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- **Article title**: Microgrids and energy access: a case study based on a rural community in the Eastern Cape province of South Africa.


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## 1. Introduction

The United Nations Sustainable Development Goal (SDG) 7 champions for universal access to affordable, reliable, sustainable, and modern energy for all. This includes expanding access to electricity. Universal access to energy is necessary for economic, social, and human development. Having access to adequate and affordable energy is also vital to address energy poverty (Gashaye, Liu and Li, 2025).

Although hundreds of millions of people have gained access to electricity since 2010, progress has been uneven. Vast regional disparities in access rates persist and continue to increase. By 2024, 91% of the world's population had access to electricity, up from 78% in 2000. The greatest growth in access was observed between 2020 and 2022 in Central and Southern Asia. In contrast, the share of Sub-Saharan Africa in the global deficit ballooned from 49.6 % in 2010 to 83.3 % in 2022. The remaining unelectrified population is more difficult to serve because most of it is remote and low-income. Electricity access in urban areas increased from 96 % in 2010 to 98 % in 2022, while access deficits in rural areas shrank from 886 million globally in 2010 to 562 million in 2022. In rural areas of sub-Saharan Africa, the deficit grew (from 376 million to 473million) in the same period (IEA *et al.*, 2024; Sachs *et al.*, 2025).

In South Africa, 94.6% of households in formal dwellings and 58.3% of households in informal dwellings have access to an electricity connection (Stats SA, 2024). Those without access to electricity are predominantly in low-income households or located in rural areas. These areas remain excluded from many opportunities to live modern lives where they are able to trade and communicate with society at large. The extension of the grid to rural and remote areas with low levels of electricity consumption and limited ability to pay can be uneconomical. Investing in more affordable, decentralised energy systems, including stand-alone off-grid and microgrids, has significant potential to reach these areas and bridge the access gap by offering an alternative electrification model for rural settlements that are currently underserved by the electricity grid (Sachs *et al.*, 2025).

Microgrids, also known as mini grids, are defined as electrical power generation and distribution systems that supply electricity to local communities, covering domestic, commercial, and industrial demand. In the energy access context, microgrids operate on the principle of bringing power generation to the point of consumption, providing communities with autonomy over their energy needs. They commonly fall into small-scale size with a decentralised power system, powered by either fossil fuel or renewable resources, requiring an energy storage system. At times, located in remote rural areas and used for residential purposes at the community level. Their primary goal is to enhance energy resilience, reduce dependence on the grid, and empower communities to manage their energy resources efficiently (Dickson, 2024; Suryani *et al.*, 2024).

In South Africa, microgrids have gained traction as viable solutions to electrify rural and remote areas where extending the main grid is costly and impractical. These technologies are seen as means to provide localised power generation, reduce dependence on the national grid, and integrate the link between renewable energy sources (Nkambule, Hasan and Shongwe, 2025). The country's power utility, Eskom, has installed microgrids in 3 sites (Ficksburg in the Free State, Lyndoch in the Western Cape, and Swartkopdam in the Northern Cape) and aims to deploy up to 35 MW of microgrid technology to communities throughout the country in the near future (Eskom, 2023, 2025).

The study aims to assess the role that microgrids can play in enabling meaningful access to energy in remote rural communities by going beyond binary assessment measures, such as looking at whether a community has an electricity connection or not, but measures energy access by considering whether microgrid electrification induces improvement in people's livelihoods. This is done by adopting the MTF to data obtained from a microgrid deployed in the Upper Blinkwater village. The MTF is a multidimensional framework used to monitor and evaluate access to energy. The framework can be used to measure access to electricity as well (HEDERA Sustainable Solutions, 2021).

This study is organised as follows: Section 2 is the review of literature on microgrids and energy access. In addition, the co-benefits that can be realised from the deployment of these technologies in unelectrified rural communities are also discussed. Section 3 outlines the methodology, which details the MTF framework. Lastly, Section 4 discusses the MTF results, followed by the conclusion in Section 5, which considers the implications of the results.

## 2. Review of literature

### *2.1. Microgrids and energy access*

Deployment of microgrids is associated with economic, environmental, and social impacts (Saxena *et al.*, 2021). One of these social impacts is energy access. Numerous studies have been conducted internationally, regionally, and locally to understand the role microgrids can play in enabling energy access, particularly in rural and underserved areas that lack access to electricity.

Globally, microgrids have been shown to facilitate energy access in remote rural areas of middle- and high-income countries (Korkovelos *et al.*, 2020). Numerous studies further highlight their role in enhancing electrification efforts in developing and developed countries (Williams *et al.*, 2015; Hubble and Ustun, 2016, 2018; Saeed *et al.*, 2021; Zebra *et al.*, 2021; Kiehbadroudinezhad *et al.*, 2023; Onu, Zambroni de Souza and Bonatto, 2023). Studies, particularly those by Kiehbadroudinezhad (2023) and Saeed *et al.,* (2021), suggest that in addition to facilitating energy access, renewable energy-powered microgrids also offer other advantages, such as reducing greenhouse gas (GHG) emissions and reliance on imported energy sources.

Onu *et al.,* (2023) postulate that while developed countries mainly adopt microgrids to lower greenhouse gas (GHG) emissions and improve the resilience of energy supply, developing countries focus on providing energy access. For instance, Onu *et al.,* (2023) estimate that implementing microgrids in developed countries can reduce carbon dioxide ($CO_2$) emissions by 66% compared to emissions generated by traditional grid systems. The long-term sustainability of microgrids, especially in developing countries, is largely dependent on supportive policies and incentives (Zebra *et al.*, 2021; Onu, Zambroni de Souza and Bonatto, 2023). Williams *et al.,* (2015) indicate that such incentives can reduce the cost of renewable energy microgrids in low-income areas, thus encouraging private investment by improving expected marginal returns on investment.

There are different methods of measuring electricity access from the microgrid, as pointed out by Arshad et al., (2024), Narayan et al.,(2019) and Sulaeman et al., (2024). These include binary indicators, which focus on whether a household has a connection to electricity or not (Bhatia and Angelou, 2015), such as, the hybrid optimisation model for multiple energy resources, and the levelized cost of energy (LCOE) metric. However, such metrics have been found to present a narrow picture of energy access since human development factors are complex and multidimensional in their very nature (Nussbaumer, Bazilian and Modi, 2012). The Multidimensional Energy Poverty Index (MEPI) developed by Nussbaumer et al. (2012) attempts to overcome these limitations and focuses on the scarcity of access to modern energy services. The main drawback of this approach is its inability to capture service attributes, such as availability, reliability, and affordability (Pelz, Pachauri and Groh, 2018).

Consequently, the MTF has been suggested as a better measure of energy access and measures access with more elaborate attributes, including capacity, availability, reliability, affordability, legality and health & safety and has been applied in several studies. Focusing on two attributes of the MTF (capacity and availability) to measure electricity access, Arshad *et al*., (2024), suggest that remote communities in the Global South (GS) can obtain an additional 60% of energy access from an off-grid DC microgrid with distributed generation and storage compared to their standalone solar home systems (SHS). Additionally, households can use their existing or additional appliances for longer periods, thereby moving them to the MTF tier 3 of the availability attribute. Sulaeman *et al*., (2024), whose study relies on one power quality attribute of MTF to measure electricity access, indicates that power quality in microgrids is essential for mitigating malfunctions in connected appliances. The study further suggests that measuring microgrid power quality in remote areas is often challenging due to measurement and monitoring tools, such as voltage measurements, not being readily available.

In the African region, particularly in many parts of sub-Saharan Africa, lack of access to energy continues to be a significant issue. Microgrid deployment can facilitate the provision of energy access in rural areas (Baurzhan and Jenkins, 2016; Mekonnen and Sarwat, 2017) as demonstrated in various contexts, including Nigeria (Nnaji *et al*., 2019; Nwanevu, Oladipo and Ajayi, 2024), Rwanda (Muhoza and Johnson, 2018; Mudaheranwa *et al*., 2023), and Namibia (Azimoh *et al*., 2017).

However, effective deployment and long-term success of these microgrids rely on several factors, including community engagement, collaboration between the public and private sectors, international partnerships, and robust frameworks for rural electrification policy. Furthermore, several studies (Baurzhan and Jenkins, 2016; Muhoza and Johnson, 2018; Abada, Othmani and Tatry, 2021; Mudaheranwa *et al*., 2023; Nwanevu, Oladipo and Ajayi, 2024) argue that the economic feasibility of microgrids is influenced by the distance of rural communities from the national grid, where grid connection could be an option. However, for communities located at significant distances, the connection to the network is often not a practical option due to the high costs associated with extending the network and the minimal demand in sparsely populated rural areas.

Investigating the tiers of electricity access offered by microgrids in remote African communities has garnered the attention of various scholars, including (Kagimu and Ustun, 2016; Narayan *et al.*, 2018; Bekele *et al.*, 2024; Wu *et al.*, 2024). For instance, Deng et al (2025) show that a significant number of households in Doleib Hill Village (South Sudan) fall into Tier 0 as they rely predominantly on traditional energy sources such as wood, charcoal, and animal waste, with no access to modern electricity solutions. Only a few fall into Tiers 1 and 2 with minimal access to small solar systems, which remain inadequate for more advanced energy needs, such as powering larger appliances. Offering subsidies and affordable financing, along with the establishment of community-level RE-based microgrids, can help improve energy access and ensure reliable and sustainable energy for households. Bekele et al., (2024) show that in Ethiopia, low-income households fall into tier 1 of the affordability attribute of MTF for microgrid electricity access, with an expectation of more than 14 electricity interruptions per week. While medium-income households fall in tier 2, and high-income households fall in tier 3 up to tier 5 in terms of the affordability attribute of MTF.

Similarly, despite a significant electrification rate in South Africa, most rural areas in parts of the country remain without access to electricity. Several studies in the country delineated that microgrids have the potential to facilitate electricity access to rural communities for residents and businesses. They include studies whose focus was on rural communities of the Eastern Cape (Longe *et al.*, 2017; Xulaba and Allen, 2023), KwaZulu-Natal (Longe *et al.*, 2014; Longe, Myeni and Ouahada, 2019), Western Cape (Nkambule, Hasan and Shongwe, 2025) and other parts of South Africa (Motjoadi, Bokoro and Onibonoje, 2020). Using the levelized cost of energy (LCOE) metric, Xulaba and Allen (2023) determined that a hybrid microgrid (comprising wind, a diesel generator, and batteries) is economically viable at an LCOE of \$0.320/kWh, in contrast to the grid-connected power's LCOE of \$0.544/kWh. In a different study, Longe *et al.*, (2019) found that a hydropower-based microgrid is similarly cost-effective with an LCOE of \$0.384/kWh, when compared to a third of the grid connection's LCOE, which stands at \$0.128/kWh.

In contrast, Longe *et al.,* (2014) revealed that a hybrid microgrid (comprising photovoltaic and battery systems) has an LCOE of \$0.378/kWh, making it less cost-effective compared to the grid electricity's low LCOE of \$0.328/kWh. Motjoadi *et al.*, (2020) suggests that the additional costs associated with extending the electrical grid to remote rural areas in South Africa and other developing nations lacking significant economic activities make microgrids appropriate for delivering energy access to these communities.

The consequential impacts of access to energy through microgrids in rural communities of South Africa include increased productivity for local businesses, along with decreased $CO_2$ emissions and minimised health and safety risks associated with the use of conventional fuels such as wood, paraffin and candles (Longe *et al.*, 2014; Longe, Myeni and Ouahada, 2019; Xulaba and Allen, 2023). Other impacts include mitigating energy losses associated with the grid distribution network (Xulaba and Allen, 2023) and integrating renewable energy sources into energy systems (Nkambule, Hasan and Shongwe, 2025).

It can be inferred that, in addition to facilitating energy access, microgrids, particularly those powered by renewable energy, contribute to the reduction of greenhouse gas emissions, enhance the integration of renewable energy, and enhance energy security and resilience, which are the primary factors that encourage their implementation in developed countries. However, the ability of microgrids to offer energy access to communities, particularly in remote rural areas that are far from the grid, is a significant factor behind their increased deployment in developing countries. Furthermore, quantitative tools and methodologies, such as the hybrid optimisation model for multiple energy resources (HOMER) software, along with the LCOE metric, have emerged as preferred approaches by the majority of reviewed studies when it comes to the quantitative assessment of the deployment of microgrids to facilitate energy access. However, the use of these binary measures of electricity access is limited to assessing whether communities are connected or not connected to electricity. To overcome this limitation, other studies applied MTF, which considers multiple attributes to measure the levels of electricity access provided by microgrids to communities. The main challenge with using the MTF is assessing some of its attributes due to the lack of readily available data.

There is limited application of the MTF as a measure of energy access in South Africa, especially when it comes to the application of the framework to measure access to electricity from the deployment of microgrids. Therefore, this article aims to provide valuable information on the complex dynamics of electricity access and its implications for the socio-economic development of rural and low-income communities. In addition, this paper is poised to serve as a catalyst for policy consideration and evidence-based decision-making by relevant stakeholders.

### *2.2. Co-benefits of Microgrids*

As inferred in section 2 above, several studies have shown that beyond energy access, microgrids deliver a wide range of benefits, including improved health, access to education, employment opportunities, and enhanced economic growth. These benefits contribute towards the advancement of multiple SDGs (Carbon Trust, 2021; Pérez Figueroa and Ulibarri, 2024). This section discusses the co-benefits of adopting microgrids and associated SDGs.

#### 2.1.1. Health impacts

The use of traditional energy sources creates various health challenges, including respiratory and cardiovascular diseases. Renewable energy microgrids reduce greenhouse gas emissions and air pollution, consequently improving air quality and health outcomes (SDG 3- Good health and well-being). Other health benefits found include better adherence to treatment for individuals with chronic diseases in rural areas due to timely meal preparation, timely administration of medication, and secure medication storage enabled by electrification. This results in positive health outcomes (Lesala and Mukumba, 2025b).

#### 2.1.2. Access to education

Due to the lack of access to electricity, children often cannot extend their study hours, reducing productive hours. In turn, children have to assist in household chores and spend time collecting fuel for lighting, heating, and cooking. This affects their school performance, reduces school attendance and likelihood of enrollment (Nano, 2022). Microgrids provide energy access that allows lighting, allowing children to extend their study houses. This will lead to improved school performance, attendance, and increased completion rate, ultimately contributing to SDG 4 (Quality education) (UNDESA, 2014).

2.1.3. Job creation and economic growth

The development and operation of microgrids requires a diverse range of skills, thus creating jobs within communities. Jobs can be created in the construction and maintenance phase of the operation. The development of microgrids typically requires electricians, caretakers and construction workers linked to civil and infrastructure works, which can be sourced within the host communities (Kausya, 2022).

In addition, the energy access provided by microgrids in rural communities enables the establishment and expansion of existing businesses, such as local stores in the host communities, creating additional job opportunities(Adonis, 2024). This increases the income levels of communities, which in turn creates a multiplier effect as employees can spend their income on the local economy, increasing spending in other sectors, enabling the creation of additional jobs, contributing to overall economic growth and job creation (SDG 8 – Decent work and economic growth) (Kollanyi *et al.*, 2018).

2.1.4. Gender equality

Women, especially in rural areas, are responsible for collecting fuel for cooking. The deployment of microgrids can reduce the burden and save women time. This will allow them to participate in productive and income-generating activities (SDG 5 – Gender equality). According to Lesala and Mukumba (2025b) improvements in household modernisation in rural areas with increased adoption of modern appliances such as refrigerators, electric kettles, and washing machines, significantly reduced domestic labour, particularly for women and girl children.

## 3. Methodology

### 3.1. The study area

The UB community is a remote and rural community of 57 households located in the Raymond Mhlaba Local Municipality in the Eastern Cape Province, South Africa. The village is not connected to the Eskom electricity grid and has limited accessibility due to inadequate infrastructure development and sparse settlement (GIZ, 2020). The community had little prospects for electrification in the future due to low electricity demand, low population density, and high cost of grid extension.

This community was chosen as the focus of the study, as it was the first identified beneficiary of microgrid technology implemented in South Africa to address rural electrification challenges in the country. Refer to Figure 1 for a schematic representation of the project. The microgrid is also equipped with smart prepaid meters integrated into the municipal billing system (ESI Africa, 2024).

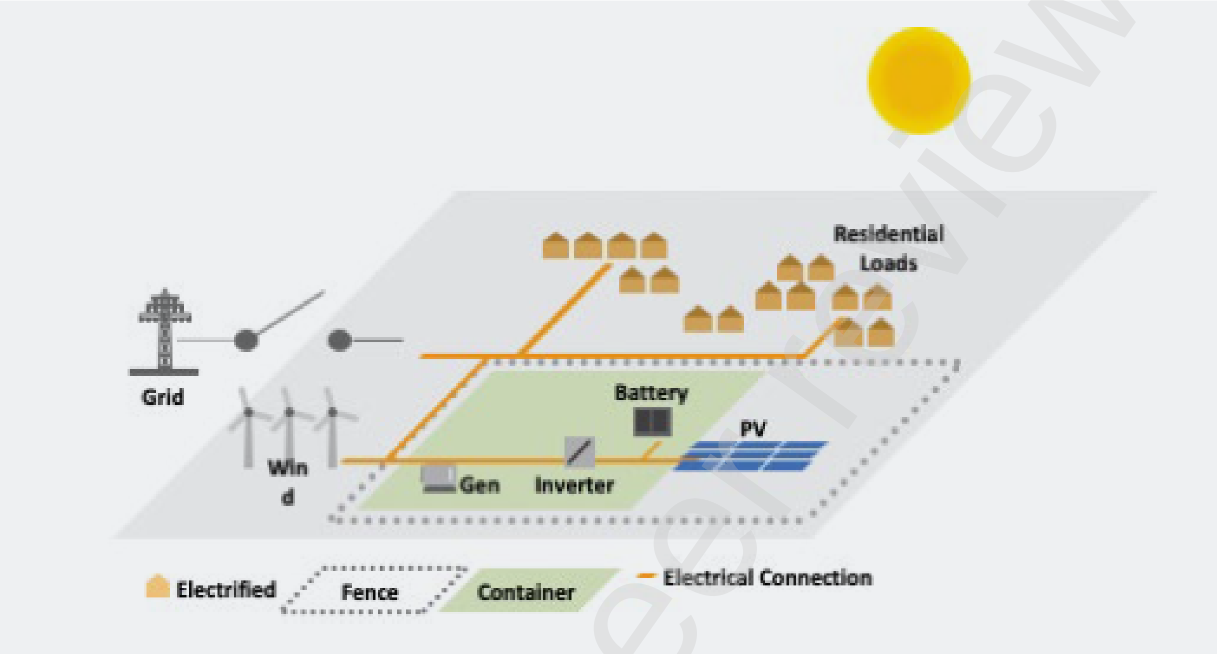


*Figure 1: Project schematic, components and connection. Source:* (GIZ, 2020)

The target supply for the UB microgrid was tier 4, which translates to a minimum capacity of 800W per household, a minimum power of 3.4kWh per day and a minimum availability of 16 hours per day. At this level, in addition to basic lighting and phone charging, each household should be able to operate energy-intensive household appliances such as a washing machine, iron, toaster and microwave (GIZ, 2020).

Community survey data collected in the community before the deployment of the micro-grid revealed that the village had high levels of poverty and unemployment and low levels of income, with the majority (90%) of households living off social grants (GIZ, 2020). The deployment of the hybrid microgrid is said to have brought some changes to the socio-economic conditions of the community, such as an increase in self-employment from 6% to 11%. This suggests that improved access to electricity may have allowed the development of small businesses, particularly those that require energy-intensive activities. The average monthly household income in the village improved slightly to range between R2 321.90 and R2 710.  However, many challenges remain. There is still high unemployment in the community and a continued dependency on social grants for income (Lesala and Mukumba, 2025b).

### 3.2. Data collection

Data was collected on an hourly basis from a publicly available portal where data from the performance of the microgrid could be obtained. The collected data is representative of 1-year of the microgrid's operation. The period reviewed was 2022, with some data from 2021 to augment where there was no data for a particular month in 2022. For instance, in June and December 2022, no data were available, so the load data from June 2021 and December 2021 are used to obtain a full representative year of load data. The assumption is that the usage would not drastically be different from one year to the next, hence the augmentation to represent 1 year.

### 3.3. Data analysis

The study used the assessment criteria set out in the MTF, shown in Figure 2, which is a multidimensional framework developed by the World Bank's Energy Sector Management Assistance Program (ESMAP) to assess electricity access for the UB community, provided by the UB microgrid that is powered by solar PV, wind power, battery energy storage and a backup diesel generator. The MTF was selected for its ability to improve on the dualistic accounting method of measuring access to electricity. Furthermore, it redefines household access to electricity based on seven standard attributes: capacity, availability, reliability, quality, affordability, formality, and health and safety. In this way, access to electricity is measured across a spectrum of levels for each household or community, from Tier 0 - no access, to Tier 5 - highest level and high quality access, with each attribute evaluated separately (Bhatia and Angelou, 2015; Jain, Urpelainen and Stevens, 2016; HEDERA Sustainable Solutions, 2021).

The assessment of the attributes of the MTF for the study, particularly the peak capacity and availability attributes, relied on the secondary data collected from a publicly available portal, as outlined in section 3.2 and analysed using the Microsoft Excel application. Due to data gaps, the secondary data was supplemented with the literature review to assess the remaining attributes, such as reliability, quality, affordability, legality and health and safety in relation to electricity access provided by the UB microgrid.

According to the framework's principles, the lowest attribute score determines the overall tier. Despite the strengths in other areas, a single shortfall can constrain the overall MTF Tier. Thus, the lowest-performing dimension defines the overall supply tier provided to the household (Pelz and Urpelainen, 2020). In this study, the MTF's energy access attributes are used to assess electricity access in the community of UB following the installation of a microgrid. The initial design of the microgrid was intended to be Tier 4. The MTF is adapted to focus on all 7 attributes.

| ATTRIBUTES | | TIER 0 | TIER 1 | TIER 2 | TIER 3 | TIER 4 | TIER 5 |
|---|---|---|---|---|---|---|---|
| **Peak capacity** | Power capacity ratings in W or daily Wh | | Min 3 W | Min 50 W | Min 200 W | Min 800 W | Min 2 k W |
| | | | Min 12 Wh | Min 200 Wh | Min 1.0 kWh | Min 3.4 kWh | Min 8.2 kWh |
| | OR Services | | Lighting of 1 000 lm hr/day | Electrical lighting, air circulation, television, and phone charging are possible | | | |
| **Availability (Duration)** | Hours per day | | Min 4 hrs | Min 4 hrs | Min 8 hrs | Min 16 hrs | Min 23 hrs |
| | Hours per evening | | Min 1 hr | Min 2 hrs | Min 3 hrs | Min 4 hrs | Min 4 hrs |
| **Reliability** | | | | | | Max 14 disruptions per week | Max 3 disruptions per week of total duration < 2hrs |
| **Quality** | | | | | | Voltage problems do not affect the use of desired appliances | |
| **Affordability** | | | | | Cost of standard consumption package of 365 kWh/year <5% of household income | | |
| **Legality** | | | | | | Bill is paid to the utility, prepaid card seller, or authorised representative | |
| **Health and safety** | | | | | | Absence of past accidents and perception of high risk in the future | |

*Figure 2: Multi-Tier Framework for Measuring Access to Energy. Source: (HEDERA Sustainable Solutions, 2021)*

## 4. Results and Discussion

The results of the study were obtained using the World Bank's Multi-Tiered Framework (MTF) to measure household energy access. The seven attributes: peak capacity, availability, legality, quality, health and safety, and affordability, were selected to measure the level of energy access brought by the adoption of the UB microgrid. The results of the selected attributes are discussed in their respective sections (4.1 - 4.7) below.

### 4.1 Peak capacity

The UB microgrid has an installed capacity of about 172.5kW, which is 3.02kW per household. This fulfils Tier 5 of the MTF, which requires that a minimum of 2kW of power capacity of an energy system, such as a microgrid, be deployed for the provision of energy access. For daily electricity output, the UB microgrid provides a daily average of 115.56kWh of electricity consumption to 57 households across all months. This translates to a daily average of 2.03kWh of electricity consumption per household, which fulfils Tier 3 of the MTF in terms of the daily capacity attribute. Additionally, as shown in Figure 3, the daily maximum and minimum electricity that can be provided are 160.67kWh for December and 88.40 kWh for September, respectively. The electricity access needs of communities can be met with appropriate capacities of microgrids. For instance, in the Chitral district of Pakistan, electricity access needs for the majority of the population have been met by Micro Hydro Project (MHP)'s capacity, which achieved Tier 5 of MTF (Khan *et al.*, 2021).


*Figure 3: Average kWh per day provided by UB Microgrid for 57 households*

### 4.2 Availability

The availability attribute of MTF measures the number of hours per day and evening during which electricity is available to end users. On average, for a representative year, UB microgrid is providing electricity access to the community for 7720 hours (88.13%) (see Table 1). This translates to 21.15 hours per day (24 hours) of electricity availability, which places UB microgrid above the minimum threshold of 16 hours on Tier 4 of MTF in terms of the availability attribute. Overall, hours without electricity access are limited to 2.84 hours. However, November is the only month with significant hours without electricity access, about 498 hours (69.17%) per month. This can be attributed to the period during which the UB microgrid is taken for maintenance services.

For evening hours, ranging from 6 to 10 pm (5 hours), the UB microgrid provides electricity access to the community for 1615 hours (88.49%) per year. This translates to an average of about 4.42 hours per evening, fulfilling Tier 4 of MTF, which requires that a minimum of 4 hours per evening of electricity access be provided by the energy system. Similarly, the month of November remains liable for a significant number of hours (105 hours) during which the electricity is not available.

The UB community's ability to achieve a high Tier of MTF through its microgrid aligns with Arshad *et al*., (2024) assertions that remote communities in the Global South (GS) can obtain energy access from an off-grid DC microgrid and possibly move to Tier 3 of MTF in terms of the availability attribute.

*Table 1: Upper Blinkwater microgrid hours per day and evening with electricity availability*

| Month | Hours per day with electricity availability | Percentage (%) | Evening hours with electricity availability | Percentage (%) |
|---|---|---|---|---|
| **January** | 726/744 | 97.58 % | 150/155 | 96.77% |
| **February** | 602/672 | 89.58% | 125/140 | 89.29% |
| **March** | 744/744 | 100% | 155/155 | 100% |
| **April** | 685/720 | 95.14% | 145/150 | 96.67% |
| **May** | 683/744 | 91.80% | 145/155 | 93.55% |
| **June** | 517/720 | 71.81% | 110/150 | 73.33% |
| **July** | 590/744 | 79.30% | 125/155 | 80.65% |
| **August** | 744/744 | 100% | 155/155 | 100% |
| **September** | 720/720 | 100% | 150/150 | 100% |
| **October** | 744/744 | 100% | 155/155 | 100% |
| **November** | 222/720 | 30.83% | 45/150 | 30.00% |
| **December** | 743/744 | 99.87% | 155/155 | 100% |
| **Total** | **7720/8760** | **88.13%** | **1615/1825** | **88.49%** |

### 4.3 Reliability

The reliability of electricity supply refers to the frequency and duration of unexpected disruptions, which imply that electricity supply should be available most of the time when required by the consumers (Choi and Koo, 2024). Section 4.2 reveals that electricity supply from the UB microgrid is available for 21.15 hours per day (24 hours) on average, which means it is available most of the time when it is needed. This renders the UB microgrid reliable in providing electricity to 57 households of the UB community. This aligns with GIZ (2020) and Lesala and Mukumba (2025b). GIZ (2020) confirm that the UB microgrid has been providing a reliable electricity supply to the community of UB in Raymond Mhlaba Municipality. GIZ

(2020) further argues that the ability of microgrids to optimise consumption increases the reliability of the electricity supply they offer. Lesala and Mukumba (2025b) reveal that the electricity supply from UB microgrid was commended for its reliability, with residents from UB emphasising its stability and the absence of load shedding or blackouts. UB microgrid fulfils Tier 4 and 5 of the MTF in relation to the reliability attribute, which allows the energy system to only experience a maximum of 2 disruptions per week with a total duration of less than 2 hours. This is supported by the findings of Lesala and Mukumba (2025b), which confirm that the UB residents never experienced load-shedding or blackouts from the UB microgrid. The UB community mostly experiences scheduled outages for maintenance purposes.

### 4.4 Legality

In the MTF, legality is assessed by determining if electricity is supplied through a formal or informal connection. This involves checking if payments are made to a utility or an authorised representative. The payments for the electricity received from the use of the UB microgrid are administered by the local municipality. Each household has a prepaid meter, which is linked to the municipal billing system (MyPR, 2022). Therefore, the connection of the microgrid can be considered to meet the legality attribute of the MTF (Tier 4 and 5).

### 4.5 Quality

The quality attribute refers to voltage fluctuations which do not damage a household's appliances. The installation of smart meters for all households at UB village has enabled energy consumption monitoring and fraud detection. In addition, the smart meters have an added feature that minimises voltage fluctuations by reducing power consumption during periods of frequency fluctuations (GIZ, 2020). The data from the smart meter is fed to the microgrid controller unit, which triggers loadshedding when households exceed the required maximum energy consumption from the system. As a result, there have been no appliance damage reports from households. Instead, there has been an increase in the use of appliances (Meeks *et al.*, 2019; DEDEAT, 2022; MyPR, 2022). This classifies the quality attribute as Tier 4 and Tier 5.

### 4.6 Health and Safety

The health and safety attribute refers to incidents caused by the use of electrical appliances. According to Tait (2017) a lack of safety knowledge among system users increases the rate of incidents. In the case of UB village, the hosting of technical learning workshops and households' visits have enhanced households' knowledge in terms of appliance use, energy literacy, and behaviour adaptation (Lesala and Mukumba, 2025a). As a result, majority of households have switched to energy-efficient appliances. In addition, due to strengthened user-system relationships and behaviour changes, there has been an improvement in safety and system performance (Lesala and Mukumba, 2025a). This can result in low incidents associated with the use of electrical appliances. Therefore, this classifies the health and safety attribute between Tier 4 and Tier 5 due to the absence of reported incidents in the past.

## 4.7 Affordability

Affordability measures whether users can afford to pay for the electricity they receive. MTF requires that to be considered affordable electricity access, a standard consumption package of 365 kWh per year should not cost more than 5% of the household's income. It is not clear from the available literature how much households are charged in tariffs to access electricity from the UB microgrid; therefore, assumptions are made. Table 2 outlines the assumptions made to calculate the affordability levels, including consumption, income and tariff.

*Table 2: Affordability attribute assumptions*

| Assumption | Monthly | Annual |
|---|---|---|
| **Average consumption** | 56.52 kWh | 678.24 kWh |
| **Average income** | R2 500[1] | R30 000 |
| **5% of income** | R125 | R1500 |
| **Tarriff** | R2.65(Raymond Mhlaba Municipality, 2025) | R2.65 |
| **% of household income** | 6% | 6% |

Taking into consideration the assumptions, the average household in the village of UB can be expected to spend approximately R1 500 (R2.65 * 678.24kWh) per year on electricity. This is 6% of the household income, which is slightly higher than the 5% desired level of the MTF. This implies that the electricity provided by the microgrid may be unaffordable for the average low-income household in the UB village. These results align with those of Lesala and Mukumba (2025b), indicating that affordability remains a concern for some of the households in UB village since it is dependent on various factors such as household size, usage patterns, and household income. As aforementioned, the majority of households depend on social grants as a source of income to sustain their livelihoods, which might be insufficient to cover energy related costs. As a result, as stated by Mutumbi *et al.,* (2021), almost all households in the community continued to use traditional sources of energy (firewood, paraffin, and LPG) post the availability of electricity in the village. The analysis confirms the assertion that due to a lack of income and high energy costs, low-income households resort to alternative energy sources to meet their basic energy needs (Masuku, 2024). Therefore, this means that the affordability attribute for UB microgrid falls between Tier 0 and Tier 2 because the electricity consumption cost is greater than 5% of the total household income.

This affordability attribute drives the overall Tier of the microgrid between Tier 0 and Tier 2, since the lowest performing attribute defines the overall Tier. This implies that unaffordability limits electricity accessibility, although the electricity from the microgrid is available for use, reliable, and safe. This therefore means that beyond the deployment of microgrids in rural communities to expand electricity access. Targeted interventions are necessary to ensure the continued use of the newly available electricity. These interventions ought to be aimed at improving the community's ability to pay for electricity, i.e. affordability.

[1] (Lesala and Mukumba, 2025b)

Beyond subsidising the electricity costs for consumers, scholars have proposed the stimulation of economic activities in rural areas to enable households to generate additional income. The additional income generated can ensure that they can pay for the electricity consumed, consequently improving the affordability attribute (Mosetlhe *et al.*, 2025). In the case of UB village, although there has been an expansion of existing businesses, which have created local employment due to electrification, the majority of the community members still remain unemployed, hence the reliance on social grants. Therefore, there is a need to expand economic activities in the area to stimulate economic growth (Lesala and Mukumba, 2025a, 2025b).

## 5. Conclusion and policy implications

This study adapted the MTF framework for the UB community microgrid to assess the role that this microgrid has played in improving energy access in this community. The majority of assessed attributes suggest that the electricity supply from the UB microgrid ranges between Tier 3 and Tier 5. However, based on the affordability attribute, the microgrid cannot be placed in the range between Tier 3 and 5. This brings the overall Tier between Tier 0 and Tier 2. Suggesting that, beyond the availability and capacity of the electricity supply, the affordability of the supply is equally important to enable rural socio-economic development and to realise the co-benefits discussed in Section 2.1 for rural communities. Policy makers should move beyond focusing on increasing and measuring the number of people with electricity access, towards ensuring that the electricity provided is affordable for low-income households, such as those in the UB village. Increasing electricity access alone is therefore not sufficient if not coupled with an enabling policy framework to lower the cost of electricity for low-income households. This approach can optimise the allocation of the government's limited financial resources and ensure that the energy solutions provided align with the unique needs of rural communities.

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