to 8	2
September	1.85	5,000	from 6 to 8 and from 18 to 20	4
October	1.85	5,000	from 6 to 8 and from 18 to 20	4
November	1.85	5,000	from 6 to 8 and from 18 to 20	4
December	1.11	3,250	from 6 to 8	2

Appendix E: The Sustainable Canvas Model



Appendix F: Cost and revenue analysis

Cost Ranking	% of Total	ZMW/ bag	ZMW	Items
			10	ton truck
			50	ZMW cost per ton
			10,000	KG raw biomass
			0.4	% carbonisation rate
			4,000	KG carbonised biomass
			80	# of 50KG bags
Cost Ranking	% of Total	ZMW/ bag	**ZMW**	**1-OFF COST**
2	9.8%	6.25	**500**	ZMW biomass Cost per 10 ton load
10	3.1%	2.00	**160**	ZMW labour cutting per day for 10 ton (25 cubic meter; 5x5mx1.2 height)
14	0.8%	0.50	**40**	ZMW labour loading for 10 ton (2 hours 4 people)
3	7.8%	5.00	**400**	ZMW cost for hiring 10 ton truck per day (2 trips per day)
7	3.9%	2.50	**200**	ZMW fuel cost for 10 ton truck - Farm to Production site
14	0.8%	0.50	**40**	ZMW labour off-loading 10 ton truck (2 hours 4 people)
1	42.3%	27.00	**2,160**	ZMW production license Total bags
4	6.3%	4.00	**320**	ZMW carbonisation labour (40 drums per day - 2 filling of drums per day; 2 general worker; total 4 days; @K40/day
7	3.9%	2.50	**200**	ZMW carbonisation labour (40 drums per day - 2 filling of drums per day; 1 foreman; total 4 days; @K50/day
12	1.6%	1.00	**80**	ZMW Monitor drying Total bags (2 people; 1 day) @K40/day
4	6.3%	4.00	**320**	ZMW total packaging (@K4/bag)
12	1.6%	1.00	**80**	ZMW labour cost packaging Total bags (2 people; 1 day; @K40/day)
7	3.9%	2.50	**200**	ZMW market linkage cost (@K2.5/bag)
18	0.2%	0.13	**10**	ZMW cost talk time communication (@K10 for 64min Zamtel weekly)
			4,710	ZMW TOTAL COST 10 TON TRUCK
		58.88		***ZMW Total Cost per bag***
			ZMW	**CONSUMABLES**
			60.00	ZMW material cost per drum
11	1.9%	**1.20**		ZMW material cost per drum depreciated over 100 loads (50 x 50Kg bags)
			10.00	ZMW labor cost drum cutting
17	0.3%	**0.20**		ZMW labor cost per drum depreciated over 100 loads (50 x 50Kg bags)
			150.00	ZMW cost for drying roofing sheets
6	4.7%	**3.00**		ZMW cost for drying roofing sheets depreciated over 100 loads
			5.00	ZMW fire lighter
14	0.8%	**0.50**		ZMW fire lighter depreciated over 20 loads
		4.90		***ZMW Total Consumable Cost per bag***
	100.0%		***5,102***	***Grand Total Cost***
			63.78	***Grand Total Cost per bag***
			127.55	Target Sales price per bag
			10,204	**Turnover**
			5,102	Profit