National University of Lesotho

Analysis of the categories of the sustainability dimensions to achieve sustainable mini-grids

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Abstract

Taking into consideration the rise of mini-grids globally, their important contribution in reaching the universal access to energy goal, and the uneconomic costs of national grid extension to certain areas, it is only befitting that mini-grids are studied extensively. This study intends to find the variables of a sustainable mini-grid and what makes a mini-grid sustainable, analysed and identifies the sustainability of the different models of mini-grids and finally finds which mini-grid business model is sustainable and is better suited Lesotho in order to raise the countries electricity access and better the populations livelihoods. The study assesses the categories of four (the community-owned, private, Public-Private Partnership (PPP), and utility business models) sustainability dimensions of mini-grids across selected countries with similar conditions to Lesotho. It shows that for a mini-grid to survive throughout its lifetime it has to adequately satisfy the economic, environmental, institutional, social, and technical sustainability dimensions.

The developer-consumer and the multi-tier frameworks developed by James Knuckle (2016) and the World Bank (2015) respectively were used in the assessment of the categories of sustainability dimensions for all four mini-grid business models. With the help of the frameworks, the study findings show that the PPP and private mini-grids proved to be the closest models to sustainability in all the assessed categories and dimensions failing in the cash recovery and affordability categories respectively. They are followed by community mini-grids which fall back on some categories (cash recovery,tariff coverage of the operations and maintenance and tariff setting) for this reason are not sustainable. The PPP model has similar operations to utility mini-grids, as suggested by the frameworks, but has proven to be slightly better in a few categories. Utility minigrids are the furthest from sustainability of the studied mini-grids. They failed in the cash recovery category, failed to have tariffs covering their O&M cost, have low tariff settings and have limited power supplied to their customers.

From the already existing research on mini-grid models in Lesotho, suggestions are provided for Lesotho and its upcoming mini-grids. The study shows that a combination of private and community mini-grids is found to be the best uptake provided there are subsidies to help people afford the cost-reflective tariffs.

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Acronyms and abbreviations

BM	Business Models
COMGD	Community-owned Mini-grid
ESMAP	Energy Sector Management Assistance Program

GHG	Greenhouse Gases
IEA	International Energy Agency
IPP	Independent Power Producers
IRR	Internal Rate of Return
IRENA	International Renewable Energy Agency
L.E.C	Lesotho Electricity Company
LREEAP	Lesotho Renewable Energy and Energy Access Project
MOSCET	Mos-Sun Clean Energy Technologies
MTF	Multi-Tier Framework
NUL-ERC	National University of Lesotho- Energy Research Centre
O&M	Operations and Maintenance
PMGD	Private Mini-grid
PPP MGD	Public Private Partnership Mini-grid
PUE	Productive Use of Electricity
SSA	Sub-Saharan Africa
SDG	Sustainable Development Goals
SE4ALL	Sustainable Energy for All
UMGD	Utility Mini-grid
UN	United Nations

1 Introduction

This chapter gives a brief background of the research that evolves around mini-grids and their importance in energy access. The chapter also presents the problem statement, the research question and objective and the significance of the study. The advancements of mini-grids in Africa and the world, with a focus on Lesotho in particular, are also briefly laid out in this chapter.

1.1 Background

A number of countries have gained faith in renewable energy technologies because of their ability to reduce both environmental and energy-related problems, mostly because of their lower CO_2 emissions and costs , (Gross *et al.*, 2003; Jebli *et al.*, 2020). The decrease in renewable energy production costs also makes them more favoured, with large solar PV prices, as an example, decreasing by 89% over the 10 years between 2009 and 2019 and the lithium-ion batteries accompanying the PV systems decreasing by 97% since 1991 (Ro, 2022).

The provision of electricity is an important aspect of any country's economic growth and the bettering of its population's well-being. Its presence helps lower the poverty rate and advances the education and health sectors as well as the livelihood of people. Despite this, as of 2021, there were 759 million people out of 7.89 billion around the world who still lacked access to electricity (Antonanzas-Torres, Antonanzas and Blanco-Fernandez, 2021).

Electricity prices are expected to increase by 2030 due to fossil fuel and CO_2 price rises (Panos and Densing, 2019), thus further making electricity access to the remaining un-electrified areas a hustle. One other problem faced by these areas is the cost of grid expansion. According to Taele *et al.* (2012), grid expansion in Lesotho cost an average of $1500-$1800 per connection (between M12,000.00 and M14,000.00) within a 3.5km distance from the distribution line. It costs above $2250 (around M18,000.00) for distances beyond 3.5 km and even higher for areas with more complex terrain. Lesotho's electricity masterplan also shows that a new connection will cost M 15,000.00 (around $1133) per household (Hadjicostas and Padayachy, 2018). Due to these high grid expansion costs, mini-grids are increasingly becoming acceptable and are viewed as an integral option for achieving universal energy access to electricity (Bukari *et al.*, 2021).

Mini-grids are defined as stand-alone electricity generation and distribution over a network that supplies a local group or community (Knuckles, 2016). Their main purpose is to increase energy access and to provide affordable electricity to a wide range of consumers in the process. The hybrid stand-alone renewable energy mini-grids are increasingly popular due to their ability to work with or without the availability of some renewable energy resources.

Quite a large number of mini-grids fail. Globally an average of 60% of them fail within about six months of operation (Press, 2021) due to the regulatory issues, poorly forecasted demands and very high or very low payment rates. This situation, in turn, gives mini-grids a bad record of sustainability. Their sustainability depends on its ability to be properly maintained, its ability to cover operations and maintenance costs through tariffs and or subsidy schemes and its ability to cover the initial investment costs and its efficiency (Peters, Sievert and Toman, 2019).

There are four major mini-grid models (Duran and Sahinyazan, 2021):

- Utility Model: in this model, the mini-grid is owned and controlled by the utility company in the same way as it operates the main grid. These mini-grids are usually subsidised by governments since they are owned by governmental utilities. The Semonkong mini-grid is an example of a utility-owned mini-grid in Lesotho (Department of energy Lesotho, 2023).
- Private Model: this mini-grid model occurs when a private company creates, operates and maintains a mini-grid and directly sells to the consumers. The private company usually invests capital through equity and loans. An example of this type in Lesotho is that of OnePower at Ha Makebe (OnePower Africa, 2020).
- Community Model: Community models are usually created by non-governmental entities for the communities. The communities are responsible for the running and up-keep of the mini-grid. Their designs and implementation are usually done by hired, qualified professionals who get their capital investments through grants and community contributions. Two such mini-grids have been erected at Linakeng and Motete by a consortium consisting of the National University of Lesotho (NUL) Energy Research Centre (ERC), Mos-Sun Clean Energy Technologies (MOSCET) and Smart Village Research Group (Smart Villages in Lesotho Minigrids, 2020).
- Public-Private Partnership (PPP) Model: This model combines public and private key players. In this case, each key player operates a mini-grid for a certain period and passes over the operations to the other player/s. The Lesotho Renewable Energy and Energy

Access Project (LREEAP) is set to deploy mini-grids of this model in Lesotho (World Bank, 2023).

This study analyses the categories of sustainability dimensions (economic, environment, institution, social and technology) for the four models to determine which mini-grid model is best to employ in Lesotho, taking the terrain, financial costs, operations and maintenance costs as well as the output power of each mini-grid into account.

1.2 Problem statement

As of 2021 an average of 60% of mini-grids fail globally within about six months of operation (Press, 2021). The challenge with their failure is problematic since there are different mini-grid business models. Currently, there is no literature on the characteristics of any mini-grid model that guarantees ideal satisfaction of sustainability dimensions.

For countries such as Lesotho, which are just beginning to implement mini-grids, it is crucial to know which route to follow to mitigate against the high mini-grid failure rate. Lesotho is currently implementing a number of models without any informed decision. There are planned PPP minigrids under the LREEAP project (The World Bank Group, 2020) while MOSCET and the NUL ERC have just erected two community-owned mini-grids (NUL-ERC| Energy Research Centre, 2020). OnePower is also in the process of rolling out ten privately owned mini-grids (Onepower Lesotho, 2022).

Adopting different models does not ensure the sustainability of the mini-grids because if all minigrids are of different models and only a certain model(s) is found to be sustainable in Lesotho, this would imply that projects that do not adopt that model(s) will most probably fail. Being fully aware of the type of model to follow will help the success of mini-grids, hence rural electrification will rise. tremendously.

1.3 Research question and objectives

This subchapter concentrates on the research question and the objectives that aid in the answering of the research question. And the tools that will be used as the methodology in route to answering the research question.

1.3.1 Research Questions

As of 2021, 759 million out of 7.89 billion, globally, lacked access to electricity (AntonanzasTorres, Antonanzas and Blanco-Fernandez, 2021), while in Lesotho, 49.6% of people lacked access to electricity in 2020 (World Bank, 2023). It has been suggested that mini-grids could be the key factor to the breakthrough in solving this problem (Gollwitzer *et al.*, 2018; AntonanzasTorres *et al.*, 2021; Mpholo *et al.*, 2021). In the process of making this breakthrough, questions that this study intends to answer arise: what is a sustainable mini-grid and which is the best business model to implement to attain a sustainable mini-grid project in Lesotho?

This study is thus concerned with answering this question; it compares the models of mini-grids in terms of the sustainability dimensions (economic, environmental, social, institutional and technical dimensions).

1.3.2 Objectives

To answer the research question outlined in section 1.3.1, the following specific objectives are addressed:

- To define a sustainable mini-grid.
- To identify the variables that make a sustainable mini-grid.
- To analyse and identify the sustainability of the different models of mini-grids

With objectives are addressed and subjected to already existing frameworks being the developer consumer and the multi-tier frameworks to determine the sustainability of the sustainability of the mini-grids and mini-grid models regarding to how they perform based in the frameworks.

In answering the research question and following the research objectives the research study then gives recommendations to already existing mini-grids (unsustainable ones) on what to follow to make them sustainability.

1.4 Justification

Even though researchers around the world have studied mini-grids, no analysis has been carried out on which business model is the best to follow for countries similar to Lesotho, at least to the best of the author's knowledge. Studies that have been carried out mainly focus on the technical aspects of mini-grids. This study is intended to identify the aspects that make mini-grids sustainable.

According to Mpholo *et al.*, (2018), as of 2017, only 5.5% of rural households in Lesotho were connected to the grid, and the number was expected to rise to 14% by 2030 (Mpholo *et al.*, 2021). The low figures are due to the high grid extension costs in the rural areas (Taele *et al.*, 2012; Hazelton, Bruce and MacGill, 2014; Amutha and Rajini, 2016) hence mini-grids are more ideal to implement. Because mini-grids are identified as a solution to lack of access to electricity, this research study is intended to identify the best way to deploy and to operate mini-grids sustainably.

1.5 Dissertation organization

This dissertation is organised into five chapters. Chapter one is the introduction; it provides the background to the study, focusing on access to and the importance of mini-grids. The chapter also presents the problem statement, the research question and the objectives. Chapter two reviews the recent literature on mini-grids, their progression, downfall and their sustainability. The third chapter gives the methodology followed in the assessment of mini-grid sustainability and the data collection strategies employed. The fourth chapter presents the findings of the study and discusses them. The final chapter focuses on the conclusions and policy recommendations for Lesotho.

2 Literature Review

This chapter is concerned with the literature on mini-grids. It focuses on the recent studies on minigrids progression and challenges in the developing countries, mostly the Sub-Saharan African countries since they have the lowest electricity access percentages (Soares *et al.*, 2023). It reviews the studies on how to assess the mini-grid's sustainability. The definition of mini-grid models and their sustainability dimensions are also provided in the literature review. The mini-grid model differences are also explained in this chapter. The literature is focused on the developing countries, mostly the Sub-Saharan African countries since they have the lowest electricity access percentages (Soares *et al.*, 2023).

2.1 Mini-grids overview

The world still finds electricity access, affordability and reliability quite a challenge, particularly in the developing and under-developed countries' rural areas (Zebra *et al.*, 2023). The world energy outlook shows that Africa's electrification rate is at 45%, as compared to other continents such as Asia with an electrification rate of 94% from 2019 to 2021 (Byaro and Mmbaga, 2022).

Mini-grids provide an opportunity for the achievement of the United Nations (UN) energy-related SDG (SDG 7) and reaching one of the Sustainability for All (SE4All) initiatives towards universal access to electricity by 2030 (Peters, Sievert and Toman, 2019). Due to their low costs, they are projected by the World Bank as the least costly solution to electrification and grid quality and to providing electricity to over 60% of the unelectrified areas in Africa (ESMAP, 2019; IEA *et al.*, 2019).

2.1.1 Status quo

In pursuit of electrification and in the light of mini-grids being regarded as the way forward, many countries have created suitable environments for mini-grids enabling them to be better and to increase the electrification rates of the various countries. This subsection reviews the literature on the different initiatives that the Sub-Saharan African (SSA) countries have made for the progression of their mini-grids.

According to Farahmand-Zahed *et al.* (2020), the International Energy Agency (IEA) showed that to reach the 100% electrification rate by 2030, grid extension has to get a 30% increase and minigrids and other decentralized energy systems need to share the remainder. This shows that minigrids and other decentralized energy systems are to be given priority in the improvement of electrification. For this reason, there needs to be a lot of improvement in their systems in order to perfect the mini-grids.

One of the problems that mini-grids face and that slows down their advancements is the cost to the consumers. Mini-grids usually have lower connection fees as an incentive to attract potential customers. The heavy investment costs are recovered from high tariffs. Bahaj *et al.* (2019) show that mini-grids tariffs are higher than the main grid even though the mini-grid is only catered to making enough money to cover its operational costs.

Costly appliances further increase the struggle of the mini-grids. People do not use all the power at their disposal because they cannot afford to buy appliances; this creates a ripple effect that leads to the mini-grid economic sustainability being affected. As a solution, the mini-grids in Kenya and Tanzania have since offered users credit for connection and credit to buy appliances as a way to increase their demand and the number of connections, the credit programme showed a 66% increase in consumption (Lukuyu *et al.*, 2021).

One of mini-grids greatest progress is brought about by the advancement of technology. Developers are now greatly helped by technology; it presents another solution for demand and supply. The software, such as HOMER, that forecasts the demand, is used by developers for their ability to simulate the performance of the planned system. It also simulates the supply of the energy of the system throughout the lifetime of the system and optimises the system by sizing for the ideal achievement of the system economic state (Shahinzadeh *et al.*, 2016). The use of the software has since made mini-grids avoid failure by reducing the over and under-sizing of the systems.

2.1.2 Challenges that lead to failure

Most mini-grids (globally) fail and get decommissioned within their first six months of operation (Press, 2021). To combat this issue, developers such as Alpha and Beta of Kenya come together to create a "symbiotic partnership". In this partnership, Alpha uses Beta as its supplier in its projects and Beta uses Alpha as a contractor in its projects (Pedersen and Nygaard, 2018); this helps either and/or both to finish their projects and to avoid failure which, in turn, gives a good reputation for mini-grids and results in their growth.

In as much as mini-grid deployment over recent years has been rising with over 19000 mini-grids installed in 134 countries as of 2019 (ESMAP, 2019), mini-grids are still held back by a few aspects that give them a bad reputation. According to Wassie and Ahlgren (2022) mini-grids in developing countries are mostly unreliable, underperforming or even abandoned. Wassie and Ahlgren state that mini-grids in Ethiopia, for example, suffer in terms of reliability and performance due to the fact that research studies done are mostly on grid-connected grids and not off-grid systems. Because of this situation, there is little known about the performance and reliability of off-grid systems in order for their performance problems to be countered. As a result, development and improvement of the off-grid mini-grid systems is hindered. This leads to the failure of the mini-grids hence the slow progress of rural electrification.

Furthermore, most studies give more attention to the technical aspects concerned with the minigrid functioning over the social aspects to do with its viability (Zebra *et al.*, 2023). Social aspects such as community acceptance and community participation in the mini-grid are important aspects of mini-grid sustainability. They need careful consideration. To show the importance of community participation, Gill-Wiehl *et al.* (2022) found that community participation is globally seen as essential to a project's sustainability. They furthermore show that the participation of the community in mini-grids appears in the operations and maintenance phase (mostly done by community-owned mini-grids), where the community is taught about minor grid maintenance and thus contributes largely to the sustainability of the mini-grid. There are small savings of money in having the community do minor maintenances over hiring expensive experts all the time.

Some mini-grids face challenges such as the inability to maintain a steady cash flow and satisfactory revenue returns for the sustainability of the projects. As a result of a lack of appropriate skills, mini-grids are more dependent on public funds, subsidies and donations (Wen *et al.*, 2023). Due to the challenges that face mini-grids, their progress is very slow, Wen *et al.*(2023) observe that independent studies carried out by the World Bank, IEA and the International Renewable Energy Agency (IRENA) find that if mini-grids continue at the current pace, about 660 million people will still lack access to electricity by 2030 by 2030. This will be interpreted as a failure to achieve SDG 7 by 2030.

Political instability in countries that are in need of mini-grids is another challenge (Bukari *et al.*, 2021; Soares *et al.*, 2023). According to Soares *et al.* (2023), political stability plays an important role in mini-grid implementation and could drive away investors as was the case in Mozambique. Investors are driven away mostly by the fact that renewable energy projects are long-term investments. If there is an instability, such projects are liable to abandonment in the long run.

The financial capacity of developing countries also affects mini-grid sustainability. According to Suri (2020), there is uncertainty about financial returns in mini-grid installations for the rural areas due to them being less energy intensive than they would be if put elsewhere. Thus there is a low return on mini-grid project investments. For this reason, it is important to create employment or businesses for people using electricity to help in the generation of income (Hartvigsson *et al.*, 2021).

2.2 Sustainability dimensions and their categories

The sustainability of a mini-grid shows its ability to be properly maintained, its ability to cover operations and maintenance costs through tariffs and or subsidy schemes and its ability to cover the initial investment costs and its efficiency (Peters, Sievert and Toman, 2019). Irrespective of the implemented business or ownership model, the sustainability of mini-grids is done across five dimensions. A mini-grid is considered sustainable if it adequately satisfies each of the five dimensions, the economic, environmental, institutional, social and technical dimensions (Tozzi, 2018; Katre, Tozzi and Bhattacharyya, 2019). The addition of technical and institutional dimensions is done when the assessment is of renewable-based grid services (Poudel, Parton and Morrison, 2022).

The economic, environmental, social, institutional and technical dimensions of assessing the sustainability of mini-grids are broken down into 11 categories (for the purpose of this research study). They are discussed and the categories of each of them are given. The categories are discussed from section 2.2.1.1 through section 2.2.5.4 and an elaboration on how each affects sustainability as well as the importance of each are given.

The mini-grid is sustainable only if all the five dimensions are sustainable. Each dimension is considered sustainable if it is carried out as follows (Tozzi, 2018; Katre, Tozzi and Bhattacharyya, 2019):

2.2.1 Economic Dimension

This dimension measures the cost-effectiveness of the project business model in assessing whether the presence of a mini-grid provides or generates income for its users. It is mostly directly concerned with consumers because some of the mini-grid models such as the community-owned models are not into profit-making. Although they are not into making a profit, the money made by the community should at least cover the Operations and Maintenance (O&M) costs of the minigrid to keep it running.

The economic dimension of a mini-grid for this research study has several economic parameters. These include the economic viability of the mini-grid and its capital recovery time), the O&M costs, the mini-grid ability to stimulate productive use of electricity amongst its users, and the tariffs setting.

2.2.1.1 Category 1: Cash Recovery

According to Aziz and Chowdhury (2012), the salvage value of the mini-grid for a sustainable mini-grid is expected to be around 20% of the initial investment cost. The investment recovery time is expected to be 15 years. Tariff setting plays an important role in the economics of the minigrid. From the tariffs, the financial indicators such as the Internal Rate of Return (IRR), the capital investment recovery times and the equity returns are calculable (Kapole, Mudenda and Jain, 2023).

Viability, one of the categories of the economic dimension, is determined by the mini-grid ability to operate throughout its lifetime and to successfully conduct its operations. Economic viability is an important factor in the viability context. The economic viability of a project is its ability to attain funding or to cover its capital investment and O&M costs from its generated revenue for the entirety of its lifetime. It should further be able to have an adequate rate of return for the investment cost coverage (Kapole, Mudenda and Jain, 2023). Customer identification is an important factor in the mini-grid economic viability since the mini-grid depends on its customers for money making. Mini-grids can provide electricity to a large variety of customers. They can supply households, health and community centres and public offices. The ability of the mini-grid to have largely dense connections or just one large consumer such as a factory can promote economic viability (Chaurey and Kandpal, 2010; Knuckles, 2016).

2.2.1.2 Category 2: Operations and Maintenance

The sustainability of the mini-grid also relies on its operations and maintenance. A plant needs good maintenance which includes the change of batteries and inverters, when the time comes, and the replacement of charge controllers (Kapole, Mudenda and Jain, 2023).

McMorland *et al.* (2022) show that there is a balance between the mini-grid operational expenditure and the opportunity cost of a plant in relation to its capacity as seen in Figure 1. The plant opportunity cost is the money that is lost due to failure and or the revenue that the plant could have made if there were no unexpected problems. Figure 1 shows that for a mini-grid of higher capacity, even the smallest expenses on maintenance present a large opportunity cost for a plant; for this reason, operations and maintenance affect the plant's sustainability since they drain the farm’s revenue.

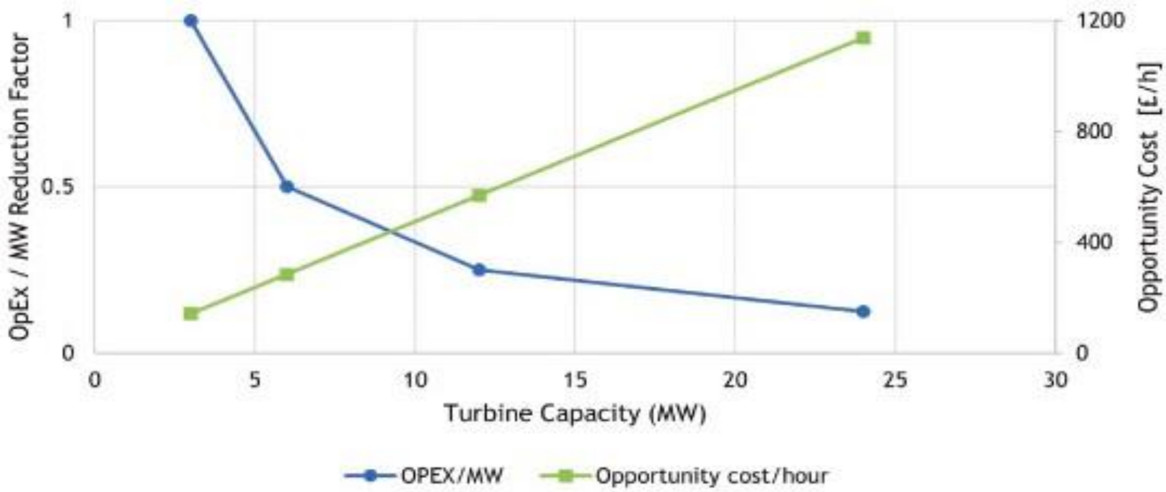

Figure 1: Operations and maintenance relative to the opportunity cost

Similarly, Aboagye *et al.* (2022) shows that maintenance plays an important role in the performance of solar mini-grid and that if done improperly it affects the performance of the system. They found that their systems of selected mini-grids had 14.5% of installed capacity due to poor maintenance practices and that more than 50% of their customer base experiences performance problems. This leads to the mini-grid being technically unsustainable. The loss of money due to the lost capacity also leads to economic unsustainability.

2.2.1.3 Category 3: Productive use of supplied electricity

Mini-grids struggle a lot because of their customers' inability to afford them. Their customers are of low-income status. For this reason, they are far from the economic sustainability (Kapole, Mudenda and Jain, 2023). This brings the concept of productive use of electricity into the picture. Productive use of electricity is the use of electricity for the production of goods and services that generate income or that are of value. Productive use of energy can be in agricultural, commercial or industrial forms (Hartvigsson *et al.*, 2021; Little and Blanchard, 2022). According to van Hove, Johnson and Blechinger (2022), if mini-grids are more specific and put more effort into the productive use of their electricity there would be lower risks of the failure of mini-grids.

Productive use of energy is a sustainability determinant here because the lack thereof becomes a financial constraint to the sustainability of the mini-grid (Domegni and Azouma, 2022). People in rural areas find it difficult to afford electricity although it is beneficial to have a source of income created by the presence of the mini-grid to pay for electricity used. Productive use of energy is an important link between electricity consumption and rural development (Hartvigsson, Stadler and Cardoso, 2018). Thus the sustainability of the mini-grid has a dependence on the productive use of the energy for the consumer.

2.2.1.4 Category 4: Tariff setting

The buying power of an individual or a group of people shows the availability of money for purchases. This is important in the sale of electricity. If a developer intends to make a profit from the sale of electricity, it is in their best interest to know whether the consumers have enough buying power or willingness to pay. The insufficiency of buying power may affect the livelihood of the mini-grid and it is important in tariff setting. Tariff setting also sets a good pathway to the sustainability of a mini-grid. A balance between cost recovery, the cost of electricity supply and the average income of the supplied population can be reached by setting the tariff accordingly. A study conducted in Ghana by Bukari *et al.* (2022) showed that properly designed tariffs, with an application of tariff regulations already operational in the country, can lead to improved financial performance and guaranteed sustainability of a mini-grid.

Willingness to pay is linked with a person's how much each person earns and their expenditure rate. For this reason, it is best to know each household's expenditure and thus learn their willingness to pay for the electricity provided by the mini-grid (Riva *et al.*, 2018; Zebra *et al.*, 2023). Riva *et al.* (2018) show that in as much as the expenditure is important in the determination of the household's willingness to pay for electricity, the quality affordability and reliability of the supplied power also play an important role in determining the willingness to pay for electricity. According to Mpholo *et al.* (2020), electricity is affordable for a household if its consumption is less than 5% of their income. Such a family is considered electricity-poor. Knuckles (2016) demonstrates that tariff setting has led over 70% of utility companies to operate at a loss in SubSaharan Africa. This is because utility companies, as stated by Knuckles (2016) are required to charge new rural customers a fee similar to the national tariff which does not recover the investment and operating costs, leading to slower energy access coverage, hence the need for an extensive study on mini-grids.

In line with Duran and Sahinyazan (2021), community-owned mini-grids have an increased social acceptance because of community inclusion and ownership and this leads to their high success. On the other hand, their tariff settings do not include inflation as the years go by. This makes them take a long time to recover their investment. This shows that when setting tariffs, affordability, adjustability and coverage of O&M should be considered.

2.2.2 Environmental Dimension

Environmental dimensions are measured on global and local scales. At the local scale, the measurement includes the indoor air quality of the household while at the global scale, the overall carbon emissions are the focus of concern. If the mini-grid presence shows a reduction in carbon emissions due to less usage of kerosene in the community and an improvement in the indoor air quality of the users of the mini-grid, then the mini-grid is sustainable in the environmental dimension.

This dimension has environmental sustainability which encompasses the improvement of indoor air quality (locally). At the global stage, the reduction of carbon emissions is due to the presence of the mini-grid.

2.2.2.1 Category 5: Environmental sustainability

According to Dong and Hauschild (2017), sustainability is defined (in an environmental context) as a way to meet the present needs without causing harm to future generations.

For mini-grids, environmental sustainability can also be put as an implication on the decrease of emissions of greenhouse gases, environmental damage and control of pollution (Kapole, Mudenda and Jain, 2023). This means that the mini-grid should be operational, meet the needs of the customers and be environmentally friendly. By so doing, the mini-grid will be in alignment with SDG 3, SDG 7 and SDG 11 (IEA *et al.*, 2019; WHO, 2023) which refer to good health and wellbeing, affordable and clean energy as well as sustainable cities and communities.

2.2.3 Institutional Dimension

As far as the institutional dimension is concerned, what is important in this area of interest is the governance of the mini-grid. The governance not only involves the mini-grid developers but the consumers as well. They need to have trust in the mini-grid developers for the governance to be considered effective; there should be a high level of satisfaction for the consumer concerning the service delivery and the tariff settings. There should be a degree of local ownership in the governance of the mini-grid. The institutional dimension has the viability of the mini-grid as its category.

2.2.3.1 Category 6: Viability

The African Development Bank (2020) indicates that when selecting a mini-grid site, the distance from the mini-grid and any planned grid expansions should be at least 23 km long to ensure the sustainability of the mini-grid. The accessibility and terrain of the area should also be considered. The terrain of the area has implications on the voltage lines to be used; there is a difference in voltage between the mountainous and the flat places. This affects the capital expenditure of the mini-grid. Accessibility in terms of roads also has an impact on the mini-grid sustainability because the lack thereof creates more problems and increases capital investment. This leads to the minigrid being technically unsustainable. The loss of money due to the lost capacity also leads to economic unsustainability and affects the sustainability of the mini-grid.

For a mini-grid to succeed through its lifetime, there are a few aspects that should be considered. The presumed time frame of the arrival of the main grid is then followed by the terrain of the place of the mini-grid deployment, whether the main grid poses a threat to the mini-grid or not and customer identification.

2.2.4 Social Dimension

Social sustainability measures the well-being of the households that the mini-grid supplies with electricity as well as the connectedness of the community being supplied. The well-being is mostly related to child education enrichment because of the mini-grid, the health and safety of the households and public areas due to the presence of the mini-grid. If the households and the community are seen to be safe and healthy and the education of children seems to be improving due to the presence of the mini-grid and the community has an increased sense of connection as well as being included in the governance of the mini-grid, then the mini-grid is said to be sustainable in the social dimension.

The social dimension has community engagement which includes customer satisfaction and household connectedness as its categories.

2.2.4.1 Category 7: Community engagement

Community participation is an important aspect that affects the mini-grid sustainability (GillWiehl *et al.*, 2022). To enforce this concept, Zebra *et al.* (2021) show that in practice project interaction with locals is highly a determinant of the project sustainability.

Community engagement is important for the success of the mini-grid. It gives the community a sense of ownership, regardless of the mini-grid model. For this reason, it helps the mini-grid to avoid system failures that could be brought about by the community itself (Zebra *et al.*, 2023). The engagement should be considered from the infancy of the system to ascertain the sustainability of the project; it also leads to the acceptance of the mini-grid.

2.2.5 Technical Dimension

The technical dimension measures the operations of the mini-grid from inception throughout its lifetime. For a mini-grid to be sustainable in this dimension, it needs to be able to meet the present and future energy needs of the people who are being provided with electricity for commercial or domestic use. This dimension focuses on household energy consumption, the domestic supply of electricity and public lighting all of which constitute or raise the safety of the community. Moreover, usability, reliability, affordability, quality and capacity also indicate the technical dimension. The benchmark of these is set by the Multi-Tier Framework (MTF) developed by the World Bank (The World Bank Group, ESMAP and Climate investment funds, 2015).

The technical dimension is divided into four categories and these include availability, capacity, quality and reliability of the supplied electricity.

2.2.5.1 Category 8: Capacity

The capacity of the mini-grid determines how many people can be connected to it. Developers then do a load profile for the assessment of the demand and the capacity needed to be supplied. A load profile is defined as the demand of the energy system for power over the lifetime of the system (Narayan *et al.*, 2020). Load profiling is very helpful in the sustainability and the system sizing of the mini-grid. This saves the equipment and the project spending. System load profiling helps the designer not to prevent the oversize or undersize and finds the optimal capacity needed for the system (Narayan *et al.*, 2020).

2.2.5.2 Category 9: Availability

Electricity availability is defined in terms of whether there is sufficient good quality electricity available for consumers and whether there is adequate generational capacity (Best and Burke, 2018). This shows that for a mini-grid to be considered available to its customers it has to give adequate electricity for the consumer’s consumption and has the means of improving its capacity.

For this reason, the electricity availability of a mini-grid is an important issue to consider when assessing the sustainability of a mini-grid.

2.2.5.3 Category 10: Quality

The direct and technical quality of electricity is linked to the safety of the customers. The power quality, availability and reliability go hand in hand as far as mini-grids are concerned (BaringGould *et al.*, 2016); that is, they have similar importance. Power quality refers to electricity-related nominal of voltage, harmonics and frequencies and how the variations affect the operations from the generation through to the user (Energy and Petroleum Regulatory Authority, 2021). Power quality is linked to the appliances' compatibility with the supplied electricity and the potential risk of damage that the electricity can cause to the appliances if it exceeds the set threshold.

2.2.5.4 Category 11: Reliability

Mini-grid reliability relates to how often a mini-grid has disruption of the supplied electricity (ESMAP, 2022). Regular disruption leaves customers without electricity and shows a lack of reliability for the mini-grid. Antonanzas-Torres, Antonanzas and Blanco-Fernandez (2021) exhibit that mini-grids in the SSA are negatively affected by frequent disruptions. Disruption of electricity affects the mini-grid sustainability. It is a category under the technical dimension and if the minigrid has more disruptions than the quota of 14 per week, the mini-grid becomes technically unsustainable.

2.3 Mini-grid Business Models

Mini-grids have a variety of business models and getting the choice of model deployment right is seen as an important aspect of a successful diffusion of mini-grids across rural Africa (Ogeya, Muhoza and Johnson, 2021). The differences between these mini-grid business models are explained as follows:

a. **Community owned mini-grids**

The community-owned mini-grid is owned by the community which the mini-grid serves. The community manages the grid for its benefit (Green Mini-grids Development Programme, 2016). Community mini-grids are usually financed through grants and help from the community through small contributions such as land, labour and materials (Zebra *et al.*, 2021). The tariffs set through this model are only for operations and maintenance costs. They are not profit-oriented business models and for this reason, scaling up is problematic since no profit is made. A team is selected from the community to oversee the operations and an external company is usually hired to maintain the plant. The community is taught about operations and minor maintenance to avoid the costs of professional maintenance companies for minor maintenance.

In this model, the community participates in the decision-making and management of the mini-grid. Community participation is an important aspect of the community-owned minigrid. The community is involved in the planning through implementing and running the minigrid. The community takes ownership of the energy supply and manages it in a way that meets its specific needs (Katre, Tozzi and Bhattacharyya, 2019). Community mini-grid developers conduct many community meetings before inception; for that, they are very particular with socio-economics. Community involvement is a great social, economic benefit for the community itself. This model relies on the community being able to pay tariffs for it to keep running. Therefore, during the mini-grid inception, the community is provided with opportunities that either expand the businesses or present them with ways to have employment or businesses in order to pay for the mini-grid so that the system may be well maintained (Safdar, 2017).

Community-owned mini-grids face several challenges compared to their counterparts. The challenges include financing since they rely on grants for their kick-start. Since communityowned mini-grids rely on the community members for minor maintenance they also face quite a number of technical challenges. They need to outsource external expertise on major issues since the community can only be educated to a certain extent.

b. Private mini-grids

The private mini-grids are usually built by private investors who own and operate the minigrid independently. This mini-grid model is financed through the developer's sourced funds (grants and loans). Consumers find electricity costly and hard to supply as the government does not offer subsidies to help the customers (Green Mini-grids Development Programme, 2016; Pedersen and Nygaard, 2018).

Private-owned mini-grids are a new business model in the SSA. Pedersen and Nygaard (2018) indicate that private-owned mini-grids began in Kenya in 2011 and are making a rapid expansion across all other SSA countries.

Private mini-grid challenges revolve around their risk management, capital cost and policy environment which affect the scalability of privately owned mini-grids (Bandi *et al.*, 2022). Since their capital cost needs to be recovered and profit made, there needs to be high-risk management. They also benefit from the policies of cost-reflective tariffs in countries of deployment. Bandi *et al.* (2022) argue that the private sector involvement in the mini-grids may prove helpful in the achievement of the SDGs despite the challenges that the private minigrids face.

c. Public Private Partnership (PPP)

PPP mini-grids are a collaboration between governmental agencies and the private sector. In this model, each key player has a responsibility (Safdar, 2017). Governmental institutions provide the needed framework, policies and regulations to follow. They provide financial assistance either from the government's pocket or from grants or other forms of funding (where they can). The private sector's key role in this collaboration is the capital investment, operation of the mini-grid, and provision of technical expertise. The private sector in this model owns the mini-grid since it is responsible for its maintenance and operations.

The PPP model brings together different institutions and the strengths of both of them to achieve a common goal. This model also reduces the risks involved in mini-grid deployment in the private sector since the government provides policies, financial help and regulations for the mini-grid to avoid failure. The PPP model mini-grids are the most easily scalable mini-grid model in terms of financing. However, due to a few parties involved in the mini-grid inception, they are the hardest to upscale; they involve regulation change when upscaling and coordinators (being many) may not see eye to eye.

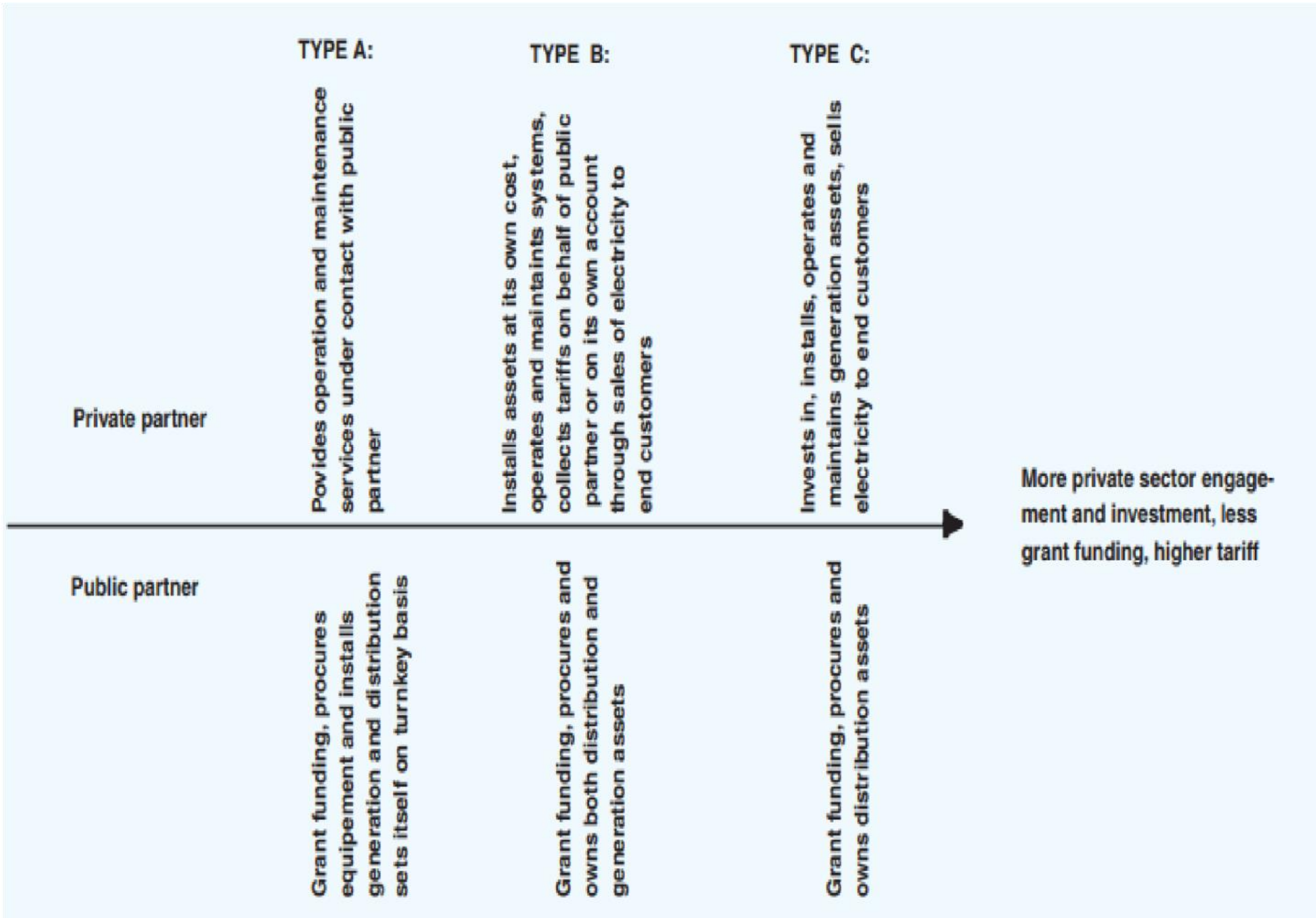

Figure 2 shows the PPP model's interaction between the private and public sectors, and what each sector does as its responsibility.

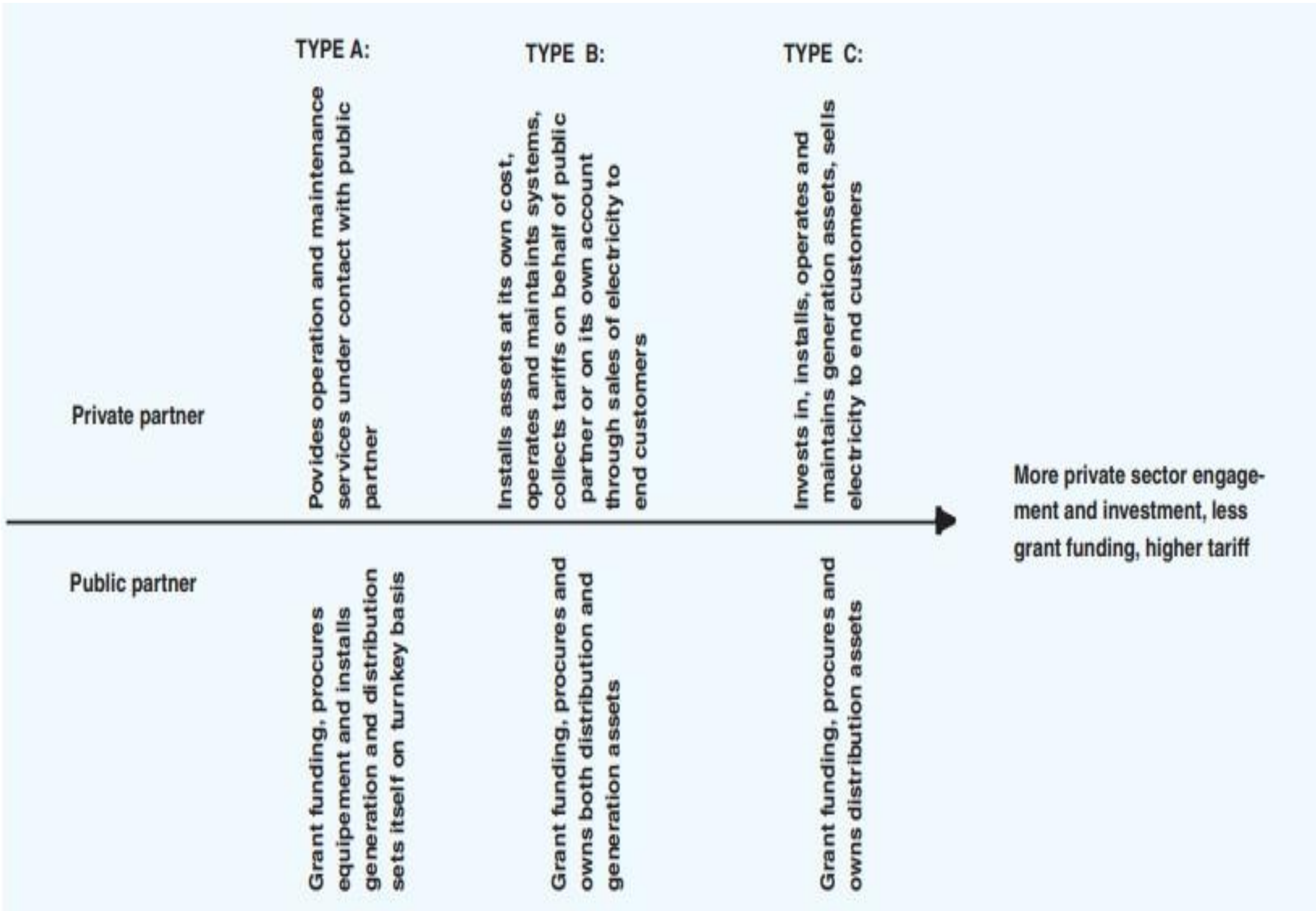

Figure 2: The interaction between the private sector and government in the PPP model

d. Utility owned mini-grids

Utility mini-grids are owned by the utility companies. When the utility is solely responsible for the rural electrification of the country it is at its discretion whether to build a mini-grid or to expand the existing one due to the conditions involved in each. Utility mini-grids make their presence in cases of dispersed settlements that are costlier to connect to the main grid. In this model the utility company is responsible for the installation, the O&M, the running of the mini-grid as well as the collection of the tariffs (Safdar, 2017).

Utility mini-grids are often inclined to charge their customers the same tariffs as those charged to the national grid customers and because of the mini-grid inception, national grid users crosssubsidize mini-grid users. In as much as the national grid users cross-subsidize the mini-grid users, the initial financing is usually from the government or other sectors affiliated with the grid at its inception (Safdar, 2017).

For a mini-grid to be sustainable, it needs to meet the sustainability dimensions mentioned in Section 2.2; that is a mini-grid has to be economically, environmentally, institutionally, socially and technically sustainable.

2.4 Arrival of Main Grid

The arrival of the main grid poses a threat to the mini-grid. Six possible actions can be taken upon the arrival of the main grid in an area where the mini-grid is operational (Energy Sector Management Assistance Program, 2018). The mini-grid could be:

- turned into a **small power producer (SPP)** where the mini-grid sells electricity to the main grid and not to the consumers
- turned into a **small power distributor (SPD)** where the mini-grid buys from the main grid at wholesale prices and sells to the consumers without the mini-grid being involved in the generation
- turned into an **SPP+SPD**
- operating **Side-by-side but not interconnected**
- **Compensated and exit** strategies made
- **Abandoned,** abandonment poses the highest threat to the mini-grid.

2.4.1 Regulation

Since this research study is conducted as a benchmark for mini-grids to be deployed in Lesotho, it is only befitting that the regulation of the country on mini-grids is reviewed. This subsection briefly gives the regulation of mini-grids and regulation upon confrontations of mini-grids and the main grid in Lesotho.

On 27 January 2021, the government of Lesotho released a government gazette on the regulation of mini-grids regarding their generation, distribution and supply (Lesotho Electricity and Water Authority, 2021). According to the Gazette, the purpose of the Lesotho Electricity and Water Authority (LEWA) is to provide the regulatory framework for mini-grids to facilitate the achievement of universal electricity access. Secondly, regulation is intended to give guidelines for the promotion, usage and development of the mini-grids.

The government gazette shows a strict rule concerning the quality of electricity from the mini-grid and shows that there should be accountability and reporting from the mini-grid in cases of voltage imbalances, transients by lightening, both frequency and voltage variations, noise and many other quality-related matters. Power availability is also an important aspect of the quality of electricity. The mini-grid is also held accountable for the number of hours of available electricity in a day as well as the reliability (frequency and power outages).

Lesotho regulations state that the main utility grid is not allowed to make a connection in areas where there is an existing mini-grid and if there is a case where that happens the mini-grid, as mentioned in Section 2.4, can continue operations side by side the main grid, become an SPD, become an SPP, become a combination of SPD and SPP or decide to be bought out by the main grid and transfer all its assets to the main grid. If there is no agreement between the mini-grid and main grid upon their confrontations, the final decision lies with the Authority on what happens and the Authority has a final say in that case.

2.5 Synthesis of the Literature

The literature gives elaborate descriptions of mini-grid models and their major differences, sustainability and the dimensions needed to be followed for a mini-grid to be sustainable. The literature further shows the regulations surrounding mini-grids and their encounters with the main grid. However, to the best of the author's knowledge there is a gap in literature on Lesotho on what would be a suited and sustainable mini-grid model to follow given the country's economic status, terrain and regulations.

Because of the high rate of failure of mini-grids globally this study was intended to find the ideal mini-grid business model that guarantees sustainability to be employed in Lesotho. Since the country is about to have a roll out of mini-grids of different models this study may mitigate the failure rate and give the country its suited mini-grid model with the country's characteristics in mind. The study furthermore may curb the failure of mini-grids that will be deployed in the country by showing that mini-grids of certain model(s) are or are not suited for the country. Being fully aware of the model to follow may help in the success of mini-grids hence rural electrification may rise.

3 Methodology

This chapter concentrates on the methodology considered in the assessment of the mini-grids sustainability. The assessment is carried out using the sustainability dimensions through their categories, as tabled out in Section 2.2, with observations of operational mini-grids. Lesotho has the most recent mini-grids in the study; they are included because the objective of this study is to inform the effective implementation of mini-grids in Lesotho. The study assesses mini-grids of different operational timelines because according to the employed frameworks, one should be able to tell whether a mini-grid will be sustainable regardless of how long it has been in operation.

3.1 Case Studies

The total number of mini-grids analysed in this study is sixteen, four for each business model. Given the limited dataset on mini-grids in developing countries, this number enables one to determine a trend in the operations of the mini-grid. The chosen mini-grids were selected because of the different characteristics that they offer. Such characteristics include their attention to the provision of productive use of electricity to their consumers, their tariff settings which make them suitable for study and the satisfaction feedback brought about by their users. The countries of deployment of these mini-grids show similarities to Lesotho in terms of their geographical landscape and share of rural population to the total population.

3.2 Data Acquisition

The data used in this study was acquired from interviews with mini-grid developers, experts in mini-grid deployment and the published literature.

The sixteen mini-grids that were discussed in this study are in India, Kenya, Lesotho, Tanzania, Uganda and Zambia. Three (two community owned and one PPP models) of the mini grids are in India, three in Kenya (two utility owned and a private model), Lesotho has two mini-grids (utility and private models). In **T**anzania three mini-grids (PPP, Private and utility) are analysed, Uganda has two PPP models and three mini-grids are in Zambia with two being community owned and one privately owned.

India is the only non-SSA country was considered in this research study. It is part of the study due to its similarity to Lesotho in the percentage of rural population and rural terrain. These characteristics made it get through the selection criteria because people in need of mini-grids are in rural areas where the main grid finds it hard to reach and thus the terrain plays an important role here. Moreover, the Indian mini-grids were chosen because of their success. Their deployment and their customer satisfaction could be a good example for the mini-grids to take place in Lesotho. Apart from being in the SSA region, Kenya, Uganda and Zambia were chosen because their minigrids had clear data to be used in the framework; moreover, Uganda and Zambia had low electrification rates of 45.2% and 46.7% respectively as of 2021, which are lower than Lesotho with a 50.4%. Kenya had a higher electrification rate of 76.5% which can be used as a good example for other countries (World Bank, 2023b).

Lesotho mini-grids considered here include the utility mini-grid in Semonkong and OnePower private mini-grid. These are the only mini-grids with enough ground operating experience for a sustainability check and conclusions.

Babayomi *et al.* (2023) demonstrated that the SSA region has 75% of the global unelectrified population amounting to almost 500 million people and these people live in the rural areas. This creates an opportunity for study and lesson learning for a few countries that are succeeding in their mini-grids in the same region.

3.3 Analysis of Framework and Modifications

The methodology followed was adapted from a framework proposed by James Knuckles (Knuckles, 2016). This methodology was selected due to its most important attribute of being able to assess both mini-grids that are in the planning process and those already operational, as opposed to some that only need a mini-grid to have been working for a couple of years to assess their performance, as in other methodologies (Katre, Tozzi and Bhattacharyya, 2019; Poudel, Parton and Morrison, 2022). The framework also uses a simpler system of scoring, assigning 1's and 0's for the analysed categories.

Since different mini-grid business models have different characteristics, the framework by Knuckles (2016) was adapted to fit the context of this assessment; the edition resulted in the model being of two parts, the developer consumer framework and the Multi-Tier framework. The first part of the model is the developer and consumer framework (

Table 1). The adaptations on Knuckles' (2016) framework, according to

Table 1 (the developer and consumer framework), are in the economic parameters, environmental sustainability and viability.

The scoring system for the mini-grid analysis was a one (1)-point award for mini-grids that are successful in the given category and a zero (0) for a failure in that category. The categories outlined considered the sustainability dimensions mentioned in section 2.2. The categories included cash recovery, operations and maintenance, tariffs, productive use, environmental sustainability, viability, community engagement, capacity, availability, quality and reliability. The sub-categories provided the basis for point awarding. Each category was given a scoring number according to how many sub-categories it had. For example, if a category had five sub-categories, then it had five points altogether. The total number of points from each category was then added and a minigrid model with the most points at the end was seen as the most sustainable.

Table 1:Developer and consumer framework scoring for sustainability based on Knuckle Framework (Knuckles, 2016).

Sustainability Dimension	Category	Sub-category	Scoring
Economic Dimension	Cash Recovery	□ Investment cost recovery	1= 10 to 15 years 0= above 15 years
	O&M	□ Tariff covers O&M expenses	1= yes 0= no
	Productive use	□ Productive use of energy	1= there's any productive use 0= none of the energy is used productively
Environmental Dimension	Environmental Sustainability	□ The presence of the mini-grid encourages less usage of traditional fuels	1= users of energy have adopted to use of electricity over the use of kerosene and other traditional sources of energy 0= there is no significant change
Institutional Dimension	Viability	□ Distance from existing grid	1= > 23 km 0= < 23 km
		□ Terrain (how reachable the place is)	1= accessible 0= inaccessible
		□ Threat of main grid to mini-grid	1= the mini-grid could be connected to the main grid 0= the mini-grid cannot be linked with the main grid
		□ Customer identification (Buying power of the customer)	1= there is enough buying power amongst the consumers 0= no buying power
Social Dimension	Community Engagement	□ Is electricity cheaper than kerosene	1 =yes 0= no
		□ Community acceptance and customer satisfaction	1= over 50% of the area is connected and satisfied 0= less than 50% is connected

The multi-tier framework shown in Table 2 was used to assess the mini-grid technical dimensions and its categories were availability, capacity and quality, the economic dimension (with the category tariff which in this case revolves around the affordability of the electricity and how its tariffs are set), delivery mechanism of the generated electricity and how the generated electricity is used in terms of consumption. The model is adopted from the multi-tier framework by the World Bank Group, ESMAP and Climate Investment Funds (2015). The multi-tier framework is a globally used energy access tool that already has the categories that this research study was intended to assess. It was chosen to complement the categories that the Knuckles' framework did not assess.

The differences between Table 2 and the World Bank Group, ESMAP and Climate Investment Funds (2015) are the addition of the "use if supplied electricity" category which was added to show the consumptions of the users and the affordability and formality from the World Bank's multitier framework were combined under the tariffs category because the research study combines the two under the economic dimension. Health and safety was eliminated because in Lesotho it is catered for under the quality category.

The multi-tier framework is an initiative that redefines the measurements of energy access. It goes beyond the binary measurements of connectedness for electricity access (ESMAP, 2022). The tiers are stacks of rows or layers arranged in ranks over each other.

The scoring criteria in this section is that each Tier is given a number of points corresponding to the Tier number. That is, Tier 1 had 1 point and so on. For categories such as the quality of the electricity, reliability and the tariff that cross over through different Tiers, as seen in Table 2, each had a different scoring depending on the number of columns that it has. If the category has two columns it gets a score of 1 or 0 and if it has more than two columns it follows the trend similar to all other categories, getting the score pertaining to the Tier number. In cases of quality, tariff and billing, the scoring system is 1 and 0 since, for example, in quality either household appliances get damaged or they don't. There is no in-between. The tariff used is categorized into two forms: affordability and the setting. This is due to the fact that some mini-grids offer fixed tariffs which do not change with inflation. Others have their tariffs connected to inflation. Tariffs also needed to consider the buying power of the household and thus included in the multi-tier framework is the price of electricity in comparison to the household income.

The colour coding in Table 2 represents the good, bad and neutral. The first two Tiers have the colour red which indicates bad in this framework, through the yellow colour that is neutral for Tier 3 to good represented by the green colour in Tier 4 and Tier 5. The model to be most recommended for uptake, due to its sustainability, is the one with the highest achievement in the above-mentioned sustainability dimensions. The model that achieves the dimensions is the one closest to the total number of points.

The min-grids were assessed individually with the categories and dimensions and then an average was presented of the mini-grids' scores in terms of their models and the mini-grid business models with the highest points closest to the total point of 33 was seen as the sustainable one.

Table 2: Multi-Tier framework for the mini-grids based on (The World Bank Group, ESMAP and Climate investment funds, 2015)

Categories		Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Availability	Daily availability	Below 4 hours		At least 4 hours	At least 16 hours	At least 23 hours
Capacity	Power (W)	≥3	≥50	≥200	≥800	≥2000
	Energy (Wh)	12 Wh	between 12 and 200 Wh	Between 200 and 1 kWh	Between 1 and 3.4 kWh	Between 3.4 and 8.2 kWh
Quality		Appliances used are affected by voltage variations			Appliances used are not affected by voltage variations	
Reliability		More than 14 disruptions per week			14 disruptions per week	3 disruptions per week
Tariff	Affordability	Yearly consumption of the said electricity is above 5% of the annual household income			Yearly consumption of said electricity is below 5% of annual household income	
	Setting	Fixed			Cost-reflective and Adjustable	
Use of supplied electricity	How the consumers use the provided electricity (which in turn will give them buying power)	very low load	Low load	Medium load	High load	Very high load

3.4 WEIGHTING

The categories of the sustainability dimensions assessed in this work do not have the same weight in determining the sustainability of a mini-grid. The weighting of the categories in this research study was considered as the developers' perspective on what is important or what should be considered important for a mini-grid of a certain business model. The weighting was done by the chosen expert developers. The study combines what is seen as important by the expert developers and what is observed from the assessed mini-grids.

Even though the mini-grid aspects (categories) outlined in this study were important for the analysis of sustainability and their importance could not be told right away (which is more important), the weighting analysis was needed to assess the importance. Mini-grids have their importance criteria during inception; some may consider community engagement as an out most important aspect and others may consider the cash recovery time.

The importance of these categories is crucial because, from them, one can know how bad the mini-grid is in terms of sustainability and whether it violates a certain aspect because of its rating. For the importance rating or weighting, interviews were conducted with some selected experts to find out what they viewed as important from each model. The combinational average of the weighting from the published journals and interviews was done to reach the used weighting.

Interviews were conducted with experts from Gram Oorja, an Indian mini-grid developer, L.E.C a utility company, and LREEAP. For those experts that could not be contacted, published documents were used (Gollwitzer *et al.*, 2018; Liu and Bah, 2021; Palit and Kumar, 2022; Poudel, Parton and Morrison, 2022). The selected experts have the knowledge of mini-grids as well as their inception and operation because they have been part of mini-grids of different models. The weight of the mini-grid aspects is shown in Appendix 2.

From the interviews, it was given that any category with a rating below 50% does not significantly affect the mini-grid sustainability and thus has the least importance in sustainability.

4 Results and Discussion

The literature review (section 2) has outlined the definition of a sustainable mini-grid and the variables the make a mini-grid sustainable shown as was the need according to the research objectives (section 1.3.2), this section addresses the last objective (to analyse and identify the sustainability of the different models of mini-grids).

This chapter presents the findings of the study and their implications as a correlation to the third objective of the research. The findings of the study on the assessment of the categories of sustainability dimensions are shared and discussed. The mini-grids are then assessed individually on how well they satisfy the categories of sustainability dimensions; they are then assessed as mini-grid models to see which model satisfied the categories and dimensions best. The recommendations are then shared for Lesotho.

4.1 Economic Dimension and its Categories

This sub-chapter presents the study findings of the economic dimension of sustainability with its categories. The categories under the economic dimension presented in this results are: cash recovery, coverage of O&M costs by tariffs, productive use of electricity, and tariffs' cost reflectiveness and affordability

4.1.1 Category 1: Cash Recovery

Of the sixteen studied mini-grids, as presented in Table 1 under the economic dimension and cash recovery category, six had their cash recovery in or in less than 15 years, thus, only six scored 1 point while the remaining had 0 points in this category. From the weighting analysis, the experts gave cash recovery a 40% rating. This shows that although important to the sustainability of the mini-grid cash recovery is not as important as the other categories and can be ignored to some extent. Moreover, the mini-grid can still survive without it. Cash recovery is only important for some selected mini-grid models. The private mini-grids had a 100% score in this category. Due to being business-oriented, private mini-grids pay more attention to their cash recovery and strive to recover their initial expenses within a few years. This is because, unlike other models, they are inclined to pay their investors back.

Four of the six mini-grids with a point in the cash recovery category were of the private model while the other two were of the PPP model. This proves that cash recovery is mostly considered when there are investors that need to be paid back since the two PPP models had some of their capital coming from investors.

Community-owned mini-grids do not have to worry about cash recovery and do not recover cash spent on them. This leaves them at the bottom of the scale with a 100% failure in economic sustainability. Unlike private mini-grids which can use the generated profits for the creation of other mini-grid projects, community mini-grids fail in this regard due to not making any profits.

Utility mini-grids, as seen in

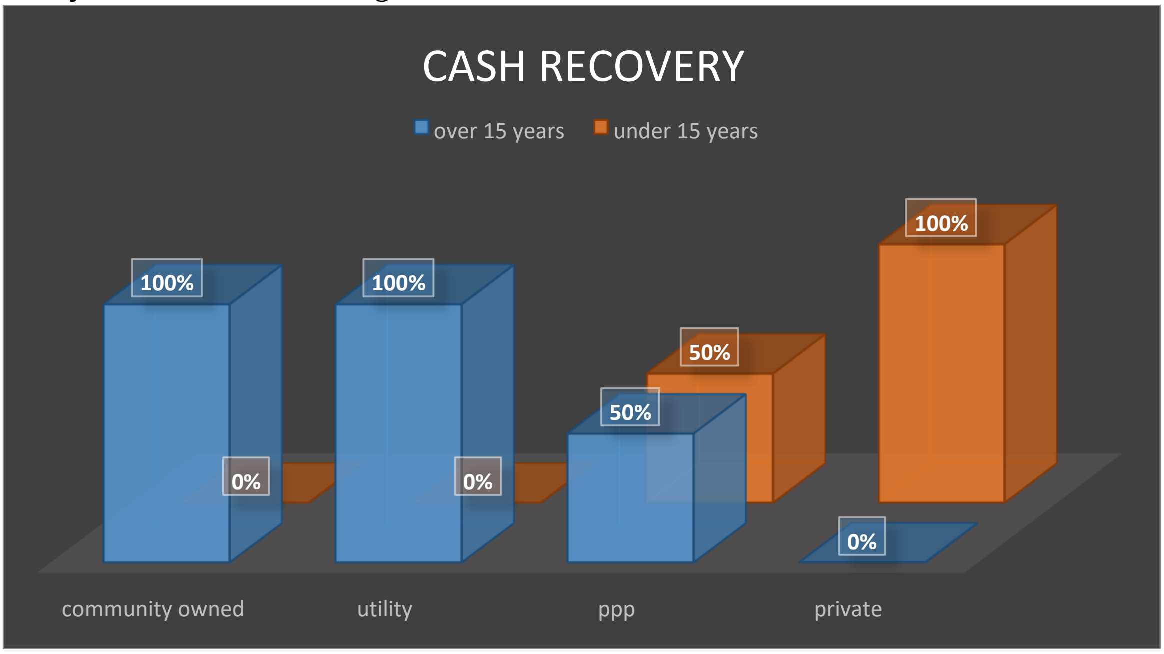

Figure 3, are similar to the community mini-grids. They have no compulsion to recover the money spent since they are subsidized by the government. The users of the main grid and the mini-grid strive to create lower charges than what would be paid if they were cost-reflective. Many utility mini-grids face closure because they are economically unsustainable and cost the utility a lot of money. They do not help in the building of new mini-grids from the funds that they generate. Even though they are unsustainable the community mini-grids still thrive because of the subsidies in countries such as Zambia (Kapole, Mudenda and Jain, 2023).

The PPP mini-grids cash recovery depends on the key players involved in the mini-grid. Of the four PPP mini-grids assessed, half were sustainable and the other half were unsustainable in this category. For mini-grids that were built with grants, there was no recovery pressure and the operating partners only sustained the mini-grid for operations and for the supply of energy to the consumers. For those that had private investors, there was a need to recover the spent funds and there was a 100% recovery rate.

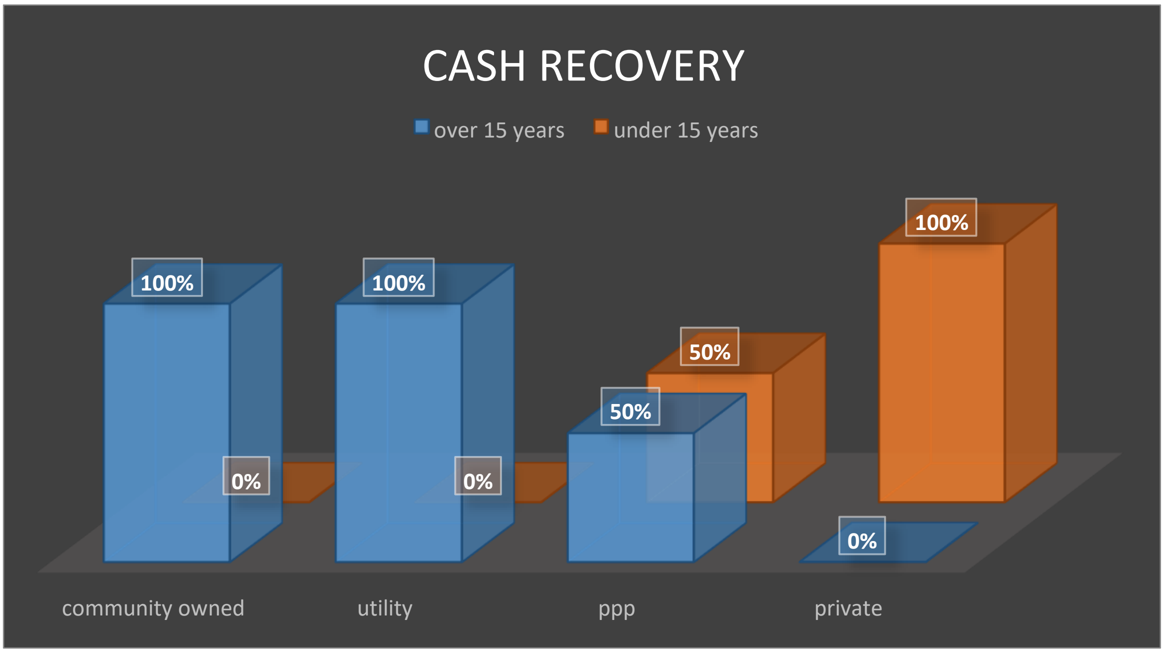

Figure 3: Cash recovery of the mini-grids

4.1.2 Category 2: O&M

O&M is an important aspect of the mini-grid and if careful attention is not paid to it, this can lead to the mini-grid failure. The mini-grid operations and maintenance costs are very high and can affect the project's economic sustainability thus the tariffs of the mini-grid should cover the operations and maintenance costs so that the mini-grid can run smoothly.

The O&M category findings under the economic dimension show that 8/16 assessed mini-grids have a point score as assessed with the use of Table 1. The 8 mini-grids had their O&M cost covered by the tariffs. and showed that when setting the tariffs, they make sure that the operations and maintenance costs can be covered by their tariffs.

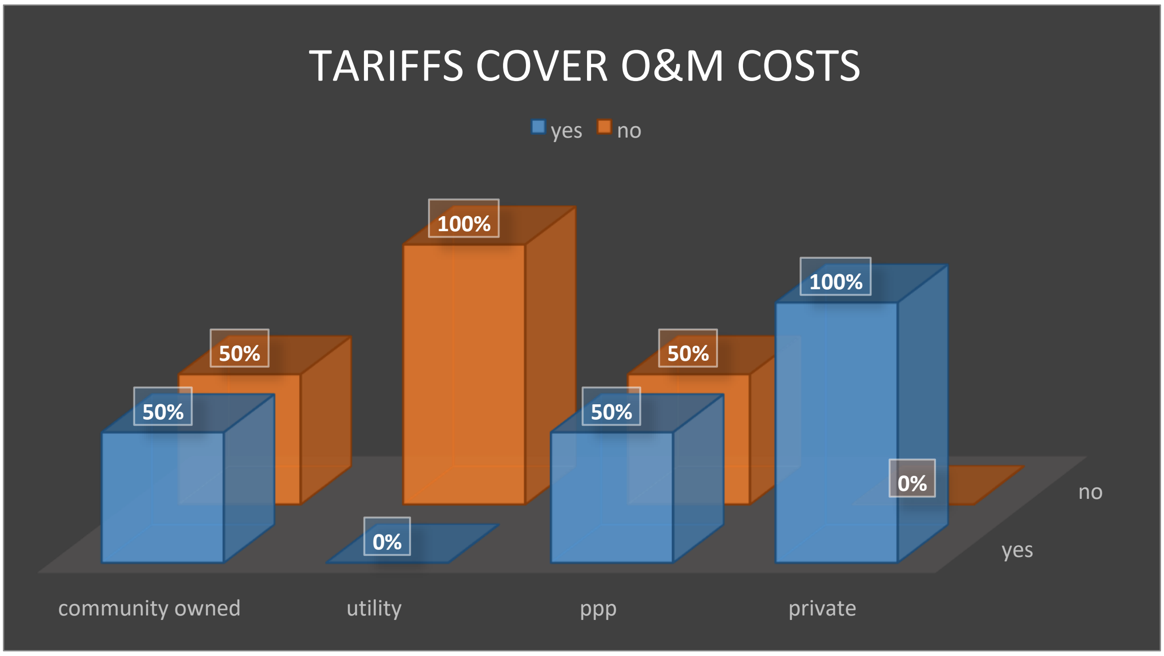

Figure 4 shows the distribution of the mini-grids that cover their operations and maintenance costs from tariffs and those that do not.

Of the 8 successful mini-grids in this category, all the four private mini-grids make 100% coverage of their operations and maintenance costs through their tariffs as seen in

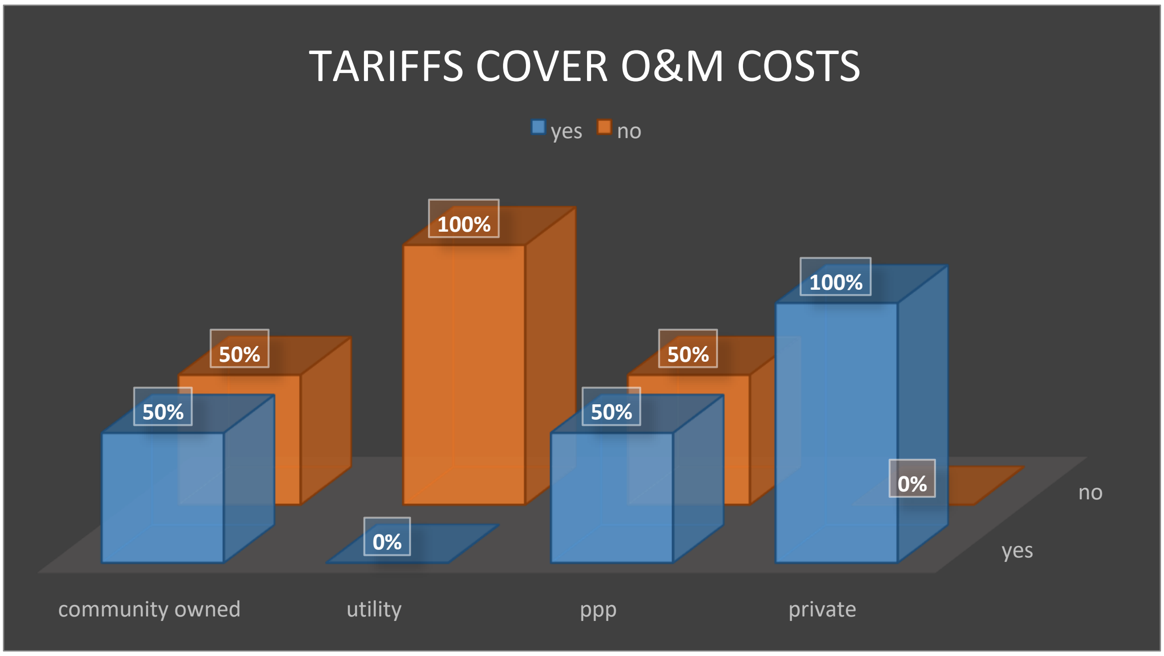

Figure 4. The PPP and community-owned mini-grids had a 50% share of the remaining minigrids. Due to being controlled by the main grid utility company, the utility mini-grids have very low tariffs similar to the main grid which hardly cover the utility operations and maintenance. Utility mini-grids are, however, able to operate regardless of not being able to cover their operations and maintenance costs from tariffs due to the subsidies that they get from

the utility grid (Kapole, Mudenda and Jain, 2023). Utility mini-grids had a 100% failure rate in this category.

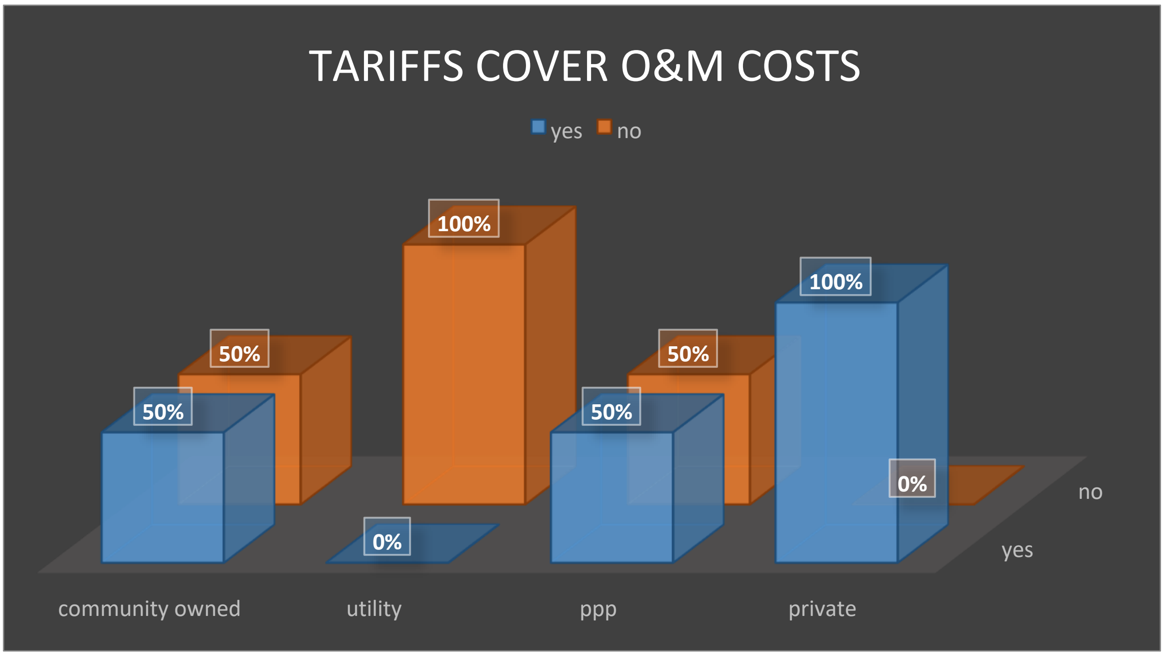

Figure 4:Tariff coverage of O&M costs

The weighting analysis shows that O&M coverage from the tariffs is a very important aspect and has 100% importance. According to Kapole, Mudenda and Jain (2023), mini-grids that do not cover the O&M costs soon face closure. Since O&M coverage from tariffs have a 100% importance rating, this category enforces the need for the tariffs to cover O&M and a failure in this category cannot be ignored because it leads to a failure in this category sustainability

4.1.3 Category 3: Productive use

The productive use of electricity category was assessed in Table 1. All the mini-grids assessed attained a 1-point score in this category. Mini-grids developers promoted the productive use of energy for the consumers. All mini-grid models supply their customers with a wide range of uses of electricity that are productive. There is the supply of electricity to schools, clinics or health centres and extended hours of operating of businesses. Private and community-owned mini-grids provide their customers with money-making means of productive use of energy as a way to make them able to pay for the electricity tariffs. In

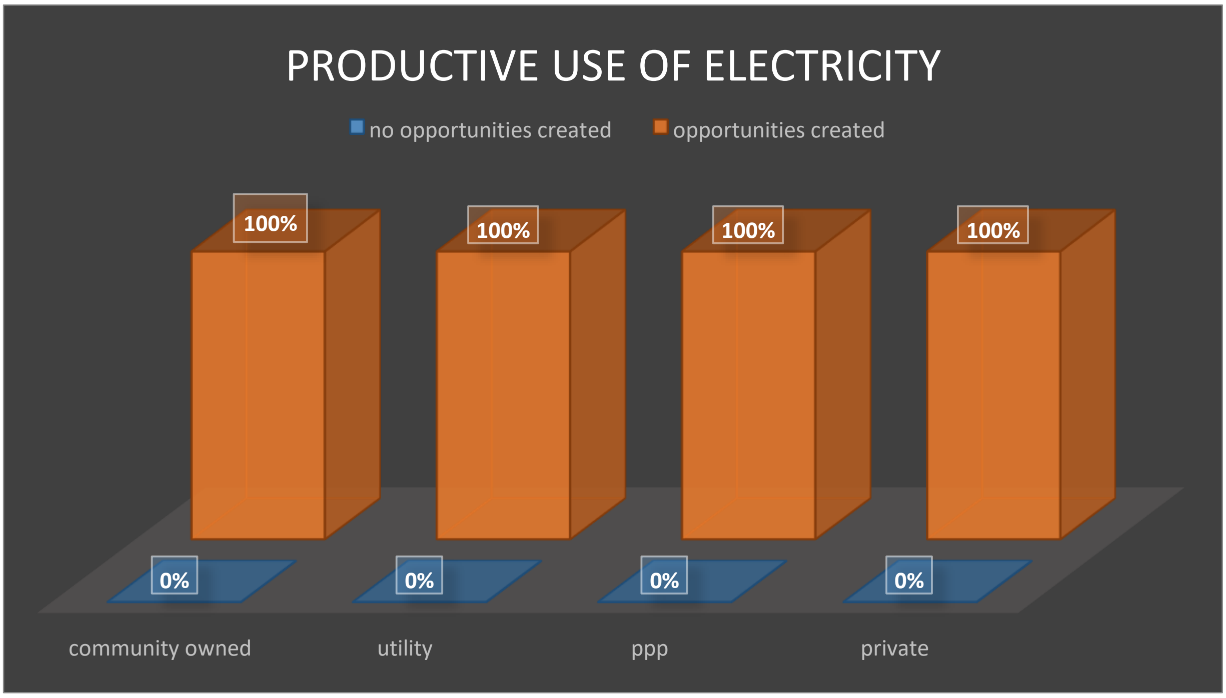

Figure 5 it can be seen that all mini-grid models attained a 100% in the productive use of electricity. Some mini-grids do it so that their customers can afford the electricity. Others, such as the utility and the PPP models, do it for community acceptance but regardless of the reasons all the mini-grid models showed a 100% consideration of the productive use of electricity among their customers.

According to Hartvigsson *et al.* (2021), 25% of the productive electricity users made up 44% of the mini-grid income. Hence it is important to provide productive use opportunities. Hartvigsson *et al.* (2021) assigned the productive use of electricity a 100% importance rating. This means that for the mini-grids to be sustainable they have to adhere to providing productive use of electricity to their customers at all costs.

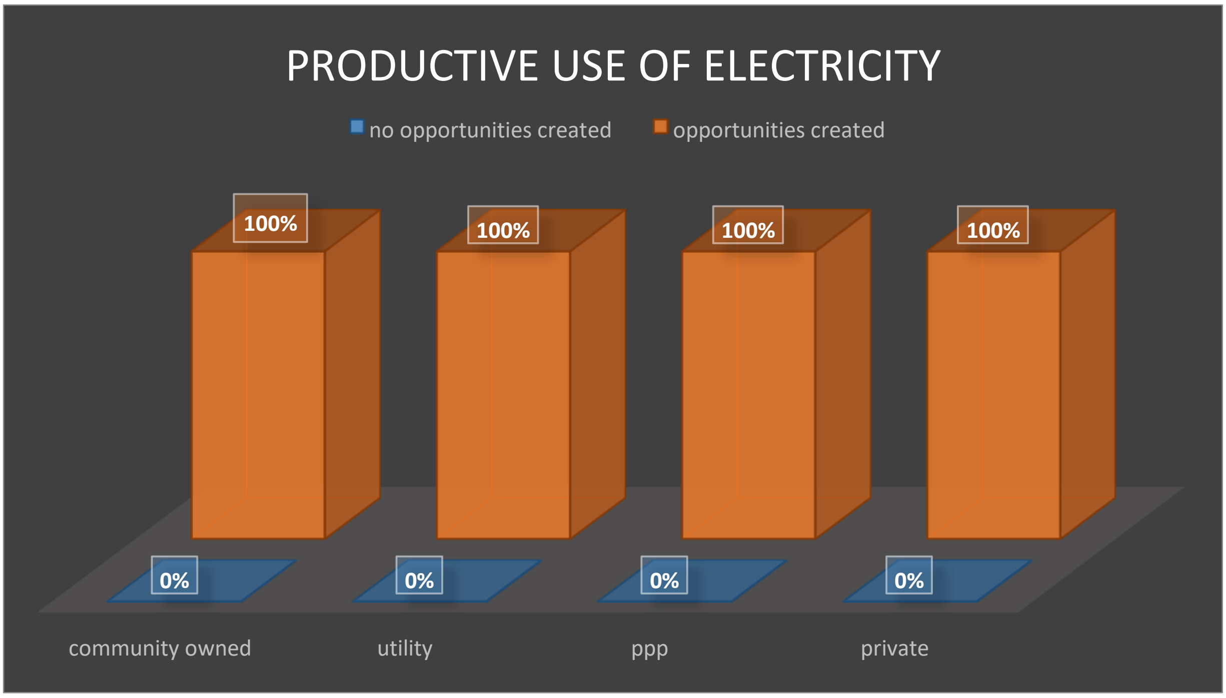

Figure 5: Productive use of electricity

Subjecting the Productive Use of Electricity PUE to the weighting analysis shows that it has an 80% importance rating and thus has to be given priority. All the mini-grids and all the minigrid business models showed a careful consideration of this category.

4.1.4 Category 4: Tariff

Tariffs are assessed with the use of Table 2 and have two sub-categories, affordability and setting. Eight of the 16 mini-grids had cost-reflective and adjustable tariffs for their customers while the remainder had fixed tariffs. Due to profit-making and capital recovery, Private minigrids tariffs are cost-reflective and all of the had a 1-point score in this sub-category. They can cover their day-to-day expenses and are sustainable, as shown in

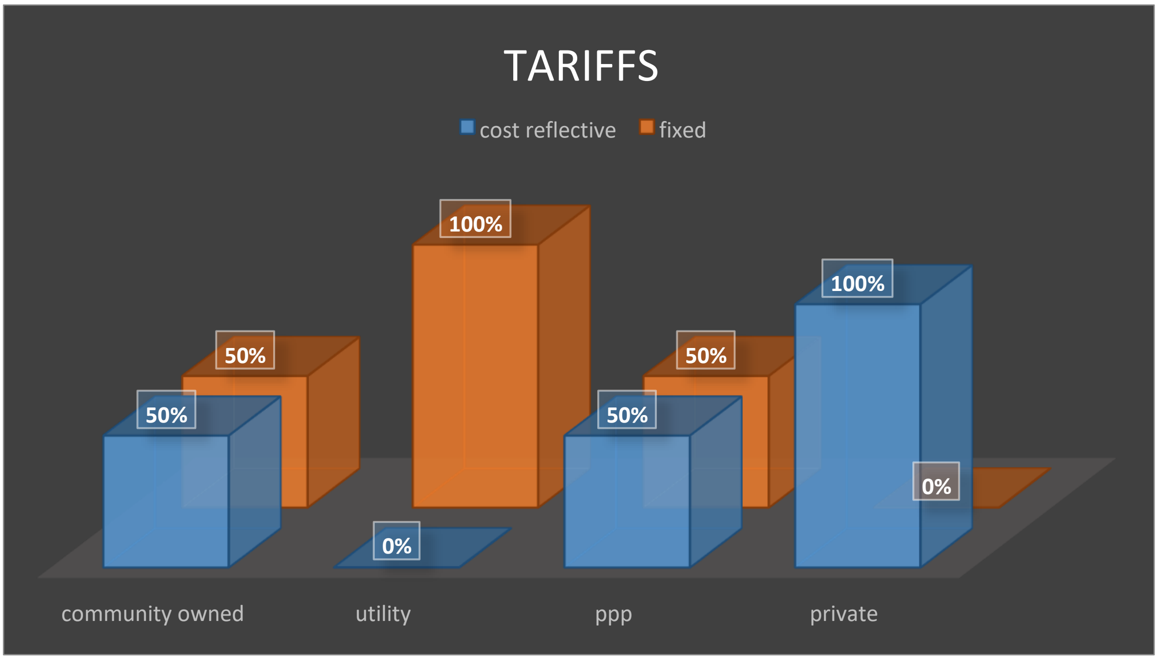

Figure 6. The PPP and community-owned mini-grids have the same struggles with regard to tariffs. Because funds can come from grants, customers refuse to pay the high bills. They feel that the mini-grid is a gift to them and they do not have to pay for it (Kapole, Mudenda and Jain, 2023). The 50% success (those with cost-reflective tariffs) is for the mini-grids that convince the communities to pay cost-reflective tariffs.

Utility mini-grids are the worst when it comes to cost-reflective tariffs. They make their customers pay fixed low tariffs. In

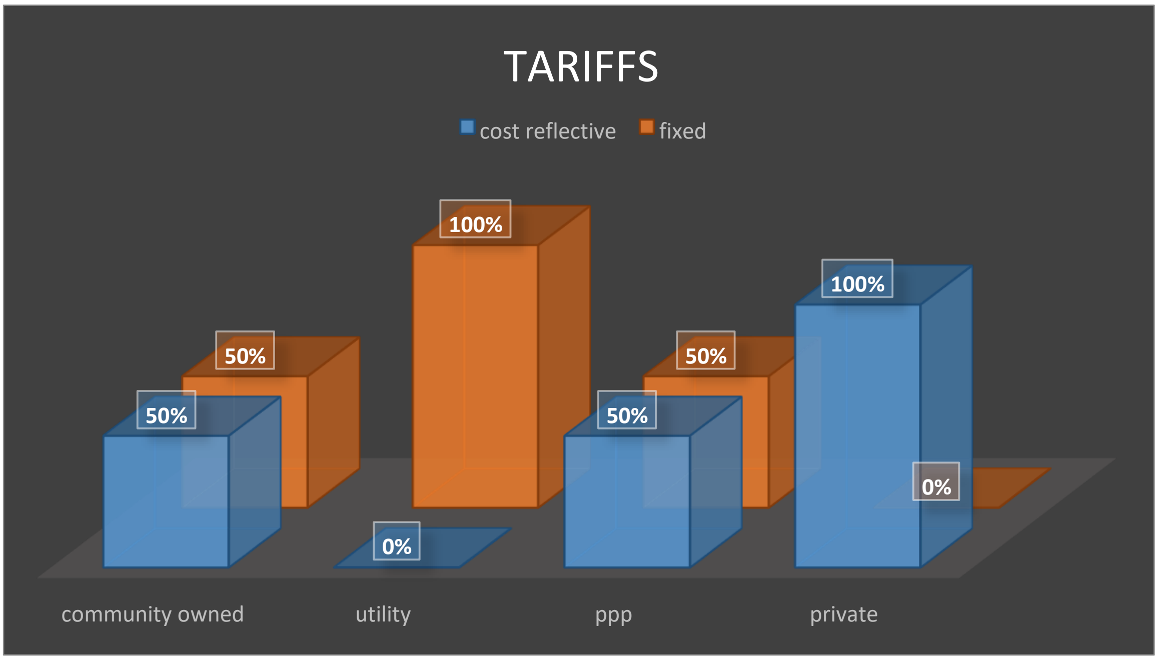

Figure 6 it is observed that all the studied mini-grids charge fixed tariffs that are usually not enough to sustain the mini-grid day-to-day expenses and for this reason, utility mini-grids are found to be unsustainable in this category.

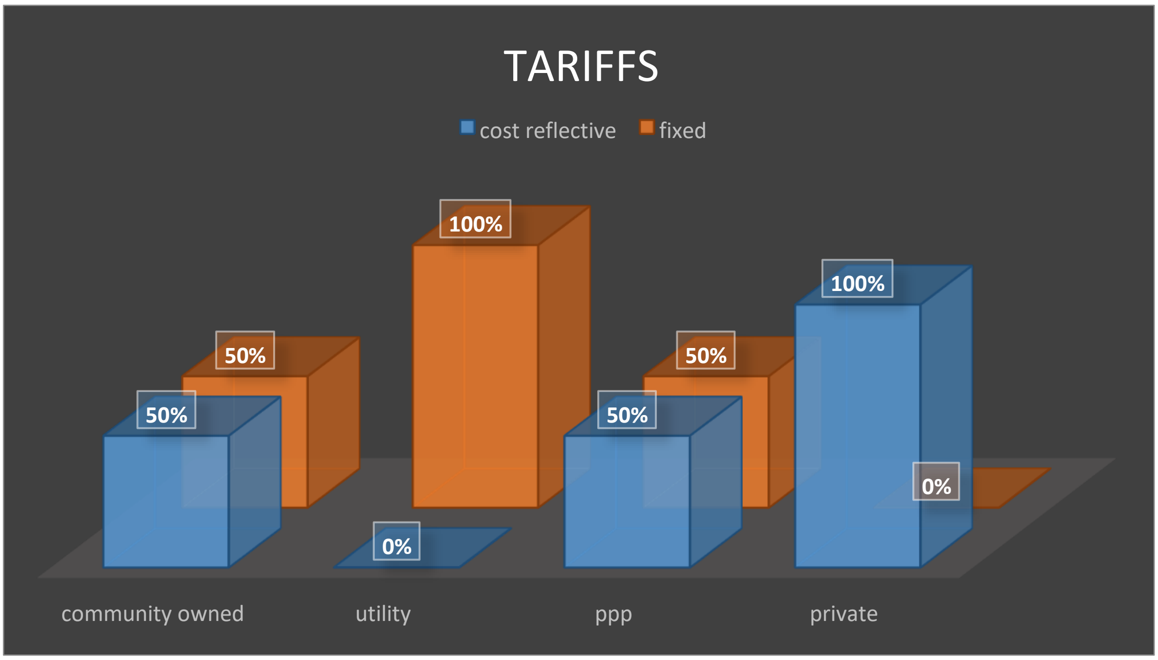

Figure 6: Tariffs of mini-grids

The affordability of all the other mini-grids, except the two private mini-grids had a 1-point score. The mini-grids were cheaper and their costs were lower than 5% of the household income, as mentioned by Mpholo *et al.* (2020). Because of their cost reflective tariffs the Private mini-grids proved to be unsustainable in this sub-category.

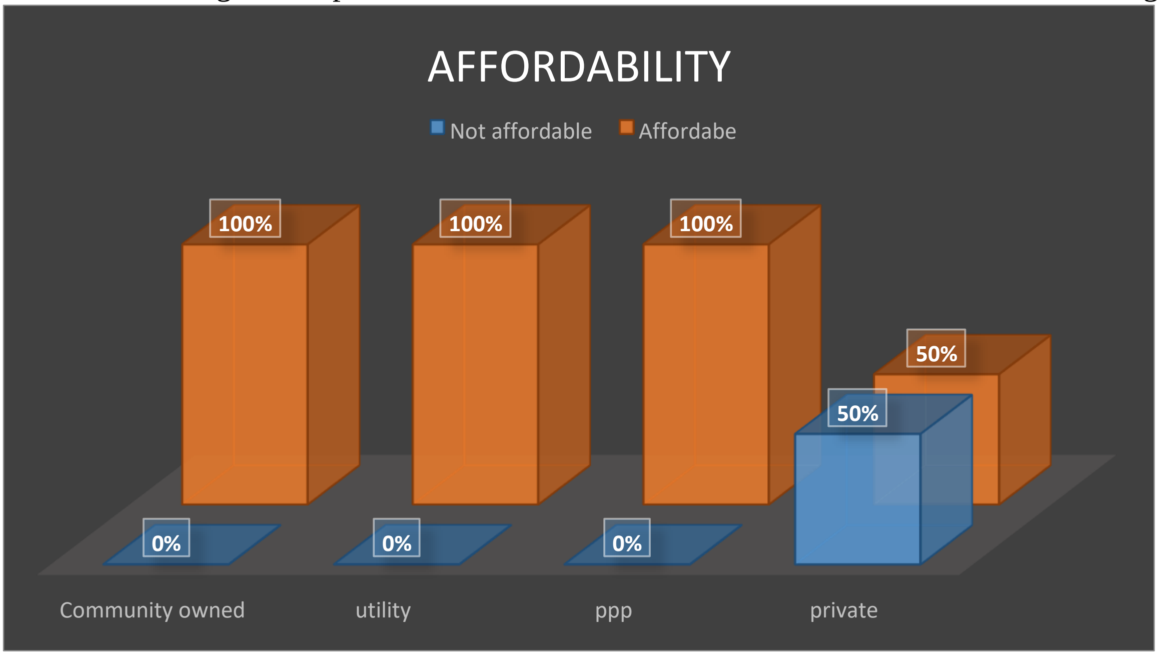

Figure 7: Affordability shows that 87.5% of the studied mini-grids is sustainable in this subcategory.

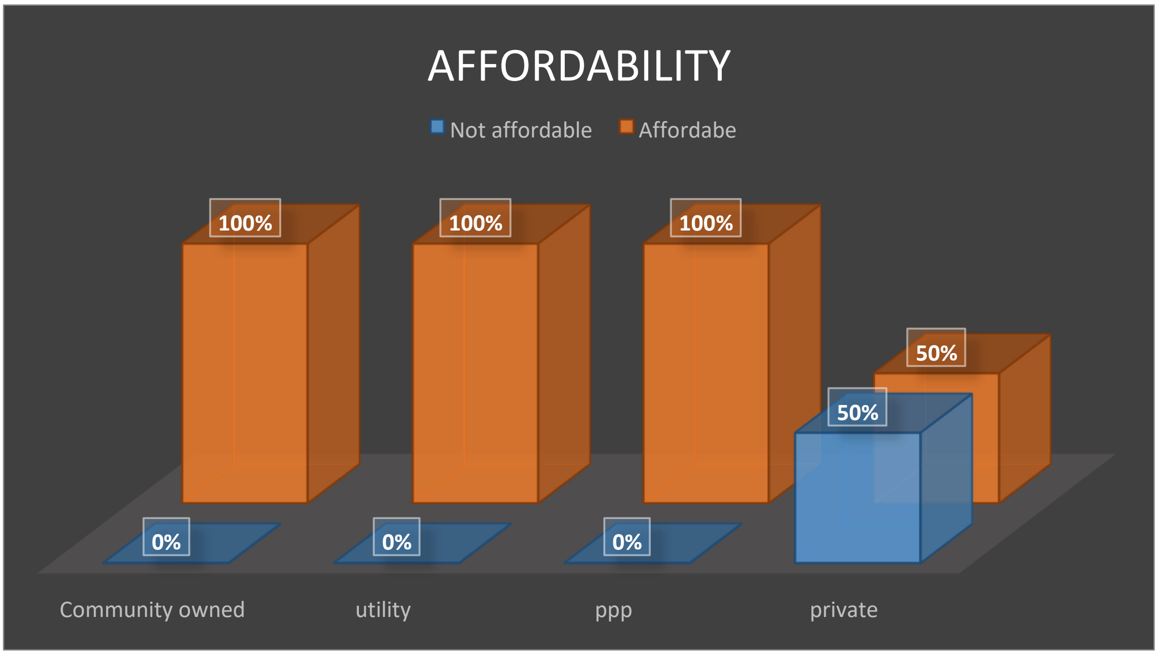

Figure 7: Affordability

The weighting analysis shows that tariff setting has a 100% weight, hence it is very important to the sustainability of the mini-grid. According to Tozzi (2018) and Katre, Tozzi and Bhattacharyya (2019), a mini-grid is only sustainable if it satisfies all the sustainability dimensions and not only one; therefore the mini-grids are unsustainable in the tariffs category.

4.2 Environmental Dimension

The findings from the study on the environmental dimension and environmental sustainability category are presented in the following sub-chapter.

Category 5: Environmental sustainability

The mini-grid environmental sustainability was assessed with the use of Table 1 to consider whether the presence of the mini-grid encourages a reduction in the use of kerosene or other traditional sources of energy or not. Of the 16 studied mini-grids, 13 proved to be environmentally sustainable and scored a point in this category, thus showing sustainability in the environmental dimension. The three unsustainable mini-grids were of the utility model. Utility mini-grids considered in the study showed low sustainability in this category. Since the tariffs in this model do not cover O&M costs, 75% of the mini-grids owned by the utility end up using their diesel backup full-time due to not being able to maintain the renewable energy equipment (Kapole, Mudenda and Jain, 2023; Tsoeu-Ntokoane, Kali and Lemaire, 2023). Utility-owned mini-grids are concerned with community acceptance. They create lower tariffs that lead them to an unsustainable environmental impact. Even though electricity is cheaper than kerosene, this becomes pointless due to their wide use of diesel generators.

Since community-owned and private mini-grids set their tariffs to cover O&M costs, maintenance does not become an issue and thus they do not use their diesel generators as often. In addition, electricity generated by these mini-grids becomes cheaper than kerosene in the long run. Both private and community-owned mini-grids show a 100% decrease in the illnesses caused by the use of kerosene, fewer fire hazards and a large reduction in carbon emissions were reported (Tozzi, 2018).

The PPP mini-grids are commendable since they show a 100% sustainability largely because they are given grants by international organisations to lower their emissions. The environmental sustainability representation of the results is given in

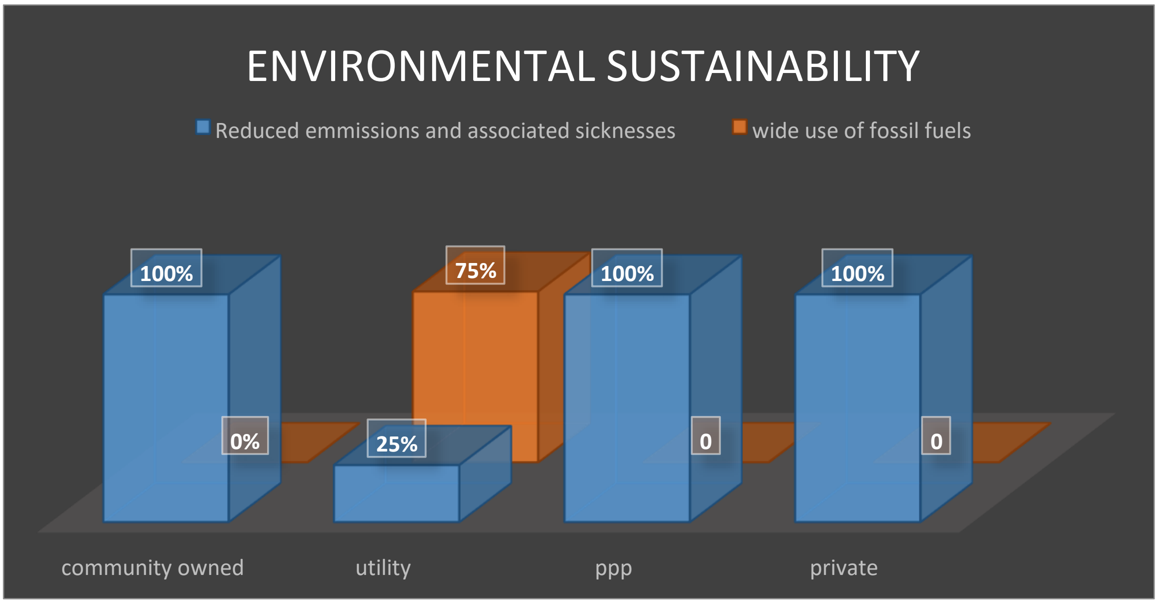

Figure 8.

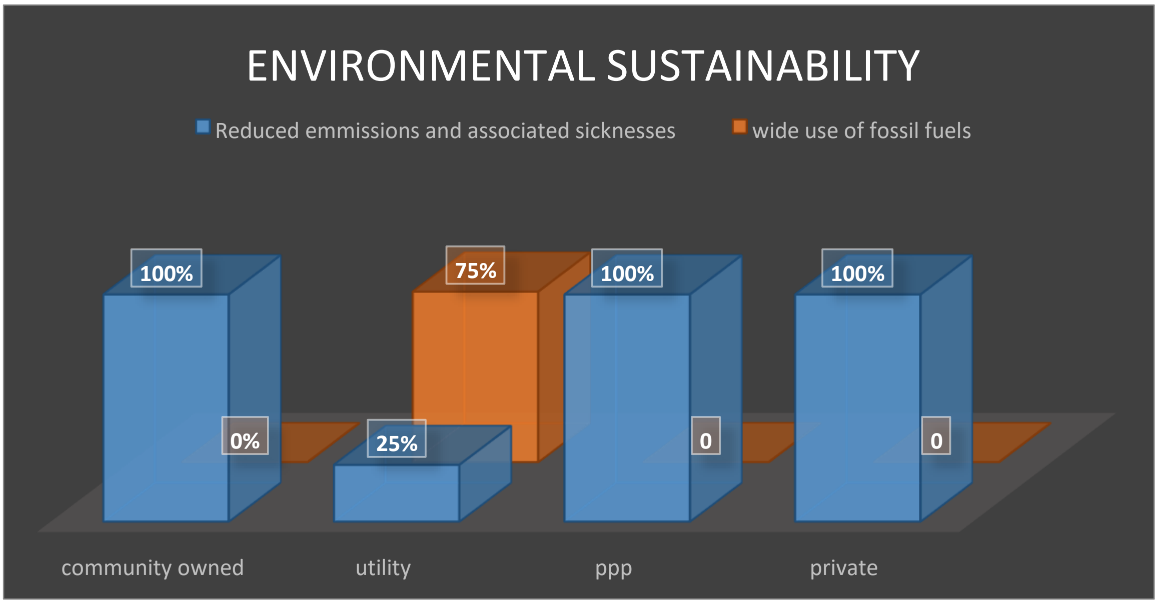

Figure 8: Mini-grid environmental sustainability results

Environmental sustainability has a 60% rating in the weighting analysis. This implies that the 75% of the utility mini-grids that failed in this category cannot be sustainable because this category cannot be ignored.

4.3 Institutional Dimension

The results of the institutional dimension and viability category are presented in this subchapter an elaborated on.

4.3.1 Category 6: Viability

With the help of Table 1, the viability category and its sub-categories were assessed. The viability of the mini-grid has a 40% rating according to the weighting analysis. This means that it is one of the least important categories in the sustainability categories. For this reason, all the 16 mini-grids decided to bypass it where possible. For example, they found the areas with existing roads instead of building roads. Kumar, Agarwal and Agarwal (2022) mentioned that creating mini-grids in hilly areas and the unavailability of roads creates more downtime for the repairs of the system. They also find places further from the main grid instead of relying on the regulations (African Development Bank, 2020). All the mini-grid projects were deemed to be within acceptable distance from the existing grid as suggested by the African Development Bank (2020) and none of them were under any threat from the main grid.

4.4 Social Dimension

Under the social dimension there is only one category (community engagement). The results of the study on community engagement and thus the social dimension are found in this subsection.

4.4.1 Category 7: Community Engagement

All the mini-grids considered community engagement and acceptance as an important issue for their sustainability. From the involvement of the community in the planning stages to the operation of and connections to small businesses, communities being served by mini-grids have different expectations on how mini-grids can add value to their respective areas.

With the use of Table 1, the results of the social dimension sustainability were obtained. Fourteen of the sixteen mini-grids were found to be sustainable in the community engagement category and each mini-grid had a 1-point score.

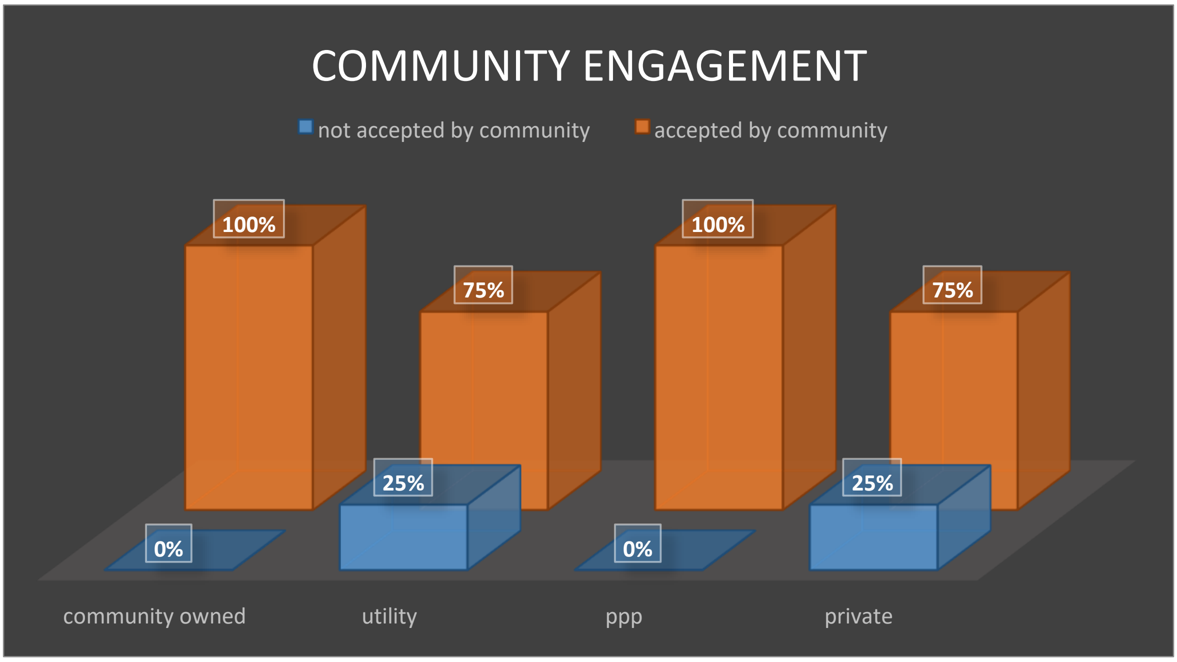

Figure 9 shows the community acceptance of the mini-grids by the community due to the engagement of the mini-grids.

When it comes to community acceptance, community-owned mini-grids are the most successful. They even let their users be in control of the O&M by giving them training sessions for minor maintenance. One other contributing factor to the social acceptance of community mini-grids is their tariffs. Most community mini-grid tariffs are low as they are covered by grants. This is pleasing to the consumers hence their acceptance for community mini-grids is high. In the weighting analysis, community engagement is given a 100% importance rating. This means it is an important category to the sustainability of the mini-grid.

The one utility mini-grid that was not accepted by the community had a lot of power outages which often left the community without electricity and even led to the mini-grid being completely dependent on their diesel generator. The community was not made aware of any change or electricity-related problems that affected them directly (Tsoeu-Ntokoane, Kali and Lemaire, 2023).

Similarly, one private mini-grid had no acceptance because the developer only connected people who could afford the expensive tariffs that were set and did not find other ways of including those who could not afford to pay for the electricity. When faced with people who cannot afford to pay for electricity, some developers try to create businesses and help them to get on their feet so that they can afford the electricity which, in turn, boosts the acceptance and hence more capacity and usage of the services (Pedersen and Nygaard, 2018).

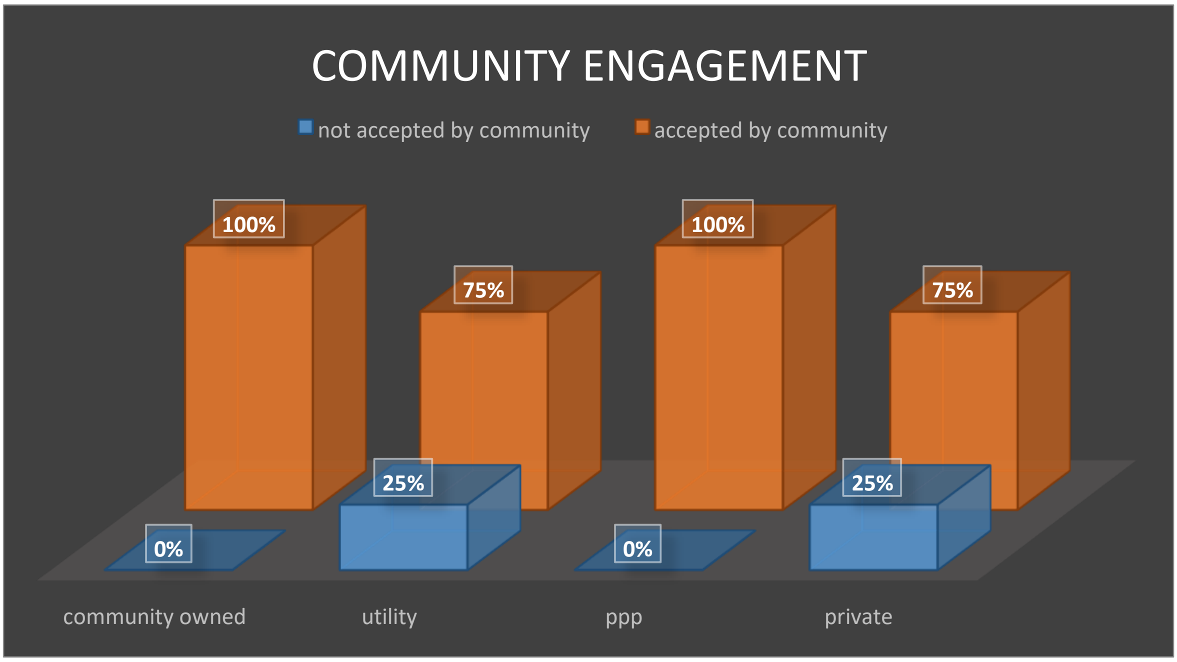

Figure 9: Community engagement of mini-grids

4.5 Technical Dimension

The technical dimension has four categories; availability, capacity, quality and reliability. The study's findings on the categories and hence the dimension are presented and explained in this subchapter.

4.5.1 Category 8: Availability

In the availability category observed in Table 2, 15/16 mini-grids had a Tier 5 and thus had 5 points. One mini-grid had a 4-point score and fell under Tier 4. Fifteen mini-grids had a 24 hours supply. The availability of electricity 24 hours a day has proven important to the community. As a result, customer satisfaction and acceptance of the mini-grid gets raised by the constant supply of electricity which is a pass socio-economic category observed in Table 1. Mini-grids provide extended study time for students. Lighting at night is said to lower the crime rate in most villages. The accessibility of the health centres at night results from the presence of the 24-hour operational mini-grids. The mini-grid backup systems also ensure a 24/7 online status of the mini-grids. This means that the mini-grids are sustainable in the socioeconomic category and the availability attribute. There is sustainability in the technical and social dimensions.

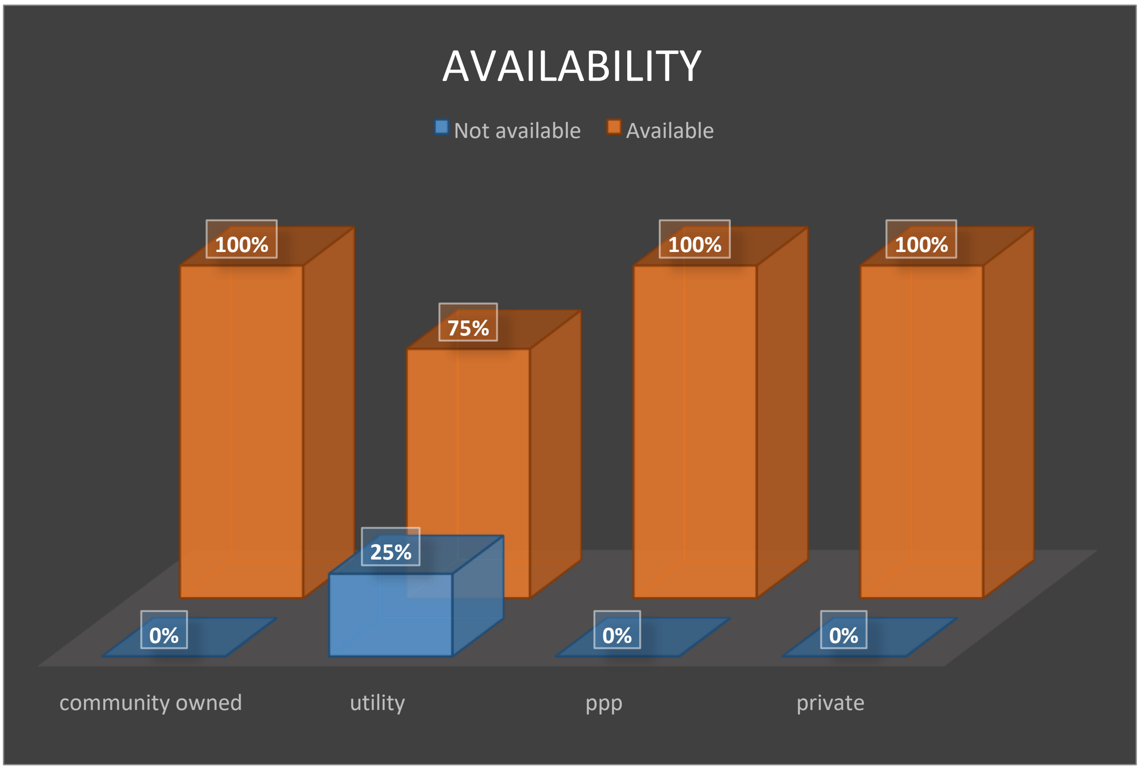

Figure 10: Availability of electricity

4.5.2 Category 9: Capacity

The capacity result follows from the multi-tier framework in Table 2. As far as capacity is concerned, all the mini-grids fall under Tier 3 and thus have 3 points. They provide between 50W and 200W to their customers and seem to be sustainable in this category. The mini-grids have their customers' appliances connected and operational with no shortage of power delivery and no shortage of people connected. Even though a few households are not connected due to their inability to pay the connection fees, all the mini-grids have enough power to extend the connections and to accommodate the already connected households. This means that a good load profiling was done before the erection of the mini-grids. All them seem to be sustainable and had a good community connectedness (Katre, Tozzi and Bhattacharyya, 2019). Capacity as a category has an 80% rating and is very important to the sustainability of the mini-grid.

4.5.3 Category 10: Quality

The quality category is assessed with the use of the multi-tier framework shown in Table 2, this assesses the sustainability of the mini-grid with regard to the customers' appliances. The studied mini-grids show sustainability in this category. They all have a 1-point score and do not have any voltage variations that destroy the connected household appliances.

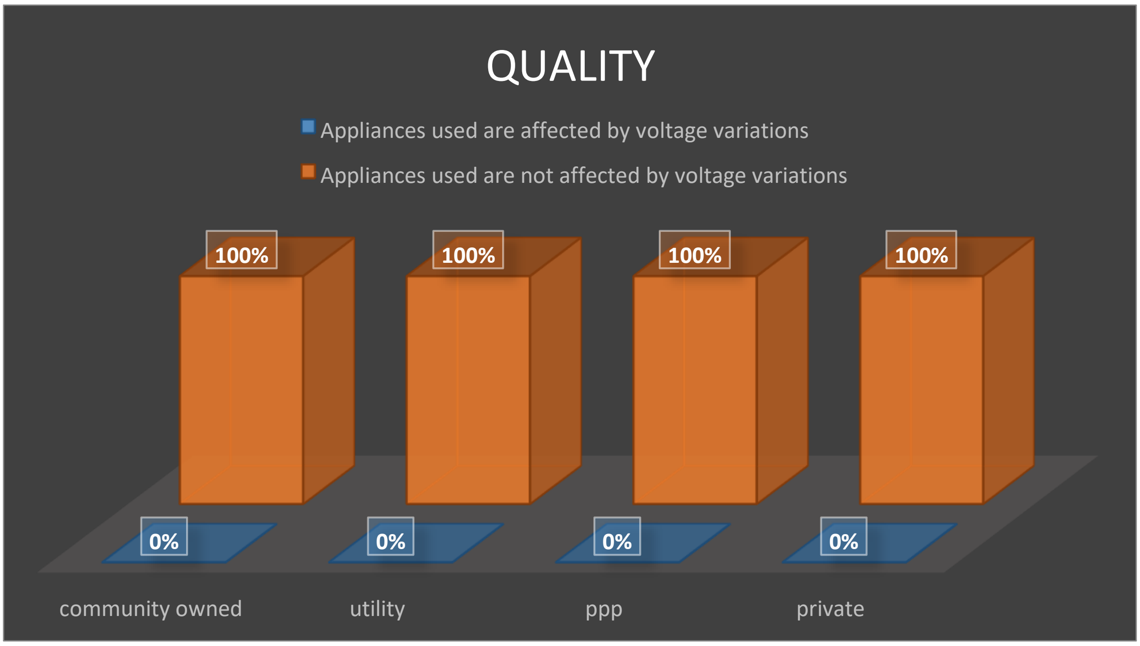

Figure 11 shows the mini-grid models quality performance. Due to the quality coverage and despite having different models, all the mini-grids have a good supply of quality electricity. This means that they are sustainable in the quality of their distributed electricity.

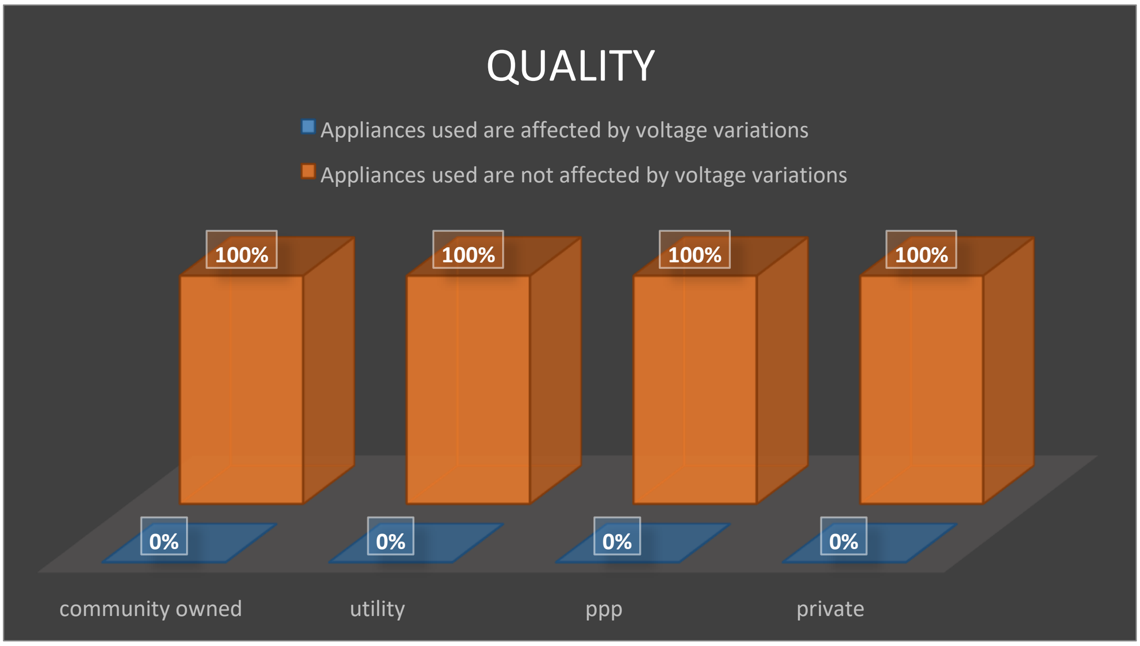

Figure 11: Quality of supplied electricity

Quality is a very important category in the sustainability of the mini-grid; it is given a 100% rating in the weighting analysis, this is proven by the mini-grid developers' careful attention to it and all mini-grid models scoring a 100% in this category.

4.5.4 Category 11: Reliability

Reliability is assessed with the use of Table 2. It is an important category in sustainability and has an 80% rating by the experts in the weighting analysis. All the studied mini-grids had a Tier 4 and had 4 points in this category. They prove to be sustainable in this category. Each mini-grid all as a maximum of 14 disruptions per week apart from the planned O&M disruptions.

4.6 Overall business model results

The total number of points to be awarded with the use of both Table 1 and Table 2 is 33 with Table 1 having a 10 points total and Table 2 having 23 points. The table representation of the average mini-grid business model results is shown in Appendix 1.

Community-owned mini-grids got a 28/33 score, having 8/10 with the use of Table 1 and 20/23 with the use of Table 2. The PPP mini-grids and private mini-grids have an equal highest score of 30/33, with 9/10 and 10/10 respectively through the use of Table 1 and 21/23 and 20/23 respectively through the use of Table 2 and are seen as the most sustainable mini-grid models. The utility models have average scores of 8/10 and 19/23 with the use of Table 1 and Table 2 respectively and a total of 27/33 points. They form the least sustainable mini-grid model.

According to the literature, a mini-grid is sustainable if it satisfies all the sustainability dimensions (the economic, environmental, institutional, social and technical sustainability dimensions) and their categories (cash recovery, operations and maintenance, tariffs, productive use, environmental sustainability, viability, community engagement, capacity, availability, quality and reliability). The assessed mini-grids have a minimum fall back on at least one category of the sustainability dimensions' categories and thus a fall back on the sustainability dimensions.

The results show analysis and identification of the sustainability of the different models of mini-grids and show that with the combination of the awarded point and the weighting analysis, the PPP and private models are the closest to complete sustainability, falling short on the economic dimension and the tariff category. The PPP model did not offer cost reflective tariffs and the private model tariffs although the cost reflective were not affordable.

The utility models fall back on all the dimensions but on consideration of the weighting analysis some of the categories that it falls behind on are not very crucial to sustainability. However, there are those that have a very high rating and are very important to the sustainability. The economic, environmental dimensions are not sustainable in the utility model; the model's tariffs do not cover the O&M costs and are not cost reflective. Most utility mini-grids are in high use of their diesel generators and so are not environmentally sustainable. Be that as it may, utility mini-grids have very low tariffs overall and are widely accepted by users for this reason.

Community mini-grids are commended for the impeccable community engagement although they still fall short on important dimensions (economic dimension) in the categories; tariff; setting and tariff coverage of the O&M are the major categories that make the community owned mini-grids unsustainable. Their costs are low because people do not pay the high rates for something that is a gift or grant.

5 Conclusion and Policy Recommendations

This section presents the conclusion drawn from the results in the preceeding section (section 4) and gives the recommendations needed to make mini-grid deployment easier and increase energy access in Lesotho.

5.1 Conclusion

In the analysis of the categories of the sustainability dimensions to achieve sustainable minigrids, this study has carried and followed the objectives shown in the introduction (chapter 1); a sustainable mini-grid and what makes a mini-grid sustainable were defined in the literature review (chapter 2) and the mini-grids were analysed and the sustainability of the different models of mini-grids identified in the results and discussion section (chapter 4) with the use of the frameworks outlined in the methodology (chapter 3)

The study analysed the economic, environmental, institutional, social and technical sustainability of mini-grids. With the use of the developer consumer and the multi-tier frameworks, the mini-grid models were subjected to the aspects of cash recovery, operations and maintenance, tariffs, productive use, environmental sustainability, viability, community engagement, capacity, availability, quality and reliability which are all the categories of the sustainability dimensions.

It is concluded through the results of the study that no one model shows complete sustainability under the considered dimensions. The Private and PPP mini-grids are the only mini-grid models that show closest to complete sustainability in all the dimensions of the sustainability provided. All the mini-grids have their strong points but are not sustainable in all aspects. They are thus considered not fully sustainable.

Private mini-grids show a strong suit in the cash recovery and cost-reflective tariffs. They are the best mini-grids to uptake for profit making. Community-owned mini-grids have their strong suit in community engagement and utility. PPP is commended for its ability to cater to the customers' needs and for lowering the tariffs. Community and PPP mini-grids meet similar problems from communities in terms of the charged tariffs. They have to charge cost-reflective tariffs in order to be sustainable. And now to answer the question this research study has been leading to (which mini what is a sustainable mini-grid and which is the best business model to implement to attain a sustainable mini-grid project in Lesotho?). A combination of private and community mini-grids is the best to implement in Lesotho.

These models have all the characteristics necessary for a mini-grid to be sustainable in Lesotho. The Private model is necessary for its impeccable success in the operation of the mini-grid throughout its lifetime, the coverage of O&M costs and the cost recovery. Its operations have a clear and concise business-oriented model that assures returns and assurance of profit that enables the building of more mini-grids. The community model is necessary for its high consideration of community participation. Basotho are a proud nation and highly need the sense of ownership and community engagement that comes with this model.

PPP mini-grids are the second best option to uptake, they have all the aspects that need to be added to the private model for it to be better suited for a country such as Lesotho but lack in the cash recovery category which limits the scalability and deployment of the new mini-grids. If they were business-oriented and operated like private mini-grids, they could overcome this problem and be suited for adoption. However due to the number of parties involved in their deployment, this model will be a highly conflict inciting route to follow in Lesotho.

5.2 Policy Recommendations

This subchapter gives the recommendations of individual mini-grid models as well as the averall recommendations for the inception and operation of all mini-grids.

PPP and private mini-grids are the closest to sustainable mini-grids as shown by this study. They are sustainable in four of the five dimensions of sustainability. They are the best to uptake for a country such as Lesotho whereas community and utility models trail behind in terms of sustainability.

Due to their high tariffs (even though cost-reflective) for a country as poor as Lesotho with the current high unemployment rate, Private mini-grids are most likely to find the charged amounts very high and unaffordable. This is where either the government or the utility aspect comes in. Although they are private, mini-grids could take the aspect of subsidies as used in the utility mini-grids. The government can provide subsidies to the consumers of the mini-grid energy in order for them to be able to use the mini-grid.The subsidies could be paid to the developer on a monthly basis and be on a pre-paid method. For developed countries with no lack of employment of their citizens and enough buying power private mini-grids are best to employ for both the developers and consumers developers will get their target cash back and profits and consumers will benefit by having a well run source of electricity through out the minigrid’s lifetime.

PPP model as commendable as and close to sustainability as is has a big weakness in operations due to the number of parties involved in their inception and operation. This often creates problems in expanding since not all the parties can always agree this could be solved by having some parties be silent partners in the operation and let it operate as a business. The involvement of governmental institutes limits it to operate as a business since the government is concerned with appeasing people for their own motives. This makes room for another weakness of cash recovery since they set their tariffs very low. Having it operated as a private business will solv this outlined problems

Community mini-grids are also good with their community participation. Private mini-grids pay attention to community participation but community mini-grids do this better. Community participation (as done by the community mini-grids) makes the community feel that it is mostly responsible for the plant that supplies them with electricity and thus increases the safety of the equipment at the plant and on the security costs. The hiring of community members in the inception of the mini-grid throughout its operations and teaching the community about minor maintenance as done by the community-owned mini-grids may benefit the country in lowering its high unemployment rates.

Community mini-grids have a weakness in coverage of the O&M costs in their operation since supplied customers feel they do not need to pay for something that was gifted to them. This can be solved by having as many meetings as possible with the community and prioritizing lesson delivered to them on the importance of the coverage of O&M costs and how the coverage will raise their tariffs and how it will benefit them in the long run. On a global standard community mini-grids can be bettered by giving the community a stake in the plant's shares and make them to actually own it and not just feel like they do. If done properly the protection of the plant and its equipment is raised and payment of hired guards is curbed.

Utility mini-grids biggest weakness is that they are utility owned and utility companies are mostly governmental and this gives a rise in their unsustainability because governments lower their tariffs a lot to drive their own motives and liking from consumers. This can be overcome by making utility companies non governmental or partially so (parastatal), to help make them have cost reflective tariffs or close to that as possible.

With the acceptance of the mini-grid models provided, there would be a rise in IPP in the country. As a result, there would be a need for improvement in their acquisition of documentation. To solve that problem, the following could be done:

- **Ease of access to documentation and shorter time in approval**
  Mini-grids take a long time from the planning and inception in Lesotho and this is mostly due to the scattered documents and the length of time needed in between document signing. This is seen as a bad investment for investors. For a project that takes 25 years or more and has to wait a long time for documentation it is not ideal for business and so this discourages investors. According to Lesotho mini-grids regulations the authority responds to the licensing of the mini-grid within 90, this means that if the license is not approved it would take 90 more days for reapplying if this happens more times the mini-grid developer will take almost or over a year to get licensing. Since Lesotho is in high need of mini-grids they could be given priority and have the authority work on them immediately and reduce the waiting time for receipt of licensing.

- **Online applications for mini-grids (or one-stop shopping)**
  It is hard for mini-grid developers to access all the documentation in Lesotho. The necessary documents are found in different locations that are also very hard to find because of unnamed streets. Since investors of mini-grids are mostly foreign people, the situation is even worse for them. To curb this problem, there should be an office in which all the documents can be found under one roof.

- **Enforcement of community participation**
  Enforcing community participation on mini-grid developers can reduce the unemployment rate and improve community acceptance and satisfaction of the minigrid and make the mini-grid sustainable. In turn, it may help the connected people and the country as a whole.

- **Subsidies**
  The government should create policies intended to help the consumers of energy from mini-grids with paid tariffs. Subsidies are a total need for Lesotho since people cannot afford to pay the cost-reflective tariffs necessary for the sustainability of mini-grids.

5.3 Limitations of the study and areas for further research

- There was a lack of information in the public domain relating to the study; some information was considered proprietary and could not be given out. Some details such as the cash recovery time of private mini-grids were seen as company confidential information and not given out by some mini-grids and those had to be filtered out and the search re done.

- Interviews were made with experts because the weighting analysis was limited due to the unavailability of people and thus the use of published papers for weighting was made. Some of the experts interviewed were in from different countries and hence different time zones and for that reason finding suitable time for meetings was a hustle and even more so when the second round of meetings was to be made.
- Time was particularly a factor in the research study, since some of the necessary information was either not easily attainable from the respective departments or time was necessary to visit the said offices. Due to the changing of the research because of its progression rescheduling of meetings was very difficult and more time was needed to and this lead to the research being cut shorter than it would have been.

The research study can be taken further through the use of statistical tools to measure the precise importance (to lowest degree of error) of the categories and dimensions of sustainability and not just the use of people's believes and opinions. A larger study area would also need to be made use of to make even better conclusions.

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Table :

APPENDIXES

Appendix 1:

Community Owned Mini-grids

Table 3: Developer and consumer framework for community owned mini-rids

Sustainability Dimension	Category	Sub-category	Scoring
Economic Dimension	Cash Recovery	☐ Investment cost recovery	0 = above 15 years
	O&M	☐ Tariff covers O&M expenses	0 = no
	Productive use	☐ Productive use of energy	1= there's any productive use
Environmental Dimension	Environmental Sustainability	☐ The presence of the mini-grid encourages less usage of traditional fuels	1= users of energy have adopted to use of electricity over the use of kerosene and other traditional sources of energy
Institutional Dimension	Viability	☐ Distance from existing grid	1= > 23 km
		☐ Terrain (how reachable the place is)	1= accessible
		☐ Threat of main grid to mini-grid	1= the mini-grid could be connected to the main grid
		☐ Customer identification (Buying power of the customer)	1= there is enough buying power amongst the consumers
Social Dimension	Community Engagement	☐ Is electricity cheaper than kerosene	1 =yes
		☐ Community acceptance and customer satisfaction	1= over 50% of the area is connected and satisfied/ highly accepted

Total = 8/10

4 Multi-Tier framework for community owned mini-grids

Categories		Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Availability	Daily Availability	-	-	-	-	✓
Capacity	Power (W)	-	-	✓	-	-
	Energy (Wh)	-	-	-	-	✓
Quality		-			✓	
Reliability		-			-	✓
Tariff	Affordability	-			✓	
	Setting	✓			-	

Total = 20/23

PPP Mini-grids

Table 5: Developer and consumer framework for PPP mini-rids

Table :

Sustainability Dimension	Category	Sub-category	Scoring
Economic Dimension	Cash Recovery	Investment cost recovery	1= 10 to 15 years
	O&M	Tariff covers O&M expenses	0= no
	Productive use	Productive use of energy	1= there's some productive use
Environmental Dimension	Environmental Sustainability	The presence of the mini-grid encourages less usage of traditional fuels	1= users of energy have adopted the use of electricity over the use of kerosene and other traditional sources of energy
Institutional Dimension	Viability	Distance from existing grid	1= > 23 km
		Terrain (how reachable the place is)	1= accessible
		Threat of main grid to mini-grid	1= the mini-grid could be connected to the main grid
		Customer identification (Buying power of the customer)	1= there is enough buying power amongst the consumers
Social Dimension	Community Engagement	Is electricity cheaper than kerosene	1= yes
		Community acceptance and customer satisfaction	1= over 50% of the area is connected and satisfied/ highly accepted
			Total = 9/10

6 Multi-Tier framework for PPP mini-grids

Categories		Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Availability	Daily Availability	-	-	-	-	✓
Capacity	Power (W)	-	-	✓	-	-
	Energy (Wh)	-	-	-	-	✓
Quality		-			✓	
Reliability		-			-	✓
Tariff	Affordability	-			✓	
	Setting	-			✓	

Total = 21/23

Private Mini-grids

Table 7: Developer and consumer framework for Private mini-rids

Sustainability Dimension	Category	Sub-category	Scoring
	Cash Recovery	☐ Investment cost recovery	1= 10 to 15 years

Table :

Economic Dimension	O&M	▯ Tariff covers O&M expenses	1= yes
	Productive use	▯ Productive use of energy	1= there's some productive use
Environmental Dimension	Environmental Sustainability	▯ The presence of the minigrid encourages less usage of traditional fuels	1= users of energy have adopted the use of electricity over the use of kerosene and other traditional sources of energy
Institutional Dimension	Viability	▯ Distance from existing grid	1= > 23 km
		▯ Terrain (how reachable the place is)	1= accessible 0= inaccessible
		▯ Threat of main grid to minigrid	1= the mini-grid could be connected to the main grid
		▯ Customer identification (Buying power of the customer)	1= there is enough buying power amongst the consumers
Social Dimension	Community Engagement	▯ Is electricity cheaper than kerosene	1= yes
		▯ Community acceptance and customer satisfaction	1= over 50% of the area is connected and satisfied/ highly accepted
			Total = 10/10

8 Multi-Tier framework for Private mini-grids

Categories		Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Availability	Daily Availability	-	-	-	-	✓

Capacity	Power (W)	-	-	✓	-	-
	Energy (Wh)	-	-	-	-	✓
Quality		-			✓	
Reliability		-			-	✓
Tariff	Affordability	✓			-	
	Setting	-			✓	

Total = 20/23

Utility Mini-grids

Table 9: Developer and consumer framework for utility owned mini-rids

Sustainability Dimension	Category	Sub-category	Scoring
	Cash Recovery	☐ Investment cost recovery	0= above 15 years

Table :

Economic Dimension	O&M	▯ Tariff covers O&M expenses	0= no
	Productive use	▯ Productive use of electricity	1= there's a productive use of electricity
Environmental Dimension	Environmental Sustainability	▯ The presence of the mini-grid encourages less usage of traditional fuels	1= users of energy have adopted the use of electricity over the use of kerosene and other traditional sources of energy
Institutional Dimension	Viability	▯ Distance from existing grid	1= > 23 km
		▯ Terrain (how reachable the place is)	1= accessible
		▯ Threat of main grid to mini-grid	1= the mini-grid could be connected to the main grid
		▯ Customer identification (Buying power of the customer)	1= there is enough buying power amongst the consumers
Social Dimension	Community Engagement	▯ Is electricity cheaper than kerosene	1= yes
		▯ Community acceptance and customer satisfaction	1= over 50% of the area is connected and satisfied/ highly accepted
			Total = 8/10

Table 10: Multi-Tier framework for utility owned mini-grids

Categories		Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Availability	Daily Availability	-	-	-	-	✓
Capacity	Power (W)	-	-	✓	-	-
	Energy (Wh)	-	-	-	-	✓
Quality		-			✓	
Reliability		-			✓	-
Tariff	Affordability	-			✓	
	Setting	✓			-	
					Total = 19/23	

Appendix 2

Table 11: Weighting Analysis score rating

Sustainability Dimensions	Important aspects for mini-grid		Rating
	Category	Sub-category	

Economic Dimension	Economic parameters	Capital recovery time	4
	O&M	Cost of maintenance (teaching the community so they can do the maintenance themselves) Cost of maintenance (getting skilled people to the location of the mini-grid)	4
	Productive use	Businesses connected	8
	Tariff	Price relative to income of residents Coverage of the O&M Affordability	10
Environmental Dimension	Environmental Sustainability	Reduction of illnesses due to the presence of the mini-grid and less usage of fossil fuels Is electricity cheaper than any form used by the residents	6
Institutional Dimension	Viability	Accessibility of area and cost to create a road network if none exists Time frame arrival of the main grid Threat of main grid to mini-grid	4
Social Dimension	Community engagement	Customer Identification Social acceptance of the mini-grid as a whole in the area (are they properly accepted) Number of connected households	10
Technical Dimension	Availability	Number of hours available during the day Number of hours available during at night	10
	Capacity	Power Energy	8
	Quality	Voltage variations for used appliances	10
	Reliability	Power cuts due to maintenance or other factors/ voltage variations	8