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The utilization of cold storage through solar PV mini-grids to reduce spoilage in fisheries in Tanzania

Master's thesis in Sustainable Energy Systems
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Abstract

The lack of electricity is a major problem in Sub-Saharan Africa, and a majority of the population live in rural areas where it might be difficult to extend the main grid. Mini-grids are a possible solution, and new mini-grids are continuously built to supply villages with electricity. The access of electricity might in turn be a part of a solution to another major problem, spoilage of fish due to the lack of cold storage. This thesis intents to add to the information of how electricity from a solar PV mini-grid can decrease the spoilage of fish. It also aims to investigate the economical possibility to implement a communal cold storage unit connected to a solar PV mini-grid and what technical requirements it puts on the operation of the mini-grid. The information required were gathered through a literature study and by performing a field study in Tanzania. The thesis is based on a case on the island Ukara in Lake Victoria. The data is used in a techno-economic analysis that simulates a walk-in cold storage room connected to a solar PV mini-grid on the island Ukara in Tanzania. The thesis also consists of a qualitative analysis, where a causal loop diagram illustrates the interlinkages between the variables in the system to identify the effects of electricity on the spoilage of fish. The findings indicates that it is economically feasible to implement a communal cold storage unit if an investor makes the initial investment and allow the fishermen to have a pay-back period of at least one year. Another finding is that the capacity of the mini-grid may need to increase to be able to cover the demand during the periods of low production of the solar PVs, where investments in increase capacity in solar PV and battery. The causal loop diagram indicates that access to electricity can be an important solution to reduce the spoilage by enabling the use of cold storage. In conclusion, access to electricity is important to small scale fisheries in rural areas, and it can help them to increase their income and decrease food insecurity.

Keywords: solar PV mini-grids, spoilage in fishery, cold storage, Africa, Tanzania

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List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

CAPEX	Capital Expenditures
CLD	Causal Loop Diagram
OPEX	Operational Expenditure
PV	Photovoltaic

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1

Introduction

In 2018, roughly 600 million people in Sub-Saharan Africa lacked access to electricity (International Energy Agency, 2019). The rate of electrification in Africa outpaced the population growth for the first time between 2014 and 2018, there is however still a challenge to provide electricity to a still rapidly increasing population. However, the lack of access to electricity still acts as a barrier to the continents development (International Energy Agency, 2019).

A majority of the people lacking access to electricity lives in rural areas, and one technology for increasing access to electricity in rural, inaccessible areas is off-grid systems (Hartvigsson et al., 2021). These technologies can be divided into different categories depending on their capacity, where the largest ones are called mini-grids. They have enough generation capacity to supply electricity to hundreds or a few thousands of costumers, as well as a wide range of productive use activities (Hartvigsson et al., 2021). Several studies conclude that linking the implementation of mini-grids to activities that is connected to rural development needs, such as agriculture, could increase the energy utilization and create environments for sustainable rural living (Candelise et al., 2021; Katre et al., 2019; Pueyo and DeMartino, 2018).

Renewable energy supplied by off-grid technologies is increasing in rural areas in Sub-Saharan Africa, where Tanzania is one of the leading countries for mini-grid development in the region (Odarno et al., 2017). While hydropower mini-grids are one of the most common energy source for off-grid technologies (Ngowi et al., 2019), Tanzania also has good conditions for producing energy with solar power, which have caused an increase in replacing diesel power generation with solar PV (Tsuchiya et al., 2020).

More studies have in recent years been investigating solar PV:s (Ogeya et al., 2021; Tsuchiya et al., 2020; Pueyo et al., 2020; Pueyo and DeMartino, 2018). Tsuchiya et al. (2020) performed a study on investments return, which showed that the return on the invested capital was negative. This could, according to Tsuchiya et al. (2020), be fixed by improving operations and maintenance and increase the number of businesses that use electricity in rural areas. Furthermore, Pueyo and DeMartino (2018) and Ogeya et al. (2021) investigated the usage and influence of solar PV mini-grids on businesses, were both studies concluded that solar PV mini-grids did not give the intended effects and that the electricity consumption remained low and the profit of businesses did not increase since the demand for the products and services produced remained low. Pueyo and DeMartino (2018) concluded that one reason for this is that 85% of costumers from the area, and their main income is from agriculture. Since the profits from agriculture are in general low, they have a limited economy and can therefore not afford the products and services produced. As a solution to this problem, Pueyo and DeMartino (2018) suggests that the mini-grids should be used more within agriculture to improve the profit in that sector. This could be done by utilizing the mini-grid to increase the life of agricultural products with refrigeration, improve yields with irrigation and increase the access to markets by using energy to transport goods. This would, according to Pueyo and DeMartino (2018), have the potential to increase income of rural areas and sustain local micro-enterprises.

Another major problem in Tanzania is food security, and while the agricultural and fish sector stands for almost 30% of total GDP in Tanzania in 2020 (World Bank, 2020), the country suffers from large post-harvest losses (Affognon et al., 2015). Post-harvest losses are generally referred to as the losses that occurs in the field, during storage and processing, and transportation until it reaches the final costumer (Abass et al., 2014). These losses mainly occur due to poor harvest techniques, lack of modern and appropriate rural infrastructure like storage and transportation and humid climate conditions (Dasappa, 2011). When referring to post-harvest losses in this study, it is mainly losses that occurs during storage that are of interest.

In Tanzania, a large part of the population are involved in agriculture and most are smallholder farmers, the practice of fishing is also at a small scale (National Bureau of Statistics, 2021). One challenge these producers have is low income and high post-harvest losses. In a meta-analysis it was evaluated that the post-harvest losses ranged from 20-55 % for different types of crops and an average of 27.3 % of fish was spoiled in Sub-Saharan Africa, where the majority of these losses were related to storage (Affognon et al., 2015). Additionally, several studies have reported that farmers and fishers sell their crops and fish soon after harvests at low prices for lacking storage capability and economical pressure (Prodhan et al., 2022; Brander et al., 2021; Abass et al., 2014). It has been shown that the farmers often buy back some of their stock at higher prices a few months after selling.

This occurs during the lean seasons and many farmers lack the resources to buy back the needed quantities, resulting in an increase in food insecurity during these seasons. Improving storage could therefore help to decrease poverty, post-harvest losses and food insecurity (Abass et al., 2014; Chan et al., 2019; Brander et al., 2021).

The lack of proper storage technologies can be seen for both crops and fish (Chan et al., 2019; Abass et al., 2014). Some of the main causes of PHL in fish are the high temperatures, delay before marketing and lack of storage facilities (Prodhan et al., 2022; Assefa et al., 2018). In the Lake Victoria Region some common preservation practices are hot smoking, deep-frying and sun-drying, where both methods suffers from a decrease of both nutrients and proteins, as well as a lot of waste (Kabahenda et al., 2009). Improvements of the cold chain for fish are therefore needed for both food security and the decrease in poverty since the reduction of PHL can improve the income generation (Prodhan et al., 2022; Chan et al., 2019; Assefa et al., 2018; Ibengwe and Kristófersson, 2012)

Access to electricity through mini-grids could be part of a solution since it allows for cold storage and ensuring heat for dehydration, which could decrease the post-harvest losses, hence also improving food security (Chan et al., 2019; Dasappa, 2011; Kabahenda et al., 2009). Moreover, the agricultural sector is not only important for increasing food security, but also for it's role in economic activities, employment generation and poverty reduction (Shafiee-Jood and Cai, 2016; Oladunjoye, 2020). Increased energy access could have significant positive effects on agricultural productivity.

Few studies have investigated how storage that utilizes electricity, such as cold storage, can contribute to decreasing post-harvest losses in rural areas. One study performed by Lukuyu et al. (2019) looked at how milk cooling facilities could contribute to decreasing milk spoilage in areas where farmers have limited grid electricity in Tanzania by using off-grid solar, wind, biomass and biogas. Through a techno-economic analysis, the conclusions were that off-grid biomass, solar and biogas can contribute to decrease milk spoilage and increase profit for the farmers by at least 78%. Another case-study was performed in Nigeria by Lamidi et al. (2019), where the focus was to estimate the economic profitability of using a biogas facility to power a cold storage and drying unit for different types of crops. By performing a techno-economic analysis, they suggests that it would have a positive effects on reduction of post-harvest losses, it would also be possible for the electricity system to be maintained and profitable without risking to economically burden smallholders' farmers unnecessarily.

However, there is still a lack of knowledge for how the access to electricity in rural areas is interlinked with reduced post-harvest losses in the literature, particularly for fisheries where the losses of fish are high due to the lack of cooling opportunities (Assefa et al., 2018). There is also an information gap for what challenges fishers have in implementing cold storage as a possible solution to decrease the spoilage of fish.

1.1 Aim

This project aims to evaluate how electrification through mini-grids can contribute to reduced spoilage within the fishing industry in Tanzania by enabling storage technologies that utilizes electricity, in this case a joint cold storage room. The objective is to assess how access to electricity within the fishing sector has a positive effect on reducing post harvest losses and if it is economically beneficial for smallholder fishermen to cooperate to implement a joint cold storage room. Furthermore, the objective is also to identify what challenges these fishermen are facing if they were to implement better storage for their fish.

1.2 Limitations

This study will be limited to a case in Tanzania where a solar PV mini-grid will be investigated. Solar PV mini-grids are the only sort of mini-grid considered in this report. It will also be limited to the spoilage of fish in small scale fisheries and the usage of cold storage to reduce the spoilage.

1.3 Research questions

The master thesis will answer the following questions:

- Would the implementation of a joint cold storage system that utilizes electricity from solar PV mini-grids be economically beneficial for smallholder fishers?
- What requirements would a connection of a cold storage system put on the operation of the mini-grid?
- How does the access to energy through mini-grids result in a decrease in spoilage of fish?

2

Background

In this chapter the information provided in the introduction will be explained in more detail and additional background will be presented and a presentation of the the studied system will be provided.

2.1 Mini-grids

The electrification of rural areas in developing countries is difficult, where the costumer base is low and the long distances causes grid-extension of the national grid to become expensive. For this reason, off-grid technologies can be a solution to supply remote areas with electricity (Ahlborg and Hammar, 2014). Mini-grids are one off-grid technology that has the capacity to supply a few hundred to a few thousands of household and productive use costumers (Hartvigsson et al., 2021). In addition, the mini-grid can later be connected to the national grid if it reaches the area (Abada et al., 2021; Aziz and Chowdhury, 2021).

There are many factors to consider in mini-grid design and operation. The geographical location will decide which technology that is most feasible to invest in (Eras-Almeida and Egido-Aguilera, 2019). Another factor that needs to be considered is the predicted consumption of the community (Abada et al., 2021; Hartvigsson et al., 2021) and if the mini-grid operator should plan ahead for an increase in demand (Abada et al., 2021). These factors will influence the initial generation capacity of the mini-grid, where a small generation capacity may result in low reliability if the demand increases, this means that the investment was too low (Abada et al., 2021; Hartvigsson et al., 2021). However, an over-investment will give a high generation capacity, but will instead increase the tariffs of the mini-grid, which may decrease the economical benefits from the mini-grid (Abada et al., 2021; Zomers, 2003).

Mini-grids can have many configurations, where renewable energy mini-grids can use renewable resources like water, solar, wind and bioenergy. In recent years, mini-grids with solar PV have increased due to the significant decrease in price of solar panels (Kittner et al., 2016; Moner-Girona et al., 2018). Many mini-grids are however hybrid where solar PV mini-grids often consist of solar PVs, batteries as support and a backup system often consisting of a diesel generator (Abada et al., 2021; Moner-Girona et al., 2018; Nuru et al., 2021). These solar-battery-diesel hybrid mini-grids have the advantages that oil consumption from diesel generators is minimized by using the batteries and that the operational cost is reduced since the usage of the diesel generator is minimized (Olatomiwa et al., 2014). The advantages of using a diesel generator are the fast start-up time, within minutes, and that it delivers reliable power. Disadvantages with the diesel generator are the high maintenance and that it is costly to run due to high fuel prices (Abada et al., 2021).

If a mini-grid is successfully implemented it may provide significant benefits to the community. The access to electricity for households allows for nighttime lighting and phone charging, which gives more time in the day to income generating activities (Nuru et al., 2021). It has also been shown to lead to educational benefits and health progress in communities with access to electricity (Uamusse et al., 2019). Other than allowing access to electricity, mini-grids also helps in creating jobs since people are needed for maintenance and operation of the mini-grid (Nuru et al., 2021). However, although mini-grids provide a solution to the electrification of rural areas, it is often difficult for the people in these communities to afford it. The fee to connect to a mini-grid is low compared to connecting to the main grid, but the tariffs is much higher for the mini-grid since the investors wants to have a short pay-back time (Pueyo et al., 2020; Johnstone et al., 2019).

Furthermore, several studies point out that productive use consumers are the most economically important for the mini-grid operators (Ogeya et al., 2021; Hartvigsson et al., 2020; Pueyo and DeMartino, 2018; Pueyo et al., 2020). The findings of Hartvigsson et al. (2020) shows for a case in Tanzania that, although productive use consumers only accounts for 26% of the connections, they generate 44% of the income to the mini-grid operator. The study also found that the load profiles of household consumers and productive use consumers complemented each other since households used most energy at night while productive uses peaked during the day. These findings are in line with the conclusions of Ogeya et al. (2021), which also point out the importance of the capacity of the mini-grid to be able to power more heavy-load machinery. This would result in a stable revenue to the mini-grid operator, as well as providing opportunity for enterprises to increase their income, thus reducing poverty in the community. This is a limitation with the mini-grid for the case in Tanzania, when high loads are connected to the mini-grid it causes outages that could cause inconvenience for some time if the local technician was not around. In addition, Ogeya et al. (2021) identifies that, due to the high tariffs, both businesses and households tended to energy stack, i.e. combining the services from the mini-grid with other sources of energy that they used before their connection to the mini-grid, to lower their expenses on energy.

From a case in Kenya, Pueyo and DeMartino (2018) found that the introduction of electricity to small enterprises in rural areas did not have the intended effect. The result showed that, due to high tariffs, the electricity consumption remained low, as well as sales and profits. Since the main consumers were households, the tariffs needed to be high for the mini-grid operators to cover their costs, resulting in lower consumption and even higher tariffs. Pueyo and DeMartino (2018) therefore points to the importance of productive use of energy during the day, this would not only result in lowering the unit price of electricity, but people would then be able to increase their income and therefore increase their ability to pay for more electricity. Furthermore, one significant factor to the failure of the mini-grid mentioned in the study were that the majority of sales came from village costumers, whose main income is from agriculture. Due the the poor income from agriculture, the demand for other services were low. This was pointed out as the main constraint to growth. Pueyo and DeMartino (2018) therefore suggests, supported by the findings of Uamusse et al. (2019) and Nuru et al. (2021), to take initiatives to use energy to improve the income of local farmers. Some suggestions is from irrigation to increase the yield, adding value to the agricultural products through processing, extending the life of products through refrigeration and facilitating access to markets by using energy for the transportation of goods.

2.2 Challenges in the fishing and agricultural sectors

This section provides an overview of the challenges within the fishing and agricultural sector in Tanzania, as well as further information about the challenges with post-harvest losses (PHL) in Section 2.2.1 and possible storage technologies in Section 2.2.2.

In 2020, the agricultural, forestry and fishing sectors contributed to 26.7% of GDP in Tanzania (World Bank, 2020), hence it is an important economic sector that plays a great role in Tanzanias national economy (World Bank, 2020; National Bureau of Statistics, 2021). Over half of the households in Tanzania are involved in agricultural activities where most of them are small scale farmers and fishers (National Bureau of Statistics, 2021).

Some of the most widely produced food crops are cereals, where maize is most common, but wheat, rice, sweet potatoes, bananas, beans, sorghum, and sugar cane are also common (National Bureau of Statistics, 2021; International Trade Administration, 2021). Small scale fisheries dominates the fishering sector where up to 95 % of the total catch is from small scale fisheries (Mramba and Mkude, 2021). Some common types of fishes in Lake Victoria is tilapia, nile perch and dagaa (Pueyo et al., 2020; Ibengwe and Kristófersson, 2012; Kabahenda et al., 2009).

Despite being an important economic sector, the productivity in agriculture is low and the progress is slow, partly due to the domination of smallholder farmers that are dependent on rainfall for irrigation (International Trade Administration, 2021). Similarly, the fishing sector is dominated by small scale fishers and high losses which poses a big challenge for the government since reduction of spoilage in fish could be a valuable part in increasing food security and reducing poverty (Chan et al., 2019; Ibengwe and Kristófersson, 2012). To increase the production, export and value-added processing, modernization of the sectors is necessary. It is however difficult due to the the struggle for smallholder farmers to afford viable technologies and storage technologies, long distances to markets is also a challenge, making it more difficult to sell the products (Chan et al., 2019; Assefa et al., 2018).

2.2.1 Post-harvest losses

PHL occur during the whole value chain, but by improving on-farm storage and cold-chain for crops and fish respectively, the losses could be significantly reduced (Brander et al., 2021; Chan et al., 2019; Abass et al., 2014; Kabahenda et al., 2009) as well as allowing producers to store their products for a longer time and be able to sell when the market price is higher (Prodhan et al., 2022; Abass et al., 2014). Many farmers are forced to sell their crops directly after harvest due to financial pressures such as expenditure needs and school fees, but also because of the lack of storage capabilities. Later in the season, however, the farmers are forced to buy back stock at a higher price, resulting in a spiral to poverty (Chegere et al., 2022; Brander et al., 2021; Ngowi and Selejio, 2019; Abass et al., 2014). The high temperatures in Africa is a large contributor to the high PHL, especially for fish if the fishers do not have access to proper cold storage (Prodhan et al., 2022; Assefa et al., 2018). Reducing PHL would increase the producers income which would later allow them to do investments to improve their production further, by for example increased storage capabilities (Chegere et al., 2022; Ibengwe and Kristófersson, 2012). Education and experience has also been shown to be significant factors in reducing PHL for smallholder farmers in rural areas (Chegere et al., 2022; Kulwijila, 2021; Acharjee et al., 2021; Gyan et al., 2020; Ngowi and Selejio, 2019; Abass et al., 2014). Surprisingly, Mramba and Mkude (2021) found that fishers with only a primary education had a higher catch and less spoilage than those with a higher education. This was due to more time spent in the fishing industry and thus more experience than if they spend more years in school. Furthermore, several studies has also concluded that the inaccessibility of markets due to long distances, poor road infrastructure and lack of transportation leads to PHL (Prodhan et al., 2022; Assefa et al., 2018; Hengsdijk and de Boer, 2017; Alidu et al., 2016; Kaminski and Christiaensen, 2014).

A case study on an island in Ghana where the majority of the population earns their living from either agriculture or fishing shows that the access to electricity provided the possibility to refrigerate the fish that would otherwise go bad from the heat. The refrigeration therefore helped to increase the income of the fishers since they could then sell the fish at a higher price on the mainland on market days (Nuru et al., 2021).

The reduction of PHL could also lead to an increase in food security since all the harvest do not need to be sold due to lack of storage capabilities as well as reducing poverty since the farmers and fishers could earn a higher income when they are not forced to sell when the price are at its lowest (Brander et al., 2021; Chan et al., 2019; Ngowi and Selejio, 2019; Abass et al., 2014; Ibengwe and Kristófersson, 2012).

2.2.2 Storage

Few studies have investigated storage solutions that utilize electricity from mini-grids, but some that have studied cold storage as one solution are Sadi and Arabkoohsar (2020); Lukuyu et al. (2019); Lamidi et al. (2019).

Sadi and Arabkoohsar (2020) performed a techno-economic analysis that investigated different types of solar cells to power cold storage units to reduce PHL in India. The study had the objective to assess which type of solar cell that were the best option both from an energy and economical point of view. The main part of the model is made by simulation and definition of the cold storage unit and the solar cells, but a small case-study is also performed to validate the model. The conclusions from the study is that by enabling access to electricity and cold storage, large amount of food that would otherwise have gone to waste could be stored with minimal waste. Thus the farmers are able to provide more food for more people without expansion of the agricultural capacity. Sadi and Arabkoohsar (2020) also states that this problem is not limited to India, and that it is important to promote access to electricity and cold storage in similar countries with hot and humid climate to prevent PHL.

Another study done by Lamidi et al. (2019) focused on the impact of access to electricity on food processing in Nigeria. Similar to, Sadi and Arabkoohsar (2020), they performed a techno-economic analysis, but the objective in this study was to determine if the implementation of the integrated system of a mini-grid and electricity driven cold storage and drying of the food could generate extra income that would counterbalance the burden of high tariffs on the smallholder farmers and at the same time result in reasonable returns. The mini-grid used in the case-study was driven on biogas produced from a community cattle market. Two villages were selected for the case-study, one that was connected to the main grid for a long time, but had only access to approximately 40h of electricity per week, and the other village had never been connected to the main grid. The predominantly cultivated crops in the two villages were cassava, maize, tomatoes and cashew. The results prove that large amounts of cassava and maize could be dried and tomatoes cold-stored each year with a reasonable investment rate of return. The study also shows that it is possible to maintain a low-tariff electricity system without putting unnecessarily burden on the smallholder farmers.

It is not only crops that are in need of cooling, therefore Lukuyu et al. (2019) conducted an interesting study that tried to determine the profitability of implementing a cooling system to prevent the spoilage of milk. A field study was performed in a rural community in Tanzania. Lukuyu et al. (2019) tested several different configuration alternatives of off-grid solar, wind, biagas and biomass technologies available and suitable for small-scale off-grid milk-cooling through a techno-economic analysis. The model they developed was divided into three parts: an economic model, a sensitivity model and a risk model. The most viable option was determined to be a biogas powered vapor compression refrigeration system, this was also scalable where the economic performance was increased with the increased cooling capacity for large diary concerns. When the farmers are able to store their milk with this technology, their income could increase up to 78% per month. The economic performance of the system did however prove to be sensitive to milk quantity, milk prices, fuel costs etc. The overall conclusion is however that the implementation of strategies to mitigate technical, economic and policy risks could increase the probability of the system to be economically viable and allow small-scale farmers to grow their business, increase their income and thereby increase their living standard drastically.

Furthermore, fish is also a product that are easily spoiled and is therefore in need of cooling (Assefa et al., 2018). A project in Tanzania by ELICO Foundation, a non-governmental organisation that operates in Tanzania and focuses on rural electrification, have therefore provided off-grid refrigerators to different businesses in rural Tanzania, where majority of them are used by fishermen around Lake Victoria. The cost of the refrigerators was completely covered by a coalition called *Efficiency for Access*, the costumers did however buy the refrigerator in order for ELICO Foundation to be able to cover their operational cost. The price was however only 30 % of the original cost of the refrigerator (Head of Programmes and Operations, ELICO Foundation, 2022). The off-grid refrigerator has a capacity of 100 liters, it has a solar PV as a power generator and a backup battery that is charged with the solar PV. The refrigerator can operate down to 2 °C, which is below the maximum recommendation of 4 °C for storing fish (Livsmedelsverket, 2022). According to ELICO, the refrigerators that they provided have increased the income of the users and improved their lives (Head of Programmes and Operations, ELICO Foundation, 2022; Fishermen 1, 2022; Fishermen 2, 2022; Fishermen 3, 2022). Several of the fishermen are however in need of larger refrigerators, and some of them have more than one to be able to store all the fish (Fishermen 1, 2022; Fishermen 2, 2022; Fishermen 3, 2022).

3

Case

The evaluated mini-grid in this study operates in the village Bwisya, located on the island Ukara in Lake Victoria. It as a population around 6,000 people (Pueyo et al., 2020) and in 2018 the village health centre was upgraded into a hospital after an accident with the ferry MV Nyerere. The MV Nyerere was the ferry going between Bwisya and Bugolora in Ukerewe, 228 people died in the accident and 41 were rescued (Odunga, 2018). The village have primary and secondary schools, local government offices, and mobile phone and television signals. There are also daily connections between Bwisya and the bigger island Ukerewe from where another ferry continues to Mwanza, the second largest city in Tanzania.

Since April 2016, JUMEME Rural Power Supply Ltd. operates a solar hybrid mini-grid in the village. The solar hybrid mini-grid has an capacity of 102 kW where 60 kW is solar PV capacity and 42 kW is allocated to the diesel generator. It was mainly financed by the European Union grant (Pueyo et al., 2020). The installed capacity has increased from the first installation, where the old diesel generator of 35 kW was replaced with the 42 kW in 2020. The battery capacity was 60 kWh but was replaced in 2021 when the battery life-time was reached (Head of Operations, JUMEME, 2022).

In 2020, the energy minister of Tanzania made a statement that all the mini-grid operators had to charge 100 TZS per kWh for households, the same price as the subsidized main grid (Chair person TAREA, 2022). This new regulation that lowered the tariffs resulted in a decrease in services since it was no longer profitable for JUMEME to run the diesel generator in Bwisya. The reliability of the mini-grid thus decreased and the provision of electricity changed from 18-24h a day to 9-13h per day (Local technician, JUMEME, 2022; Head of Operations, JUMEME, 2022). In addition, in 2021 the batteries connected to the mini-grid needed to be replaced, but due to the decrease in revenue since 2020, JUMEME took batteries from another mini-grid to avoid the investment cost. The capacity of the batteries was therefore reduced to 40 kWh (Head of Operations, JUMEME, 2022).

Depending on how much electricity the costumers consume, there are different bundles that they can buy. Each bundle have different prices on the electricity per kWh and when the consumer has used the electricity that they bought, they can buy more (Cluster manager, JUMEME, 2022). JUMEME have three different tariff levels that depend on the type of consumer and bundle: household (HH), commercial usage (CU) and productive usage (PU) (Cluster manager, JUMEME, 2022). These bundles and the tariffs for different time periods in Bwisya from the start are presented in Table 3.1. Households often use the electricity for power home appliances such as lighting and television. There are also many commercial users that uses electricity in Bwisya, like mobile charging services, compressor for pumping tires and stores with cold drinks. The productive users have the highest electricity consumption, where machines for milling and carpentry are included. However, the milling machine in Bwisya are no longer connected to the mini-grid since the change in tariffs resulted in unreliable supply of electricity and limitations of how much electricity the costumers could buy per week. This limitation was implemented during 2021 and can be seen in the right column in Table 3.1. The operator of the milling machine therefore started using the diesel powered machine that he had before (Former cluster manager, JUMEME, 2022). The weekly limit in electricity usage that JUEMEME put on the costumers was due to the increase in demand that resulted from the low tariffs, the mini-grid did not have the capacity to satisfy this increase in demand without even higher unreliability (Cluster manager, JUMEME, 2022). In an attempt to provide better service to the costumers, and in agreement with the community in Bwisya, JUMEME increased the tariffs in 2021 which is why the tariffs increases again during 2021 in Table 3.1. This was however not accepted by the Tanzanian government and JUMEME had to go back to the low tariffs again (Former cluster manager, JUMEME, 2022). Table 3.1 presents the different changes in tariffs in Bwisya since the start and also the limitations in electricity usage the costumers currently have.

Table 3.1: The tariff levels for the three different costumer groups (Households (HH), commercial users (CU) and productive users (PU)) for the mini-grid in Bwisya for different time periods. The usage constraints are also included.

Time period	Costumer	Price [TZS/kWh]	Limitation [kWh/week]
2017	HH	3 500	-
-	CU	2 500	-
2020	PU	750 (+10 000 TZS Month)	-
2020	HH	100	-
-	CU	100	-
2021	PU	356	-
2021	HH	2 000	1
-	CU	4 000	2
	CU	10 000	5
2021	PU	40 000	50
2021	HH	100	1
-	CU	610	5
2022	PU	17 560	50

The mini-grid in Bwisya is connected to two villages (Former cluster manager, JUMEME, 2022), where 16 % of the costumers are productive users, they are the biggest consumers and operates heavy-load machines such as milling machines (Pueyo et al., 2020). Between 2019 and 2021, JUMEME was one of the productive users since they had their own fish business and operated 6 freezers to store the fish tilapia that they bought from local fishers and froze to be sold to industries in Mwanza (Fisheries Officer, JUMEME, 2022). At the start, JUMEME had a monopoly on buying tilapia from the local fishermen, but after a while other buyers from Mwanza came to Bwisya and outcompeted JUMEME by offering the fishers a higher price for the tilapia. The other buyers business model was to sell the tilapia freshly to the mainland, which has a higher value than frozen tilapia and could therefore offer the fishermen a higher price for the fish than JUMEME (Former cluster manager, JUMEME, 2022).

The prices of fish changes between the different seasons because of the changing amount of fish catched. During the rain season the amount of caught fish is high which results in low prices. While the prices rise again during the dry season when the amount of fish is scarce. In Table 3.2 the amount of caught fish for the two seasons for the interviewed fishermen in Bwisya as well as the price of the fish before and after the fishermen gained access to cold storage.

Table 3.2: The amount of catched fish in different seasons and the change in price before and after being able to store the fish for the interviewed fishermen in Bwisya

Fisher interview		Amount of fish caught [kg/day]		Price [TZS/kg]
1	Dry season	1	Before fridge	2 500 - 3 000
	Rain period	10-30	After fridge	5 000 - 6 000
2	Dry season	8	Before fridge	2 500 - 3 000
	Rain period	30	After fridge	4 000 - 6 000
3	Dry period	-	Before fridge	3 000
	Rain period	25-40	After fridge	5 000 - 6 000

4

Methodology

This chapter present the methodologies used in this project. The outline of the steps are illustrated in Figure 4.1. First, a literature study (Section 4.1) was performed to get a deeper insight of the subject. Based in the literature review, interview questions was formulated and interviews with stakeholders was performed through a field study in Tanzania (Section 4.2). The interviews were analysed and used together with quantitative data that was gathered through the field study and the literature review to perform a simulation of a cold storage room connected to the mini-grid in Bwisya. A techno-economical analysis (Section 4.3) of the cooling room and the mini-grid was used to answer the first and second research question. That is, if it would be beneficiary for smallholder fishermen to implement a joint cold storage room that is connected to the mini-grid in Bwisya and what requirements this puts on the mini-grid. As Figure 4.1 shows, the simulation of the the cold storage room and the techno-economic analysis is an iterative process to test different scenarios. Furthermore, this quantitative results are used together with the analysed interviews and the literature study to make a conceptual system dynamic model of the system through a causal loop diagram (CLD) (Section 4.4). The CLD is also an iterative process as illustrated by Figure 4.1 where additional information was added continuously from the literature to build the final CLD. A CLD is a conceptual representation of the system that illustrates the interlinkages between different variables in the system and if there are any feedback loops. The CLD is analysed to answer the first research question of how the access to electricity can reduce the spoilage of fish.

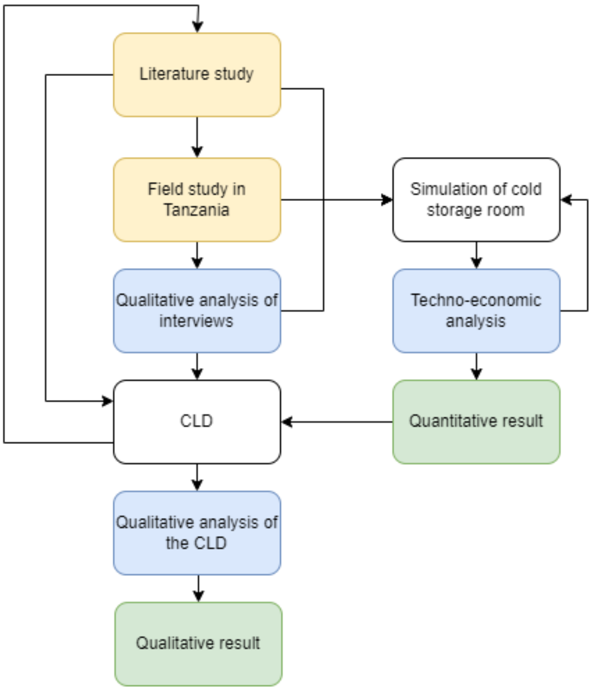

Figure 4.1: Overview of the methodology. The yellow box represents the collection of information and data, the blue boxes are analysis steps, the white boxes are modelling and the green boxes represent the results. CLD stands for causal loop diagram

4.1 Literature study

The literature review is designed to gain more insight into mechanisms behind losses of fish within small scale fisheries in rural Sub-Saharan Africa and whether electricity could be used to decrease these losses. Since there are similarities to the post-harvest losses experienced within small scale agriculture of crops this is also included in the review to be able to draw parallels between the two sectors. It also includes some of the challenges with rural electrification and how electricity usage within fisheries and agriculture could be beneficial. Furthermore, the literature review will be used in an initial causal loop diagram to aid in the formulation of the interview questions. Information that is gathered during the literature review is also used in the techno-economic analysis to complement the data that was not found in the field.

This information is gathered through scientific articles as well as reliable websites. The search engines used are google scholar, scopus and sciencedirect. Some of the main keywords used in the research are "mini-grids", "fisheries", "spoilage in fish", "electrification", "Africa", "Tanzania", "cold storage" and "post-harvest loss".

4.2 Field study and analysis of interviews

The majority of the data was gathered through a field study in Tanzania for 8 weeks between March and April in 2022 where interviews was held, and more technical data was provided from the mini-grid company JUMEME as well as different articles. Interviewing different stakeholders made it possible to detect interlinkages and information about the system in general and the case that was not covered in the literature. This was the main part of the field study.

The interviews was performed as semi-structured with open-ended questions to allow for the interviewee to tell us their point of view and for the interviewer to be able to ask follow-up questions if the interviewee said something that could benefit from a deeper understanding. The interviews is later transcribed and analysed through Grounded Theory which is used to identify themes and contexts within texts such as interview transcripts (Luna-Reyes and Andersen, 2003). All themes and and categories found in the texts are "grounded" in a set of quotations or examples in the transcribed interview. These are then linked and used to further add to the initial causal loop diagram.

The interviews was performed with three companies that owns mini-grids in Tanzania to get a wider perspective of how mini-grids are operated and the process of installation in a community. The companies that was interviewed were JUMEME Rural Power Supply Ltd., Engie and Ensol to get their perspective of the challenges with rural electrification. Some questions that were asked was "How does the process work from the start when you decide to start a mini-grid in a new location?", "How has it affected the locals that are gaining access to electricity?" and "What have you learned from previous mini-grids that could be improved?". Two interviews was also performed with ELICO Foundation. The first interview focused on general linkages with rural electrification and its effects on the community and agricultural business. Some questions that were asked was "How has the access to electricity affected the community and the lives of the people having access?", "How could you influence the people in the community to start using more electricity?. The second interview focused on their project in Bwisya on the island Ukara, where they have provided some local fishermen with refrigerators, to get more insight of the context of our field study. In addition, one interview was held with a person involved in Tanzania Renewable Energy Association (TAREA) that are working with influencing polices related to rural electrification and mini-grids. Another interview was also held with SELCO Foundation that operates in India and provides solutions for sustainable electrification of rural areas as well as working towards reducing poverty. They have installed several off-grid cold rooms in India which was the focus of the interview.

Some interviews was also performed with local fishermen in Ukara that had been provided with refrigerators from ELICO Foundation, as well as with some of JUMEMEs costumers in the village. Examples of questions during the interviews are "How has the access to the freezers changed your business and economic status?", "How much fish can you catch in one fishing trip?", "How has electricity changed your daily life?", "What problems do you experience with the electricity access?".

4.3 Techno-economic analysis

The techno-economic analysis was based on a simulation of a cold storage room that is connected to a solar PV mini-grid to analyse the economical benefits for fishermen to invest in a communal cold storage room and what requirements it puts on the mini-grid operator.

The techno-economical analysis consists of two parts as illustrated in Figure 4.2. The goal of the first part was to evaluate if it is economically beneficial for fishers to invest in a cooling unit and what compressor work the cooling unit has for one day with a resolution of one hour. The economical assessment in the first part evaluates the investment and running cost of the cooling room, and with that the profit for the fishers. The iteration in the first step is needed since the amount of fish loaded into the cooling room will influence the cooling loads (Bilgili, 2011), which will influence the refrigerator cycle that decides the size of the compressor and other components for the cooling unit. This influences the investment cost and running cost of the cooling unit, that in turn affects the profit. The iteration was iterated on the amount of fish stored in the cooling room and the iteration stopped when a certain profit was reached. Moreover, with the compressor work from the first part, the second part was used to understand how the electrical consumption from the compressor influences the operation of the mini-grid to answered the second research question. This was made by doing an investment model in GAMS, which considered the possibility to invest in more capacities in solar PV:s, batteries, and diesel generators. It also included the running cost of the diesel generator. The optimal solution of the system was obtained by minimizing the cost of running the mini-grid in one day by including the annualized daily investment cost of the three technologies and the running cost of the diesel generator.

The first part consists of three different steps modeled in MATLAB: first the cooling loads with an hourly resolution will be calculated. This will be done by using ambient temperatures for Bwisya, these are taken from Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2) though the web-page www.renewables.ninja where the calculations are based on the work of Pfenninger and Staffell (2016) and Staffell and Pfenninger (2016). The cooling unit is assumed to be a walk-in cooling room with a variable-frequency vapour compressor and the dimensions (2.4 m length, 1.7 m width and 2.5 m height) and insulation of the room will be according to the work of Kabeel et al. (2016). The second step is the refrigeration cycle simulations, this is done by using CoolProp that is a library for refrigerants, it is used to get the chemical characteristics of the cooling agent R134a. R134a was assumed to be the cooling agent as it is a common refrigerant (Uddin et al., 2022). The third step is the economical assessment and that is an iterative process to evaluate the amount of fish needed to be stored and sold to give a certain profit for the fishers. An iteration was needed to be made due to the fact that the cooling load of the cooling room is dependent on the amount of fish that is loaded (Bilgili, 2011) which will decide the size of compressor and other components of the cooling room that is needed to run the cooling room.

The second part of the simulation was carried out using a programming software, GAMS (General Algebraic Modeling System), that was used to create an investment model of the mini-grid system. An overview over the methodology for the techno-economical analysis is presented in Figure 4.2.

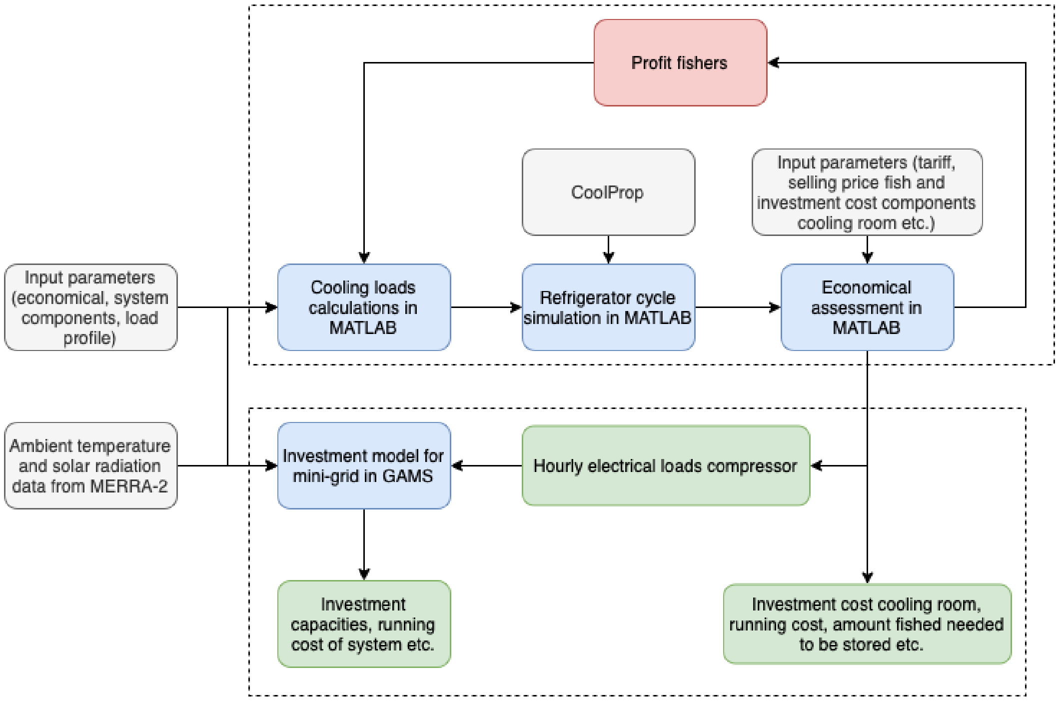

Figure 4.2: The methodology for the techno-economical analysis. The gray boxes represent input parameters, the blue boxes the modelling, the green results and the red is a iteration that stops when a conditions is fulfilled, e.g. profit for fishers. The dashed boxes shows the system boundaries for the two system: the cooling unit (the upper box) and the mini-grid (the lower box).

When modelling a cooling room it is important to consider the insulation and the ambient temperature of the system which will decide the cooling loads of the system and how the refrigerator cycle should operate to handle those. The loading of fish in the cooling room is another factor that is important to consider as it influences the cooling loads of the room over time (Bilgili, 2011). Furthermore, factors that is important to consider when modelling a solar PV mini-grid is generation from the solar PV panels as it changes with the season and weather. It is also important to consider how a change in load influence the investment and the operation of a mini-grid.

4.3.1 Scenarios

The simulation was made for two scenarios to understand the dynamics of the system. Factors like profit for fishers and solar radiation will change for the two scenarios. The Table 4.1 states the different conditions for the scenarios and the two paragraphs below describes them more thoroughly.

The first scenario was evaluated for the high and low season for fishery. The high season of fishery is during the rain season and that is when the solar radiation is limited, the day of the lowest solar radiation was chosen. The low season is during the dry period when the solar radiation is highest, where the day with the highest solar radiation was chosen. In the first scenario the fishers had no profit, which will be the condition for when the iteration stops. This comparison is made for when the cooling room is only loaded during the morning at 6 am and is cooled down to 4 °C at 5 pm.

The second scenario evaluates how the profit from the fisheries influences the system. This scenario only considers the high season when the solar PV production is low since this is is the most difficult season due to the low electricity production. Two types of behaviours of loading the fish where simulated, one where the fishermen loads the cooling room during the morning at 6 am and one case where the fish is loaded both during the night and the morning at 0 am and 6 am. In both cases the fish has cooled down to 4 °C by 5 pm. The cooling load is divided equally during that time.

Table 4.1: The different conditions for the two scenarios and their values.

Parameter	Scenario 1	Scenario 2
Solar PV generation	Low & High	Low
Loading of fish	6 am	0 am & 6 am
Profit fishers per day	0 $	0 $, 300 $ & 500 $

4.3.2 Cooling loads

The refrigeration cycle describes the energy requirements for the cooling room and how it changes during the day. The energy requirements of the refrigeration cycles will depend on the cooling loads of the walk-in cooling rooms. The cooling loads is the amount of energy that need to be supplied to a room to maintain a constant temperature, and can be calculated by estimating the energy losses that occurs in the cooling room. The biggest losses occurs through: (Hmida et al., 2019):

- Heat transfer rate though the walls, ceiling and floor to the surrounding environment of the cooling room.
- Heat transfer rate of fish though loading of the cooling room
- Heat transfer rate of the air infiltration
- Heat transfer rate from machines in the cooling room, like lighting and fans.

These losses are calculated to account for the cooling loads. There will be unknown heat gains and it is common to evaluate those as 15 % of the total cooling loads (Uddin et al., 2022).

The thermal loads that is happening through heat transfer though the walls to the surrounding environment is calculated according to

$$Q_{wall} = k_{wall} * A_{wall} * \Delta T \tag{4.1}$$

where Q stands for thermal load and have the unit W, A_{wall} is the cross section area of the wall with the unit m^2, ΔT is the temperature gradient between the temperature in the cooling room and the ambient temperature of the surrounding in Kelvin. k_{wall} is the overall heat transfer coefficient in W/$m^2 * K$. It is calculated as (Hmida et al., 2019).

$$k = \frac{1}{\frac{1}{h_e} + \sum \frac{l_i}{\lambda} + \frac{1}{h_i}} \tag{4.2}$$

where h_e and h_i are external and internal convection heat transfer in W/$m^2 * K$. l_i is the wall thickness in m and λ is the wall thermal conductivity in W/m*K. The equations 4.1 and 4.2 are also applied for the roof and floor. The cooling room layers are made of different materials. The walls and roof is made from steel, insulation and steel. The floor has concrete and lays on the ground. In Table 4.2 the material characteristics for the cold room is presented and the thickness of the layers.

Table 4.2: Material characteristics of the cold room

Parameter	Value	Unit	Source
h_e	14.5	W/m^2K	(Akusu et al., 2018)
h_i	14.5	W/m^2K	(Akusu et al., 2018)
k_{steel}	48.5	W/mK	(Raihan Uddin et al., 2021)
λ_{ins}	0.023	W/mK	(Raihan Uddin et al., 2021)
λ_{ground}	0.13	W/mK	(Hmida et al., 2019)
$\lambda_{concrete}$	1.75	W/mK	(Hmida et al., 2019)
l_{steel}	0.5	mm	(Kabeel et al., 2016)
l_{ins}	10	cm	(Kabeel et al., 2016)
$l_{concrete}$	0.2	m	(Hmida et al., 2019)
l_{ground}	1.71	m	(Hmida et al., 2019)

The heat loads of the incoming fish is calculated according to (Hmida et al., 2019).

$$Q_{fish} = F * C_{fish} * \Delta T \tag{4.3}$$

F is the amount of fish loaded into the cold room in kg. C_{fish} is the specific heat of fish above freezing in Wh/kg*K and is 0.93 Wh/kg*K (Hmida et al., 2019). ΔT is the temperature difference of the fish and the cooling room in K, in this case it is assumed that the fish have the temperature of the ambient temperature. The fish is loaded according to the scenarios in Section 4.3.1. The losses through the wall junctions is assumed to be 12 % of the total thermal loads of the walls (Hmida et al., 2019).

The thermal loads from the infiltration of air that is happening due to door opening is calculated with equation (Hmida et al., 2019).

$$Q_{inf} = 0.34 * D * \Delta T \tag{4.4}$$

where D is the air flow rate in m^3/h and is assumed to be 0.5 m^3/s according to the work of Carneiro et al. (2017). The air flow rate will happen during the time the fish is loaded into the cooling room and when the fish is sold during the afternoon.

The total cooling loads is calculated though summation of the all the losses and adding a 15 % factor to account for unknown heat gains (Uddin et al., 2022). This give rise to the equation

$$Q_{tot} = 1.15 * (Q_{wall} + Q_{bottom} + Q_{roof} + Q_{fish} + Q_{inf} + Q_{junction}) \tag{4.5}$$

4.3.3 Refrigerator cycle

The refrigerator cycle have four main components: condenser, capillary tube, evaporator and compressor (Meng et al., 2016). An schematic picture of the refrigerator cycle is showed in Figure 4.3 with its main components and the corresponding pressure-enthalpy diagram of the refrigerant R134a is presented in Figure 4.4.

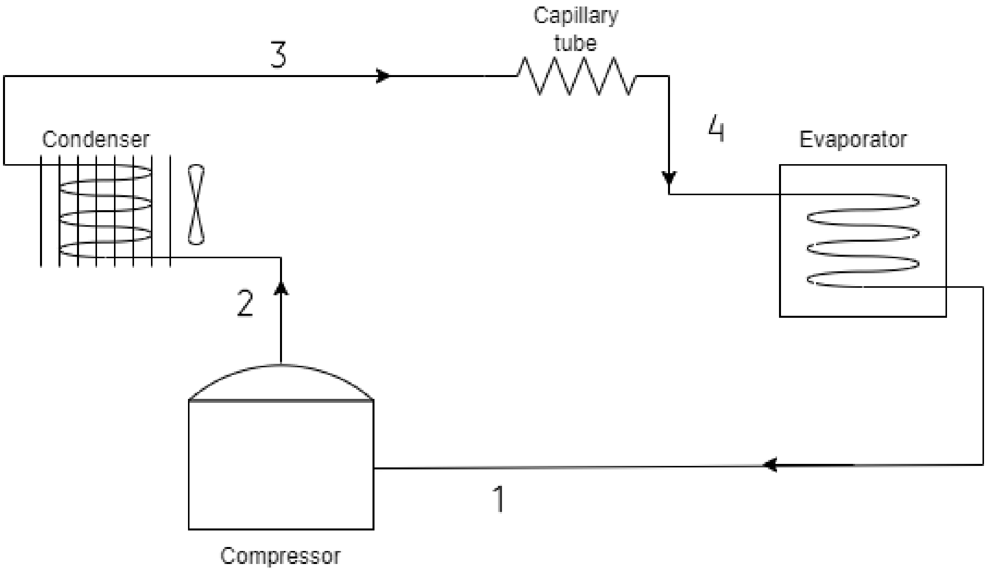

Figure 4.3: Schematic picture of the refrigerator cycle.

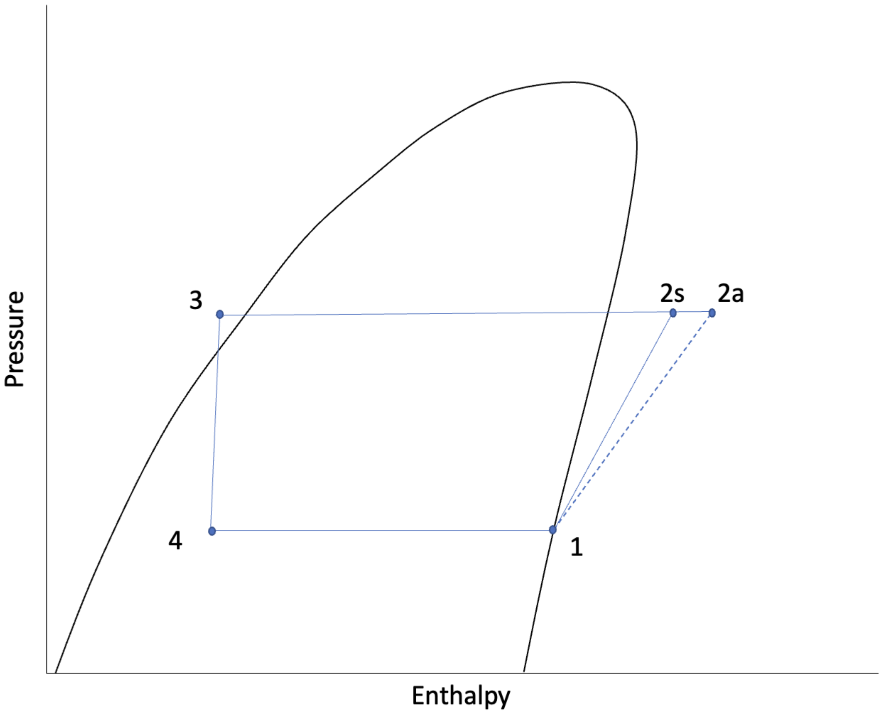

Figure 4.4: Pressure-enthalpy diagram for R134a for the refrigerator cycle.

Some assumptions are made that give rise to the Figure 4.4. The assumption made to calculate the thermodynamics of the vapour compressor cycle is based on the the work of Meng et al. (2016) and Raihan Uddin et al. (2021), which is according to the following:

- There is only pressure change in the compressor and capillary tube.
- There is no heat gains or losses to or from the system.
- The supercooling temperature is always 5 °C for the system in all operation conditions.
- The refrigerator is saturated vapor after the evaporator.
- The mechanical efficiency of the compressor is 0.8 and the isentropic efficiency is 0.6.

The temperature of the refrigerator cycle is presented in Table 4.3 where the evaporator provide cooling to the cooling room to keep it at 4 °C.

Table 4.3: The temperature for the refrigerator cycle.

Cooling room	4 °C
Evaporation temperature	0 °C
Condensor temperature	10 + T_{amb} °C
Supercooling	5 °C

To calculate the energy requirements for the refrigerator cycle the method of Raihan Uddin et al. (2021) is used. First the mass flow of the refrigerant R134a is calculated with according to (Meng et al., 2016).

$$\dot{m}_{R134a} = \frac{Q_{tot}}{h_1 - h_4} \tag{4.6}$$

where $\dot{m}_{R134a}$ is the mass flow of the refrigerant in kg/s. h_1 and h_4 is the enthalpy at the point 1 and 4, respectively, in Figure 4.3 and 4.4. Where the unit of the enthalpies is J/kg. With the isotropic enthalpy of the compressor inlet and outlet the real enthalpy can be calculated with equation (Meng et al., 2016).

$$h_{2a} = h_1 + \frac{h_{2s} - h_1}{\eta_{is}} \tag{4.7}$$

where h_{2a} is the real enthalpy at point 2 and η_{is} is the isentropic efficiency. The work done by the compressor, e.g. the electrical consumption is calculated as (Meng et al., 2016).

$$W_{compressor} = \frac{m_{ref} * (h_{2a} - h_1)}{\eta_{mec}} \tag{4.8}$$

It is assumed that the electrical consumption of the refrigerator cycle is the compressor work. This is assumed since the compressor is the component using most of the electricity in the refrigerator cycle (Sanaye and Malekmohammadi, 2004).

4.3.4 Economical assessment

The economical assessment was evaluated by using the investment cost of the cooling room unit and the running cost. The running cost will depend on the tariff for productive usage, the amount of fish caught and the selling price of fish. This was done though an iteration of the amount of fish that needs to be caught for the different cases to evaluate what amount of fish is needed to payback for the cold room during one year. One year was chosen since this is the pay-back time ELICO Foundation often have for their projects (Head of Programmes and Operations, ELICO Foundation, 2022).

The investment of the cold room is mostly dependent of the four main components in Figure 4.3: compressor, capillary tube, condenser and evaporator (Sanaye and Malekmohammadi, 2004). Where the investment cost of the compressor in $ is calculated as (Roy and Mandal, 2019)

$$CAPEX_{compressor} = 10167.5 * W_{compressor}^{0.46} \tag{4.9}$$

The investment cost for the capillary tube in $ is calculated according to (Roy and Mandal, 2019)

$$CAPEX_{capillary} = 114.5 * \dot{m}_{R134a} \tag{4.10}$$

The investment cost for the four components is summarized to get the total investment cost of the cold room by using the equation

$$CAPEX_{cold} = CAPEX_{capillary} + 3 * CAPEX_{compressor} \tag{4.11}$$

The investment cost of the evaporator and condenser is assumed to be the same as for the compressor (Sanaye and Malekmohammadi, 2004). The OPEX for the cold storage unit for one day is calculated with equation

$$OPEX_{cold} = \sum_{1}^{23} \frac{W_{compressor}(t) + W_{compressor}(t+1)}{2} * Tariff \tag{4.12}$$

where $OPEX_{cold}$ is the OPEX for the cold storage room in $. The summation give the total electricity usage from the cooling room for one day, where the compressor work was calculated for every hour for one day by using equations 4.1 to 4.8. The amount of fish needed to be sold to get a certain profit for the fishers can be calculated by the following inequality

$$Profit_{fishers} \leq \frac{CAPEX_{cold}}{365} + OPEX_{cold} - P_{fish} * F \tag{4.13}$$

where $Profit_{fishers}$ is the profit for fishers in \$, k is the fish price in \$/kg, $Tariff$ is the tariff level in \$ and F is the amount of fish needed to be sold to get that certain profit in kg and will the variable that will be iterated. The iteration will start by guessing a value of F, then the equations 4.3 to 4.13 is calculated until the statement in equation 4.13 is fulfilled.

The fish price was set to be according to be highest value in Table 3.2, which is 6 000 TZS/kg fish and the tariff level for the productive usage will be 40 000 TZS/kWh as it was the suggested level for the mini-grid company to go back to after the political statement, this can be read in Table 3.1.

4.3.5 Investment model mini-grid

The objective function of the model is to minimize the the investment and running cost of the mini-grid in Bwisya C_{tot} for the system with and without the cooling room load. It will be possible to invest in solar PVs, batteries, diesel generator and power the diesel generator that have a fuel price. This give that the objective function that should be minimized becomes according to equation

$$\begin{aligned} C_{tot} =& CAPEX_{bat,an} * Cap_{bat,invest} + (CAPEX_{PV,an} + OPEX_{PV}) * Cap_{PV,invest} \\ &+ CAPEX_{diesel,an} * Cap_{diesel,invest} + OPEX_{diesel} \end{aligned} \tag{4.14}$$

where $CAPEX_{i,an}$ is the annualized CAPEX of the solar PV per day, battery and diesel generator, respectively, in \$/kW*year. $OPEX_{PV}$ is the operational expenses of the solar PV in \$/kW day for the new solar PV installed. $OPEX_{diesel}$ is the operation expenses of the diesel generator in \$/day. $CAPEX_{i,an}$ is calculated as

$$CAPEX_{i,an} = \frac{CAPEX_i * AF_i}{365} \tag{4.15}$$

where the $CAPEX_i$ is the capital expenses of the component i. AF is the annuity factor for unit i and is the present value of a cash flow. The annuity factor is calculated by

$$AF_i = \frac{r}{1 - (1 + r)^{-N_i}} \tag{4.16}$$

where r is the discount rate and N_i is the component lifetime in years. The discount rate is set to be 7 % (Focus economics, 2022).

The $OPEX_{diesel}$ is calcualted with equation

$$OPEX_{diesel} = \sum_{1}^{t} Gen_{diesel}(t) * (OPEX_{men} + OPEX_{diesel,running}) \tag{4.17}$$

where the $Gen_{diesel}(t)$ is the power production from the diesel generation at time t in kW, the $OPEX_{men}$ is the operational expenses for maintenance of the diesel generator in \$/kWh and the $OPEX_{diesel,running}$ is the expenses for buying and transporting the diesel in \$/kWh.

The battery balance equation calculates the battery state of charge, SoC(t) (Soroudi, 2017). The battery level is modeled according to the battery balance equation

$$SoC(t) = SoC_{initial}(t = 1) + SoC(t - 1)(t > 1) + v_{ch}(t) - v_{dis}(t) \tag{4.18}$$

where the v_{ch} and v_{dis} is variables that decides how the battery should be charged and discharged. The $SoC_{initial}$ is the initial storage level of the battery when the model starts running, the unit is in kWh. The storage level of the battery must be the same as when the model started, for example at time 24 (Soroudi, 2017), which gives the equation

$$SoC(t = 24) = SoC_{initial} \tag{4.19}$$

4.3.5.1 Constraints equations

The system will have some constraints that will be integrated in the GAMS model. A constraint is put on the range that the SoC can lay between, which is according to

$$(Cap_{bat,ex} + Cap_{bat,invest}) * (1 - DOD) \leq SoC(t) \leq Cap_{bat,ex} + Cap_{bat,invest} \tag{4.20}$$

where the DOD is the depth of discharge and $Cap_{bat,ex}$ is the existing battery capacity. One constraint of the system is that the generation from the solar PV, diesel generator and discharge of the battery most be bigger than the load of the cold storage unit and the mini-grid consumers and the charging of the battery. This gives rise to the equation

$$\begin{gathered} Gen_{PV}(t) * (Cap_{PV,invest} + Cap_{PV,ex}) + Gen_{diesel}(t) + \\ v_{dis}(t) * \eta^{dis} \geq Load(t) + \frac{v_{ch}(t)}{\eta^{ch}} + Load_{cold}(t) \end{gathered} \tag{4.21}$$

where the $Gen_{PV}(t)$ is the solar generation for 1 kW solar panel in kW/1 kW panel. The charging of the battery can not be higher than the available storage level left in the battery according to

$$v_{ch} \leq Cap_{bat,ex} + Cap_{bat,invest} - SoC(t) \tag{4.22}$$

The generation from the diesel generator is limited by the capacity of the diesel generator according to

$$Gen_{diesel}(t) \leq Cap_{diesel,invest} + Cap_{diesel,ex} \tag{4.23}$$

Table 4.4: The values for some of the parameters used in the model and the corresponding source.

Parameter	Value	Unit	Source
η^{ch}	95	%	Soroudi (2017)
η^{dis}	90	%	Soroudi (2017)
$Cap_{PV,ex}$	60	kW	Head of Operations, JUMEME (2022)
$Cap_{bat,ex}$	60	kWh	Head of Operations, JUMEME (2022)
$Cap_{diesel,ex}$	42	kW	Head of Operations, JUMEME (2022)
$CAPEX_{diesel}$	450	\$/kW	Wilson (2018)
$OPEX_{diesel,running}$	3.85	\$/kWh	Local technician, JUMEME (2022)
$OPEX_{diesel,men}$	0.04	\$/kWh	Uddin et al. (2022)
$CAPEX_{PV}$	2145	\$/kW	Abid et al. (2021)
$OPEX_{PV}$	$\frac{10}{365}$	\$/kW*day	Tsai et al. (2020)
$CAPEX_{bat}$	129.2	\$/kWh	Wilson (2018)
DOD	80	%	Huneke et al. (2012)
N_{diesel}	13	years	Wilson (2018)
N_{bat}	5	years	Head of Operations, JUMEME (2022)
N_{PV}	25	years	Tsai et al. (2020)

4.3.5.2 Load profiles

The load profile is generated by using a tool produced by Reber et al. (2018), which generates an hourly load profile specifically for the Sub-Saharan Africa region. The input to the tool is the percentage of low, medium and large income household and commercial inputs like milling, schools and small shops. It is assumed that the percentage between low, medium and large income households are divided equally. The rest of the input data is provided by Head of Operations, JUMEME (2022) where the given costumer amount is presented in Table 4.5. The average daily electricity usage between the 1st of April to the 19th of May 2019 was used and it was 87 kWh (Head of Operations, JUMEME, 2022). This data was used to fit the hourly load profile generated from Reber et al. (2018).

Table 4.5: The costumers information that was given by JUMEME Head of Operations, JUMEME (2022).

Costumer	Amount
Households	225
Milling	5
Schools	2
Clinics	2
Small shops	24

4.4 Causal Loop Diagrams

Rural electrification affects several parts of the community, such as education, health, agriculture and enterprises, but it is also affected by the same factors in return (Hartvigsson et al., 2020). Due to these interlinkages between variables, Hartvigsson et al. (2020) suggests a framework where conceptual system dynamics are used to aid in tackling complexity and problem formulation. The purpose of the analysis is to understand how access to electricity can be used to reduce the spoilage in fish.

This study uses Vensim® to build a causal loop diagram (CLD) to make a conceptual model over the system, this is done according to the framework presented by Hartvigsson et al. (2020). The first part of the framework is to get an initial understanding of the system from the existing literature and identify variables and causalities between them. Smaller subsystems were constructed based on the literature and some assumptions not found in the literature. The second step in the framework includes the merging of the entities from the subsystems found in the literature into an initial CLD. In the third step of the framework the CLD is used to reduce the scope and assist in focusing on the issue. In this step, additional information is needed to re-evaluate the CLD. This was done by a field study. During the field study, additional data was collected, resulting in identification of new entities and causalities. It also reduced uncertainty in already identified causal relationships. Finally, the results from the techno-economic analysis is also added to the CLD since it confirmed some interlinkages in the system. By adding the new information and re-evaluating the scope of the variables, a new causal loop diagram was obtained.

In a CLD, the arrows are assigned a positive or negative sign depending on the variables causal relationship. A positive sign means that if the variable at the arrow base increase or decrease, so does the variable at the arrow head. If the sign is negative, it means that if the variable at the arrow base increase, the variable at the arrow head decrease (Sterman, 2000). It is important to note that a CLD does not show what is currently happening within the system, but what would happen if a variable changed. It does not indicate whether a variable increases or decreases, only the causal effects it would have on variables linked to it (Sterman, 2000).

The final CLD is analysed by analysis of the systems behaviour through identification of balancing- and reinforcing loops in the system. If the loop are balancing or reinforcing is determined by identifying the polarity of the loop. According to Sterman (2000), the right way to do this is by assuming a small change in one of the variables and tracing the effect as it propagates around the loop. If this small change reinforces the original change, it is a reinforcing loop with a positive polarity. If the change however opposes the original change, it is a balancing loop and has a negative polarity. It does not matter which variable is assumed to change originally, the result must be the same (Sterman, 2000).

5

Result

In this Chapter the results from the techno-economic analysis are presented in Section 5.1 and the results from the causal loop diagram are presented in Section 5.2.

5.1 Techno-economical analysis

The techno-economical analysis will give an understanding if it is economically beneficial for the fishers to invest in a walk-in cooling room and how it interacts with the operation of the mini-grid. This will answer the first and second research question.

The investment cost, running cost and amount of fish needed to be sold per day to cover the running cost and pay back the investment cost in a year is presented in Table 5.1 for dry and rain season. The amount of fish needed to be sold is calculated with equation 4.13. The energy consumption and the running cost of the cooling unit is calculated with equation 4.12 and 4.12, respectively. The investment cost of the cooling room is calculated with equation 4.11.

Table 5.1: The Table shows the results from the economical assessment for the investment of a cooling room and the amount of fish needed to be sold to cover the running costs and the investment cost with a pay-back time of one year. This is presented for dry and rain season.

	Dry season	**Rain season**
Fish needed to be sold [kg/day]	55	47
Energy consumption [kWh/day]	5.6	4.6
Running cost [$/day]	96	80
Investment cost [$]	17 000	15 000

According to the results in Table 5.1 the investment cost of the cooling unit will be 2 000 $ higher during the dry season, this is correlated with a need for a bigger compressor to handle the higher ambient temperature that can be read in the Figure A.4 in Appendix. This is also the reason why the energy consumption of the cooling room is higher during the dry season, where the energy consumption is 1 kWh higher per day than for the case during the rain season. This results in that the amount of fish needed to be sold in the rain season is smaller. The amount of catched fish of 47 kg corresponds to about 1.5 fishers catch per day, assuming that they catch the amount stated in Table 3.2, which is around 30 kg per fisher during the high season. This means that 2 fishermen needs to collaborate to be able to reach that amount. While for the dry season, where the fisher need to catch 55 kg per day, it is difficult to obtain since the fishers often only catches 1 kg each since this is the low season in fishery.

The result for the first and second scenario is presented in Table 5.2 and 5.3, respectively. It is calculated using the investment model that is described in Section 4.3.5.

Table 5.2: The Table presents the modeled system and the running cost of the mini-grid according to the first scenario where there is no profit for the fishermen. The Table also shows how the system differs with and without the cooling unit connected to the mini-grid.

	Dry season		**Rain season**	
	Without	With	Without	With
PV capacity [kW]	60	60	72	76
Battery capacity [kWh]	60	60	62	66
Diesel capacity [kW]	42	42	42	42
Diesel generation [kWh]	0	0	0	0
C_{tot} [\$/day]	0	0	6.8	9.2

The modeled system presented in Table 5.2 shows that there is no need for the mini-grid operators to invest in extra capacities or run the diesel generator during the dry season since the capacities are the same as the initial system in Bwisya (stated in Table 4.4). However, for the rain season the model simulations show that investments are needed both with and without the cooling unit. According to the model, it is more profitable for the for mini-grid operator to invest in solar PV and battery capacity rather than running the diesel generator. The existing mini-grid in Bwisya has the diesel generator running when the solar PV generation is low, which explains why the electricity is still provided during the rain season. During one period, the mini-grid needed to have the diesel generator running for 2 months during the rainy season (Former cluster manager, JUMEME, 2022; Local technician, JUMEME, 2022). According to Table 5.2, an additional 12 kW solar

PV capacity is required to cover the load during rain season, with the cold room another 4 kW is required. 2 kWh extra capacity of batteries is required for the rain season since the solar PV generation is lower, and with the cooling room another 4 kWh is required. This makes the cost for the mini-grid company to become 2.4 $/day higher when the cooling unit is connected.

In Table 5.3 the result of the second scenario for different loading of fish in the cooling room is presented and how they changes for different profits for the fishers for the rain season where there is low soar PV generation.

Table 5.3: The Table shows the result from the second scenario with different levels of profit per day. This is done for the rainy season.

	Loading morning			**Loading night & morning**		
Profit levels for fishers [$/day]	0	300	500	0	300	500
Fish needed to be sold [kg/day]	47	170	250	48	170	250
PV capacity [kW]	76	77	77	76	77	77
Battery capacity [kWh]	66	66	67	66	67	67
Diesel capacity [kW]	42	42	42	42	42	42
Diesel generation [kWh]	0	0	0	0	0	0
C_{tot} [$/day]	9.2	9.5	9.7	9.2	9.6	9.8

The amount of fish needed to be sold to get a specific profit is not affected by when the fish is loaded, as can be read in Table 5.3. The amount of fish needed to be caught for a profit of 500 $ is 250 kg, which corresponds to the catch from around 8 fishermen per day. The cost for the mini-grid operation is increasing for the higher profit, which is correlated to a higher energy requirement that comes from the higher amount of fish stored. This can be seen in the Figures A.5 and A.6 in Appendix. The PV capacity for the case when the fish is loaded two times is lower than for the case with loading only in the morning. The results also show that an increase in battery capacity is required, which makes the cost of the mini-grid become higher for the case with the loading during the night and the morning. The need for less solar PV capacity for the morning case can be explained by Figure 5.1.

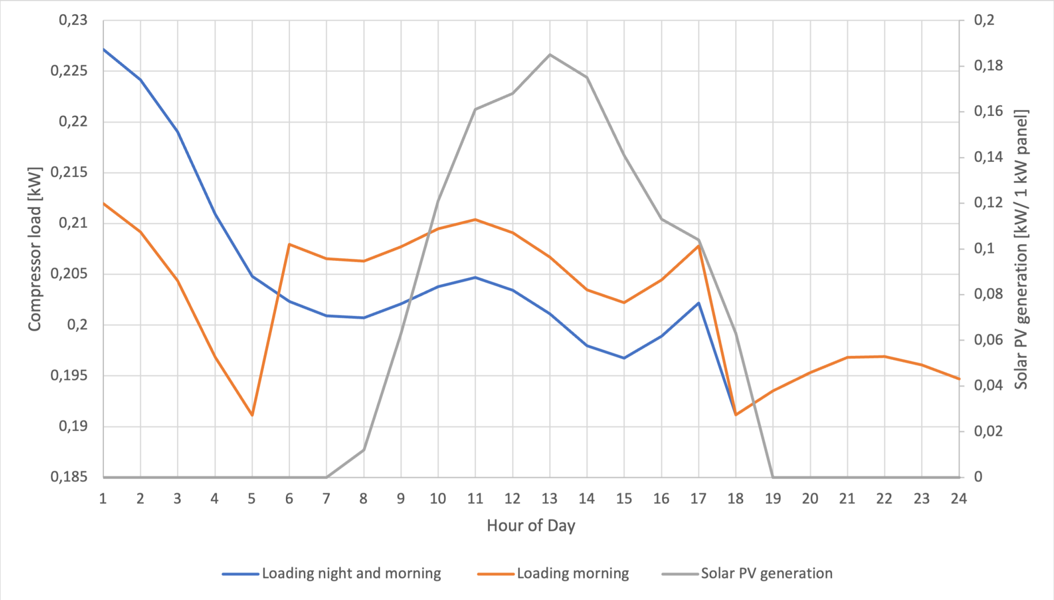

Figure 5.1: The different cooling loads for loading the cooling room in the morning and loading it night and morning for low solar PV generation.

In Figure 5.1 it can be seen that the compressor load for the loading of fish during the morning correlate better with the solar PV generation than the case with loading during the night and the morning. This means that less capacity in battery is required to cover load of the cooling room during time periods when the solar PV generation is low. However, when the fish is loaded both during the night and the morning, the cold room will have higher load before 6 am which will be covered with batteries. Resulting in a need for higher battery capacity.

5.2 Causal loop diagram

The following section will present a qualitative analysis that will give insight to the interlinkages between the access to electricity and the decreased spoilage in fish. It conceptualizes the system that the techno-economic analysis in Section 5.1 is based on and the conclusions in the previous section is added to the qualitative results. The qualitative analysis will be used to answer the questions if and how the access to electricity affects the spoilage of fish within small scale fisheries in Tanzania. The causalities between the different variables in the system is presented by a causal loop diagram (CLD) in Figure 5.2.

When a mini-grid is installed in a rural area the community is affected in many different ways and there are several ways for people to have access to electricity. One way is to connect the household so that they are able to have electric light and other appliances such as a TV or speakers, but access to electricity also includes when different public institutions are connected to a mini-grid, such as hospitals and churches (Cluster manager, JUMEME, 2022; Executive Director, ELICO Foundation, 2022). As the access to electricity (*Electricity access* in Figure 5.2 increases in a rural community many sources conclude that the community experiences an increase in economic growth and improved services such as healthcare and *Education* (Site manager Power Corner, Engie, 2022; Cluster manager, JUMEME, 2022; Executive Director, ELICO Foundation, 2022; Nuru et al., 2021; Uamusse et al., 2019).

An important aspect in the system is the awareness from the mini-grid investor (*Mini-grid investor awareness* in Figure 5.2) about the community that the mini-grid will be installed in (Executive Director, ELICO Foundation, 2022). Most of the people in rural areas are not aware of the benefits of electricity, so it is important to show the people what electricity can be used for. Thus the awareness of the mini-grid investor has a positive effect on the *Costumer awareness*, which leads to an increase in *Productive usage of electricity* which is the usage of a larger amount of electricity in a business, for example refrigeration of fish, milling or carpenting. I addition, *Productive usage of electricity* increases the *Profits from the mini-grid* (Executive Director, ELICO Foundation, 2022; Hartvigsson et al., 2021; Ogeya et al., 2021). If the investors are aware of the context, they often also promote the *Productive usage of electricity* and provide *Financial assistance* since it is often difficult for people in these communities to make large investments (Executive Director, ELICO Foundation, 2022).

Furthermore, the *Electricity access* provides opportunity to use cold storage (*Cold storage opportunities* in Figure 5.2) as a preservation method (Fishermen 1, 2022; Fishermen 2, 2022; Fishermen 3, 2022; Nuru et al., 2021; Mramba and Mkude, 2021). An important aspect to consider is also the *Reliability.* Cold storage was used at the hospital in Bwisya to cool blood for surgeries, however, when the *Reliability* of the mini-grid decreased, the hospital had to stop storing blood since the the blood could become bad when there was a blackout (Former cluster manager, JUMEME, 2022). Additionally, the local technician from JUMEME said in an interview that, due to the decrease in *Reliability* of electricity in Bwisya in recent years, the costumers started to harass and threaten him (*Technician harassment* in Figure 5.2). Furthermore, since cold storage has many benefits, it is utilized (*Cold storage utilization* in Figure 5.2) if they have the opportunity (*Cold storage opportunity* in Figure 5.2) (Fishermen 1, 2022; Fishermen 2, 2022; Fishermen 3, 2022; Former cluster manager, JUMEME, 2022). The utilization is however also positively affected by the *Cold storage demand*, and when cold storage is utilized, the demand is decreased. *Cold storage demand* is in turn positively affected by the amount of *Fish caught*.

Interviews with some fishermen on the island that got the opportunity from ELICO Foundation to use cold storage to preserve their fish explained that this had resulted in a significant reduction in *Spoilage of fish*. This lead to a higher *Income* when a higher quantity could be sold. In addition, all the interviewed fishermen mentioned that they no longer had the *Pressure to sell* at low prices since the risk of spoilage was not as high when the fish could be cooled. It had also allowed them better *Access to markets* when the fish could be stored for a longer time and be transported. When there no longer was a *Pressure to sell* the fish and more *Access to markets*, they could charge a higher price for the fish. Another common denominator for the fishermen were also that, with this increase in *Income*, they could increase their *Ability to pay* to invest in more cold storage units to expand their business. It is however assumed that when an investment is made for more cold storage (*Cold storage utilization* in Figure 5.2), the *Ability to pay* is decreased.

Moreover, *Electricity access* allows the fishermen to use electricity for *Value addition* of the fish by, for example, refrigeration and drying of the fish (Executive Director, ELICO Foundation, 2022; Head of Programmes and Operations, ELICO Foundation, 2022; Das and Behera, 2020). Using electric equipment to dry the fish reduces the spoilage since the fish would otherwise lie on the ground to sun dry and expose it to both sand and birds (Das and Behera, 2020; Gyan et al., 2020; Kabahenda et al., 2009). The *Value addition* is however dependent on the amount of fish that is caught. Several studies also suggests that better *Education* can lead to a decrease in *Spoilage of fish* (Acharjee et al., 2021; Gyan et al., 2020).

Based on the techno-economic analysis in Chapter 5.1 there is a positive causality between *Financial assistance* and *Cold storage opportunities*, this is due to the high investment cost of a cold storage unit. It is therefore necessary for an investor to invest in the technology so that the fishermen can pay back the cost over a set period of time. The techno-economic analysis also supports the positive relationships between *Productive usage of electricity* and *Mini-grid capacity* as well as *Mini-grid capacity* and *Mini-grid investment cost*.

In Figure 5.2 above it can be seen that there are several feedback loops in the system. When the opportunity to use cold storage increases it will cause more fishermen to utilize cold storage since this technology has many benefits. As more cold storage is used it leads to a decreased pressure to sell the fish since it can be

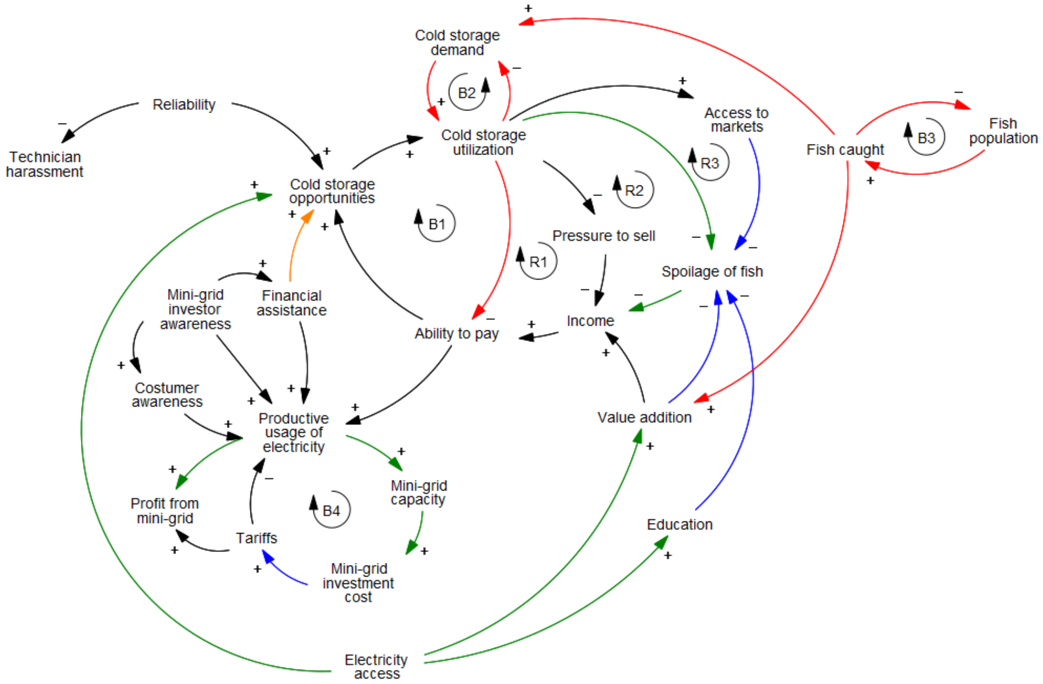

Figure 5.2: Causal loop diagram of the system related to the ability to use cold storage to preserve fish. It consists of 3 reinforcing feedback loops and 4 balancing feedback loops. The black arrows represent information from interviews, blue arrows represent information from the literature study, the green arrows are information that is confirmed by more than one source, the red arrows are based on assumptions and the orange arrow represents results from the techno-economic analysis. See Appendix A.2 for a summary of the feedback loops and a complete list of the references for the causalities.

preserved for a longer time, hence making it possible to increase the income by charging a higher price. It also directly decreases the spoilage of fish and makes it possible for fishermen to expand their business into new markets farther away, which also leads to reduced spoilage since more fish can be sold. This results in a larger quantity of fish that can be sold, thus increasing the income. Since the majority of people in these rural areas are poor, the possibility to earn a higher income has a large effect on their ability to pay, thus increasing the possibility to expand their business by buying more cold storage. These effects that *Cold storage opportunities* have on the income and spoilage of fish are described by the reinforcing feedback loops *R1, R2* and *R3*. However, the utilisation of cold storage also costs, which decreases the ability to pay and in turn the possibility to use cold storage. This is described by the balancing feedback loop *B1*.

The utilization of cold storage is also balanced by the demand described by *B2* since the demand for cold storage will eventually become saturated. For the case in Bwisya it may however take a while for the demand to be saturated due to the low capacities that the fishermen have today (Fishermen 1, 2022; Fishermen 2, 2022; Fishermen 3, 2022). All the interviewed fishermen expressed that they wanted to expand their business but they required more storage space. I addition, these rural areas might show tendencies to oversaturate the market when others in the area see that it is possible to earn money on this, they want to start the same business. It was noticed during the field study that many streets had a lot of similar businesses, and eventually the market will be oversaturated. The demand is also limited by the quantity of fish catched, here it is important to make sure that the fish population does not decrease over time by overfishing. The balance between *Fish caught* and *Fish population* is described by *B3*.

An increase in *Productive usage of electricity* for the use of, for example a cold storage room, may also require an increase in the *Mini-grid capacity* which was shown in the techno-economic analysis in Section 5.1. The techno-economic analysis also showed that this will lead to investments cost for the mini-grid which will, according to the CLD in Figure 5.2, lead to an increase of the *Tariffs*. Higher *Tariffs* causes a lower consumption of electricity due to the limited ability to pay. This is described by feedback loop *B4*.

6

Discussion

The results from the techno-economical analysis indicates that through financial assistance from an investor, it can be economically feasible from the fishermens perspective to have a joint cold storage unit. The causal loop diagram (CLD) in Figure 5.2 also point to the importance for the awareness of the mini-grid operator about the economical difficulties small scale fishermen often have. In addition, the CLD shows that by utilizing cold storage the income will most likely increase which indicates that it is economically beneficial to make this investment and that it can be possible to cover the investment cost over a pay-back time. The investment cost was set to be payed back in one year in the model. Although one year is a rather short pay-back time, it is important to consider that the possibility for an investor to get back the investment in a developing country can be uncertain. Having a short pay-back time that is economically feasible for the fishermen can therefore increase the willingness to invest. It is however important to consider that the investment costs are based on assumptions according to the literature, and that the real cost for a joint cold storage room may be higher than the one calculated in this work. Another cost that is not considered is the transportation of the cold storage room which may be significant since Bwisya is located remotely.

The cost of running the cold room is also high due to the higher tariff levels that JUEMEME want to change back to, but even with high tariffs it is economically possible to run the cold room, thus the investment is less sensitive of changes in the tariff level. Covering the costs of running the cold storage unit and the investment cost can, according to the model, be possible during the rainy season when the fish catch is high, if at least two fishermen cooperate with the cold room. Moreover, it might be difficult to cover the costs during the dry season when the fish catch is significantly lower, which is something that is needed to be taken into account by the investor. However, if the profit during the rainy season is high enough, it might be able to cover the costs during the dry season. Assuming that the money can be saved for a longer period. Another possibility could be to cooperate with farmers and store crops in the cold room during this period when the fish is scarce.

Furthermore, in the second scenario the fishermen are assumed to make a certain daily profit. An assumed profit of 500$ per day is high for businesses in rural areas, but it needs to be taken into account that there are several fishermen that split the profit. In addition, the fishermen may have other cost to cover such as fishing nets or salaries if there are people working on the boat. It is also relatively common to have large families needed to be taken care of. The local technician in Bwisya said that his income provided not only his own family, but also his parents and nephews.

The techno-economical analysis also showed that the mini-grid operators need to invest in more solar PV and battery capacity to be able to power the cold storage room during the rainy season where there is low solar PV generation. While for the case when the solar PV generation was high, the capacity did not need to be increased since the solar PV produced enough electricity to satisfy the demand. One of the reasons behind this is that during this season, the quantities of fish are low and a cooling room will not be utilized fully. However, this indicates a potential to use the cooling room for other products during this time of year, such as crops that need to be cooled. An important factor to consider is that the cooling room require more energy during this time of year due to the higher ambient temperatures, resulting in both a higher investment cost and running cost for the cooling room. However, it is possible that the behaviour of the other costumers in their use of electricity differ between the rain and the dry period. This means that the load profile generated may differ between these periods, causing this to be a limitation in the result that needs to be taken into account when compering the dry and rainy seasons.

Moreover, according to the model, it is more economically beneficial to invest in more solar PV and batteries than to run the diesel generator when the solar PV production is low. This may however be because the model is only running for one day. If the model were run over a year the results might be different since the solar PV generation varies during the year and additional solar PV and batteries are not needed during sunny periods. But for areas with very low solar radiation in longer periods it is better to invest in more capacity than to run the diesel generator. The investment cost for extra capacity might however be too high for the mini-grid operators to cover, which may be the reason why they choose to run the diesel generator since that cost is easier to cover in the short-term.

Another interesting factor to consider from the mini-grid operators point of view is the time when the cooling room is loaded with fish. According to the model, it is better to load the cooling room with fish in the morning to minimize the load on the mini-grid during times when the solar PV generation is low. This may however be difficult in practice, as the behavior of the local fishers may not be possible to change to match what is best for the mini-grid operator. In addition, the times for loading the fish into the cooling room are assumptions made based on the interviews with the fishermen. The behaviour can however differ between the fishermen and depending on weather which can influence the results. Furthermore, the results indicate that the amount of fish loaded in the system does not significantly change the investment cost and running cost for the mini-grid operator, as can be seen in Table 5.3. Instead, it is when the cold room is connected that affects the investment and operational costs the most since they need to compensate during the rain season when the solar PV generation is low. Table 5.2 shows that the investment and running cost of the mini-grid increases with 2.4 $ when the cooling room is connected.

By implementing a cold storage unit, the spoilage of fish can be significantly reduced, and it is illustrated in the causal loop diagram (CLD) in Figure 5.2 the importance of access to electricity to reduce this spoilage in several ways. First, the access to electricity provides an opportunity to use cold storage that directly leads to a reduction in spoilage, but also through an increased access to markets. Secondly, it also gives the possibility to use electric equipment to reduce the spoilage through value addition. Thirdly, it has also been shown that electricity results in a higher quality of education and in several studies have concluded that better education leads to reduced spoilage Gyan et al. (2020); Acharjee et al. (2021). This shows the importance of electricity in fishing communities in rural areas to reduce the spoilage of fish, but as can be seen in Figure 5.2, this also results in a higher income. In these rural areas a higher income would lead to a higher economical status and significant improvement in their standards of living Fishermen 1 (2022); Lukuyu et al. (2019). This also means that they might be able to grow their business further and continue to increase their quality of life.

Furthermore, the reduced spoilage of fish can be one solution to reduce the food insecurity in Africa Chan et al. (2019), since less food will go to waste. However, the fish industry is not the only food sector in Africa that suffers from high losses, it is also a problem within the agricultural sector where several types of crops would benefit from cold storage Sadi and Arabkoohsar (2020); Affognon et al. (2015). Even though the CLD in Figure 5.2 describes the system where the focus is fish, it can also be applied to the agricultural sector since the mechanisms behind this food waste are similar. Since the main problem in Sub-Saharan Africa is the warm and humid climate, access to cold storage could significantly reduce food losses Sadi and Arabkoohsar (2020); Lamidi et al. (2019).

As mentioned earlier, electricity does not only provides the possibility to use cold storage. It can also be used to add value to the fish as well as other agricultural products. It can be used to power machines for drying fish and milling machines to make flour. Value addition is an important part of a business since the price of the products increase which leads to a higher income. This is an important aspect since the poverty in Sub-Saharan Africa is widespread and by enabling them to develop their businesses within agriculture and fisheries it can help to reduce poverty and food insecurity (Chan et al., 2019; Ibengwe and Kristófersson, 2012).

More research is however needed within the field to increase the knowledge about the correlation between cold storage, access to electricity and decreasing spoilage in the fishery sector. More simulations with other weather data and load profiles would be interesting in the techno-economics to evaluated the robustness in the results in this study. It would also be beneficial to further investigate the possibility to use the cold storage room for crops during the dry seasons when the fish catch is scarce.

7

Conclusion

This study concludes that the implementation of a joint cold storage room can be economically beneficial for small-scale fishers in Tanzania with financial assistance. Because small-scale fishermen seldom have the capital to invest in this type of equipment on their own, it is therefore necessary for an investor to cover the initial investment cost for the installation of the cold storage room and allow the fishermen to have a pay-back time over at least one year. One requirement is however that the investor takes into account that it can be difficult for the fishermen to cover the investment cost during the dry season when the fish catch is scarce. The results suggest that the amount of fish caught during the high season is enough to cover the running costs and the investment costs if it is paid back over at least one year. One solution to cover the costs during the low season might be to use the cold storage room to preserve crops that easily perish in the hot climate during the dry season or if some of the profit from the high season can be saved.

The connection of a cold storage unit to a solar PV mini-grid would require extra investments from the mini-grid operator to be able to cover the demand during periods where the electricity production is low. The model indicates that in the long run, it is more beneficial for the mini-grid operator to invest in a higher capacity of solar PVs and batteries instead of running the diesel generator when the electricity production is low. This may however be an effect of only simulating over one day at a worst-case scenario. If the simulation was performed over a year where there are many fluctuations in the solar PV production the results may differ. The thesis can also conclude that the time of loading the fish in the cooling room influences the mini-grid operator, where a loading that matches the solar PV generation is more beneficial as it decreases the investment cost.

Furthermore, it can also be concluded that access to electricity has a significant effect on the reduction of spoilage of fish. Electricity makes it possible to utilize cold storage to preserve the fish for several days, directly decreasing the loss. Cold storage in turn also provides the opportunity to move the fish a longer distance so that the fishermen can sell more fish at different markets. In addition, electricity can also be used to power machines for drying the fish, increasing its value and reducing the loss due to birds or sand when drying traditionally on the ground. In general, access to electricity can also improve education, which also can lead to less spoilage. Since fewer fish are wasted, more fish can be sold, thus the fishermen can get a higher income. A higher income is important in rural areas since a lot of people are very poor. They can, by using electricity productively, improve their economic status and their quality of life.

These conclusions show the importance of electricity access in rural areas for small-scale fishermen to reduce the spoilage of fish and that it can be economically possible to install a joint cold storage room with financial assistance.

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A

Appendix

A.1 Cooling Loads

The cooling loads in the cooling room depend on the ambient temperature, the fluctuations for Bwisya in 2019 can be seen in Figure A.1.

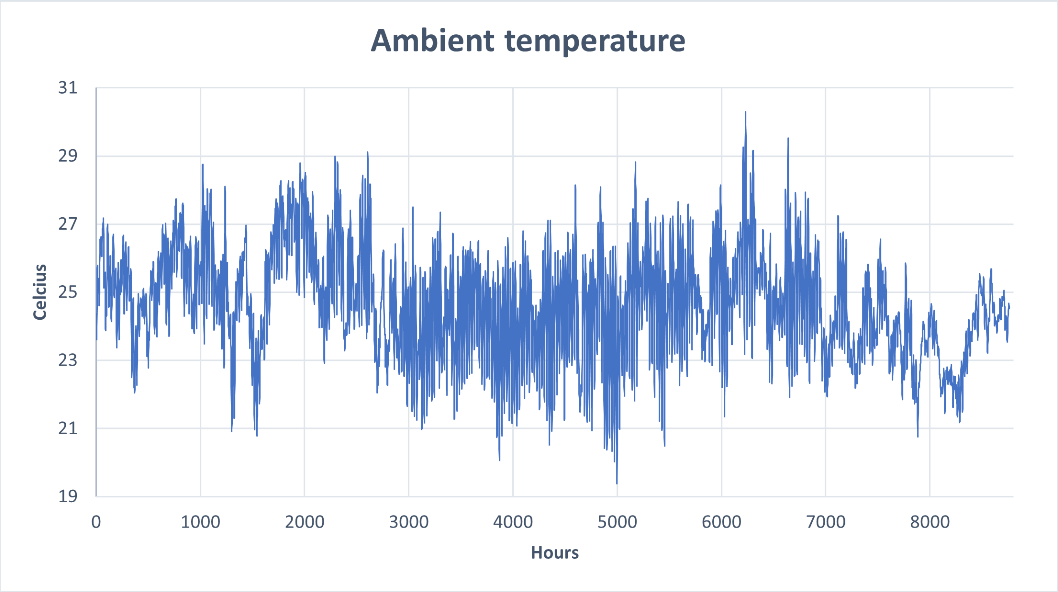

Figure A.1: Ambient temperature in Bwisya for 2019.

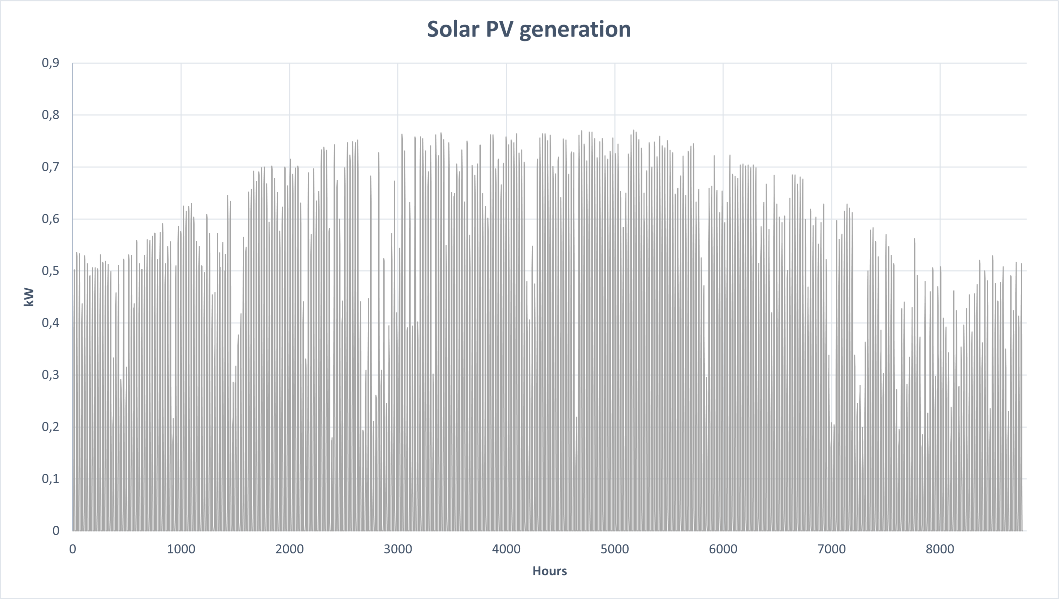

Figure A.2 and A.3 presents the electricity generation over 24h at the days when the production was at its highest and lowest, respectively. These graphs are used in the techno-economic analysis as best and worst case.

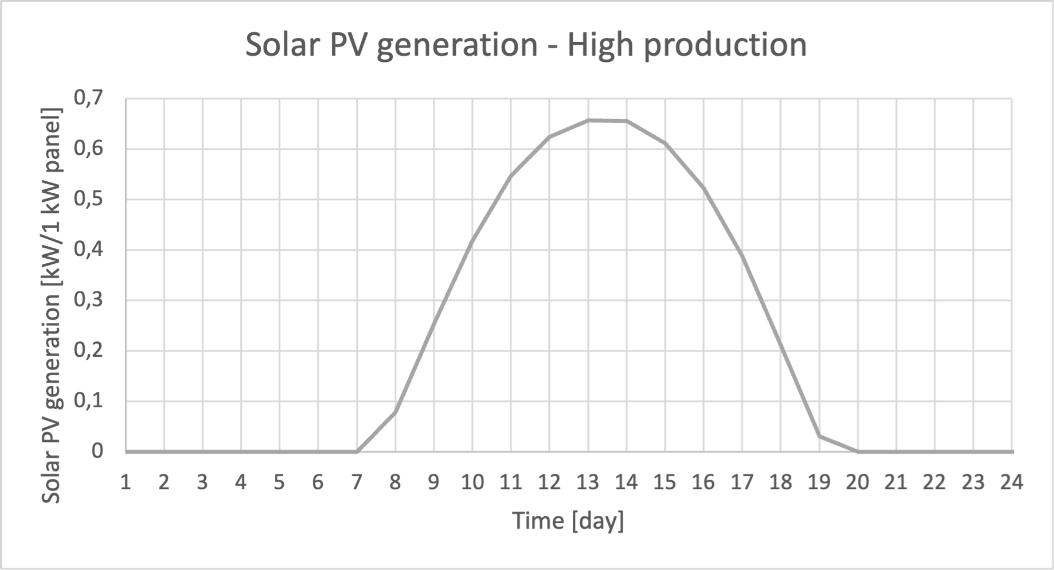

Figure A.2: Solar PV generation over 24h when the production was at the highest in Bwisya in 2019 for a 1 kW solar PV panel.

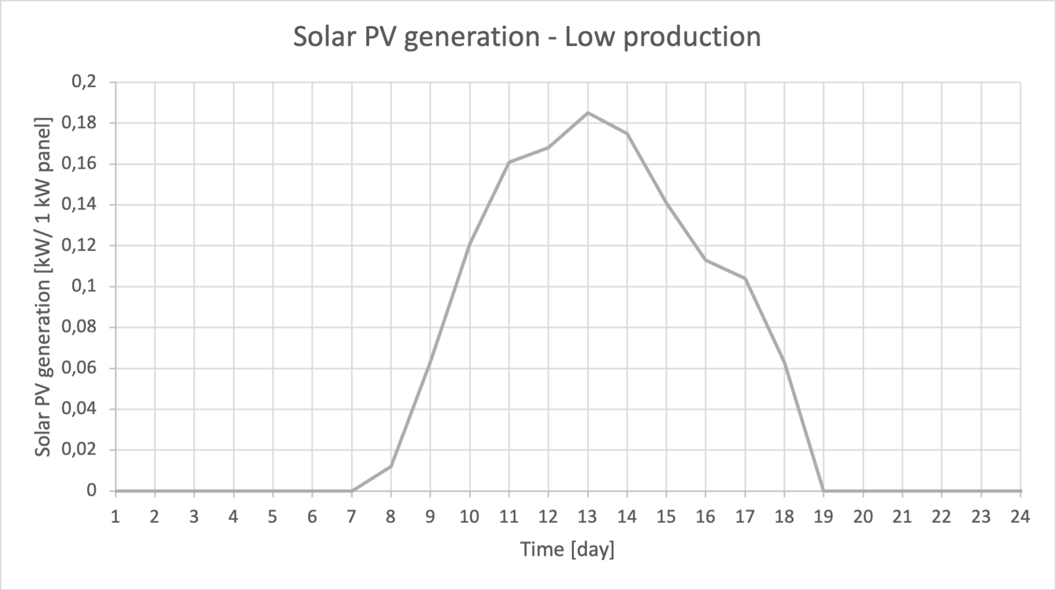

Figure A.3: Solar PV generation over 24h when the production was at the lowest in Bwisya in 2019 for a 1 kW solar PV panel.

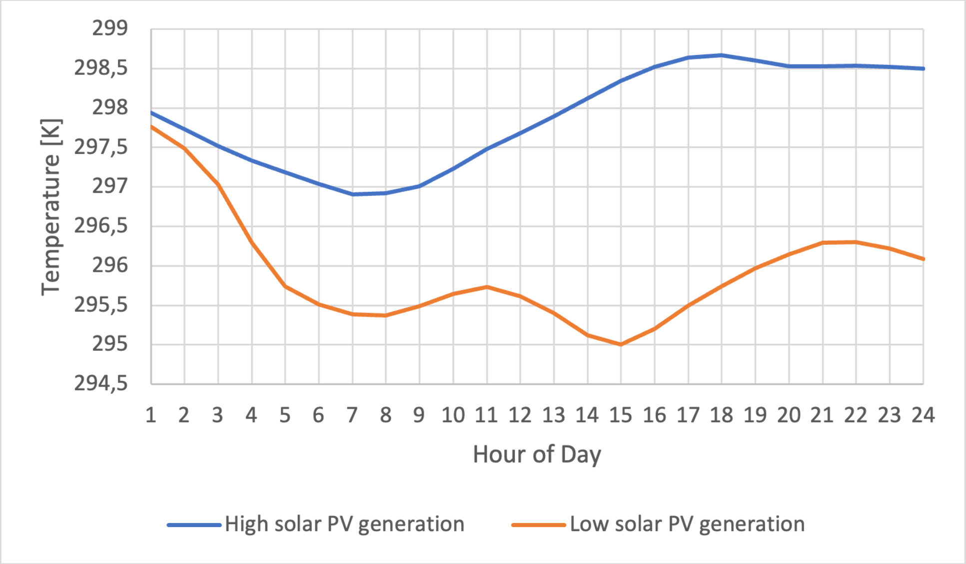

Figure A.4: How the temperature changes during the day for the different solar PV generation cases.

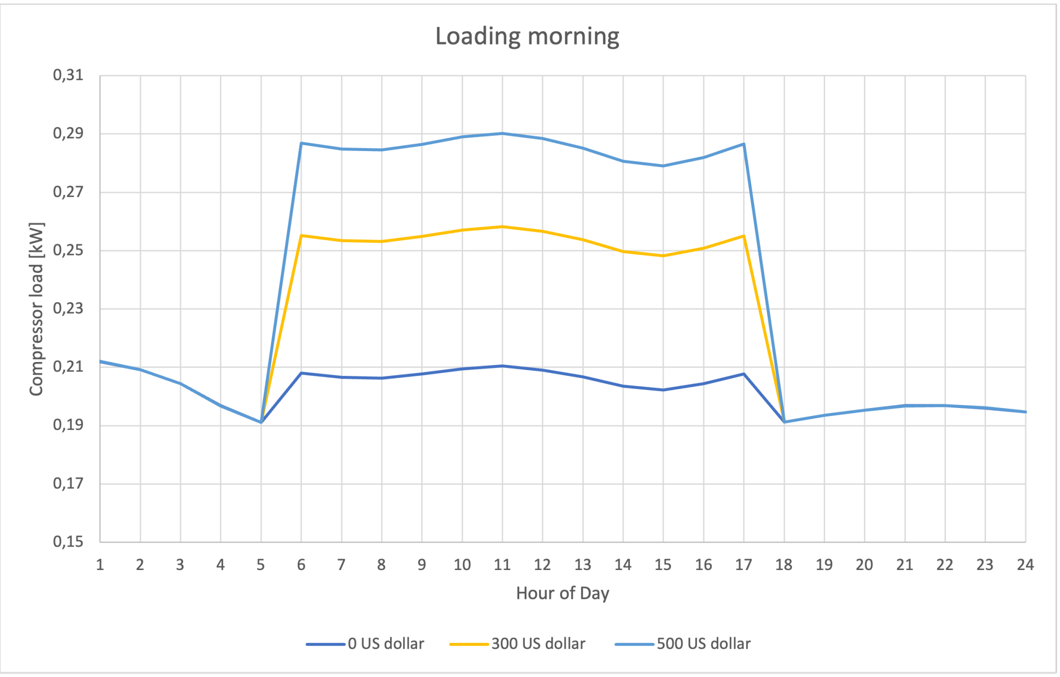

Figure A.5: The compressor load when loading the cooling room with fish in the morning.

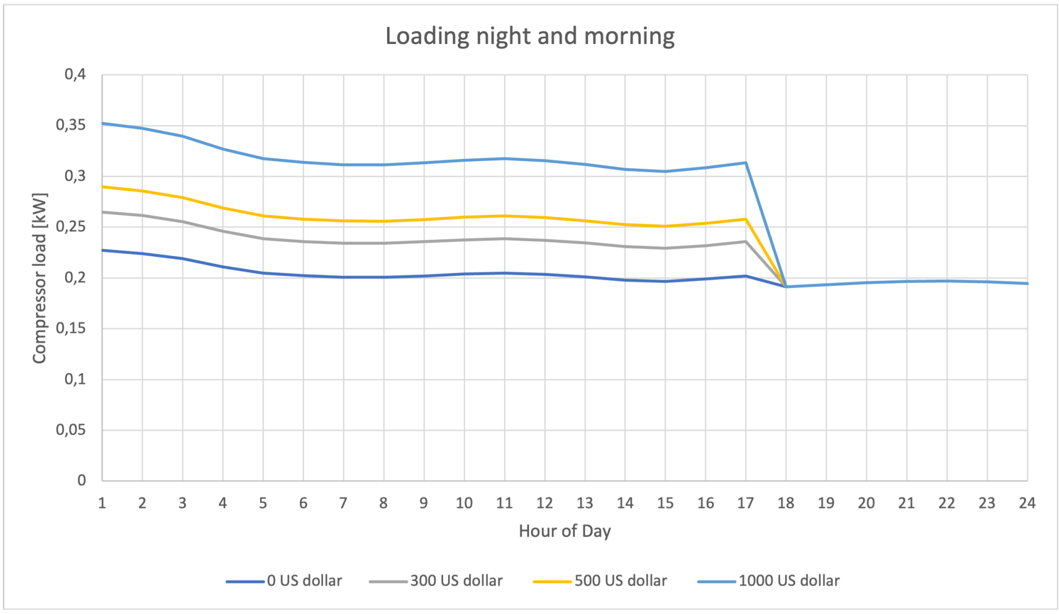

Figure A.6: The compressor load when loading the cooling room with fish in the night and morning.

Month	Precipitation [mm/month]
January	81
February	129
March	133
April	159
May	85
June	14
July	18
August	31
September	98
October	180
November	255
December	145

Table A.1: Monthy precipitation per month in Bwisya in 2019 (, noa)

A.2 Causal Loop Diagram causalities and sources

Table A.2: The causal relationships, their description and sources for the causal loop diagram in Figure 5.2

Causal Relationship	**Description and source**
Reliability → Cold storage opportunities (+)	Reliability of electricity is a necessity to be able to have cold storage (Fishermen 3, 2022; Former cluster manager, JUMEME, 2022)
Cold storage opportunities → Cold storage utilization (+)	If people have the opportunity to use cold storage they utilize it (Former cluster manager, JUMEME, 2022; Fishermen 1, 2022; Fishermen 2, 2022; Fishermen 3, 2022)
Cold storage demand → Cold storage utilization (+)	If there is a demand, cold storage will be utilized
Cold storage utilization → Cold storage demand (-)	If cold storage is utilized, the demand decreases
Fish caught → Cold storage demand (+)	The more fish that is caught, the more demand for CS
Fish caught → Fish population (-)	When fish is caught the fish population decreases
Fish population → Fish caught (+)	If the population increases more fish is caught
Cold storage utilization → Ability to pay (-)	Logical assumption, when money is invested in cold storage the ability to pay decreases

Ability to pay → *Cold storage opportunities (+)*	When the income is increased, they can expand their business by investing in more cold storage (Fishermen 1, 2022; Fishermen 2, 2022; Fishermen 3, 2022)
Cold storage utilization → *Access to markets (+)*	Being able to store the fish gave them opportunity to sell in other markets (Fishermen 1, 2022; Fishermen 2, 2022; Fishermen 3, 2022)
Access to markets → *Spoilage in fish (-)*	Long distances to markets may cause higher losses if there are not enough buyers to buy the fresh fish (Assefa et al., 2018)
Cold storage utilization → *Spoilage in fish (-)*	An improved cold chain would lead to decreased spoilage (Fishermen 1, 2022; Fishermen 2, 2022; Fishermen 3, 2022; Chan et al., 2019; Prodhan et al., 2022)
Cold storage utilization → *Pressure to sell (-)*	They had to sell the fish quickly when they were not being able to store it (Fishermen 1, 2022; Fishermen 2, 2022; Fishermen 3, 2022)
Pressure to sell → Income (-)	When being able to store and not pressured to sell, they could increase the price (Fishermen 1, 2022; Fishermen 2, 2022; Fishermen 3, 2022)
Spoilage in fish → Income (-)	Being able to store what would otherwise have been wasted has increased the income (Gyan et al., 2020; Lukuyu et al., 2019; Fishermen 1, 2022; Fishermen 2, 2022)
Income → Ability to pay (+)	An increase in income increases financial opportunities (Jumeme costumer 2, 2022)

Electricity access → Cold storage opportunities (+)	Access to electricity gives the opportunity to use refrigerators or producing iceblocks to cool the fish (Fishermen 1, 2022; Fishermen 2, 2022; Fishermen 3, 2022; Nuru et al., 2021; Mramba and Mkude, 2021)
Electricity access → Value addition (+)	Refrigeration, drying, milling etc. by using electric equipment (Executive Director, ELICO Foundation, 2022; Head of Programmes and Operations, ELICO Foundation, 2022; Das and Behera, 2020)
Fish caught → Value addition (+)	The more fish that is caught, the more fish van be processed
Value addition → Income (+)	Drying fish using solar powered drying facilities increases the quality of the product and thus increases the price (Head of Programmes and Operations, ELICO Foundation, 2022)
Value addition → Spoilage in fish (-)	Improved drying of fish decreases spoilage (Kabahenda et al., 2009; Gyan et al., 2020)
Electricity access → Education (+)	Improved studying conditions for students and teachers when connected to electricity (Director and Founder, ENSOL (T) LTD, 2022; Site manager Power Corner, Engie, 2022; Nuru et al., 2021; Uamusse et al., 2019)
Education → Spoilage in fish (-)	Improved education has showed to decrease the losses of fish (Acharjee et al., 2021; Gyan et al., 2020)

Ability to pay → *Productive usage of electricity (+)*	The ability to pay positively influences the productive usage of electricity (Executive Director, ELICO Foundation, 2022; Jumeme costumer 2, 2022)
Costumer awareness → *Productive use of electricity (+)*	When costumers are aware of what electricity can do, they can use it for more productive uses (Executive Director, ELICO Foundation, 2022; Chair person TAREA, 2022)
Mini-grid investor awareness → *Costumer awareness (+)*	Mini-grid investors/operators need to be aware that they need to educate and create awareness for their customers. Investor awareness positively affects the costumer awareness (Executive Director, ELICO Foundation, 2022)
Mini-grid investor awareness → *Financial assistance (+)*	If the investor are aware of the needs in the community they can provide financial assistance (Executive Director, ELICO Foundation, 2022)
Financial assistance → *Productive use of electricity (+)*	Financial assistance helps more people to use electricity for productive uses (Executive Director, ELICO Foundation, 2022; Jumeme costumer 3, 2022; Cluster manager, JUMEME, 2022)
Mini-grid investor awareness → *Productive use of electricity (+)*	Investor awareness positively effects the productive uses since the investor know it will be profitable for them to promote productive uses (Executive Director, ELICO Foundation, 2022)
Productive use of electricity → *Profit from mini-grid (+)*	Productive users stand for majority of the profit from the mini-grid (Executive Director, ELICO Foundation, 2022; Hartvigsson et al., 2021; Pueyo et al., 2020)

Tariffs → Profit from mini-grid (+)	If the tariffs increase so does the profit, unless the tariffs are too low for there to be any profit at all (Cluster manager, JUMEME, 2022)
Financial assistance → Cold storage opportunities (+)	Techno-economic analysis
Productive use of electricity → Mini-grid capacity (+)	If productive usage of electricity increases the capacity needs to increase based on the techno-economic study
Mini-grid capacity → Mini-grid investment cost (+)	Increasing the capacity results in higher investment cost (Director and Founder, ENSOL (T) LTD, 2022; Abada et al., 2021; Hartvigsson and Ahlgren, 2018)
Mini-grid investment cost → Tariffs (+)	The tariffs are partly based on the investment cost of the mini-grid (Abada et al., 2021; Zomers, 2003)
Tariffs → Productive usage of electricity (-)	If the tariffs are high the usage decreases because it is expensive (Head of Operations, JUMEME, 2022; Jumeme costumer 2, 2022)
Reliability → Technician harassment (-)	Costumers blamed the local technician for the blackouts and threatened him (Local technician, JUMEME, 2022)

Table A.3: Description of the feedback loops for the causal loop diagram in Figure 5.2

Feedback loop	**Description**
R1	Cold storage utilisation → Pressure to sell → Income → Ability to pay → Cold storage opportunities
R2	Cold storage utilisation → Spoilage in fish → Income → Ability to pay → Cold storage opportunities
R3	Cold storage utilisation → Access to markets → Spoilage in fish → Income → Ability to pay → Cold storage opportunities
B1	Cold storage utilisation → Ability to pay → Cold storage opportunities
B2	Cold storage demand → Cold storage utilisation
B3	Fish caught → Fish population
B4	Productive use of electricity → Mini-grid capacity → Mini-grid investment cost → Tariffs

DEPARTMENT OF SOME SUBJECT OR TECHNOLOGY
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