

# **Socio-Economic Impacts and Challenges of Electrifying Remote Rural Areas in Tanzania Using a Mini-Grid System**

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**Abstract:** This paper examines the socio-economic impacts and challenges of electrifying remote rural areas in Tanzania using mini-grid systems, focusing on the Kuruti Island project in the Pwani Region. Renewable energy-based mini-grids, particularly solar-powered systems, offer a viable solution to improve energy access in off-grid communities. The study reveals significant socio-economic benefits, including enhanced livelihoods, local business growth, improved healthcare and education services, and increased productivity, especially in the fishing industry. However, challenges such as affordability, long-term system maintenance, and limited technical capacity persist. Key policy recommendations include the need for flexible payment schemes, community engagement, hybrid energy solutions, and ongoing technical training to ensure sustainability. Additionally, the paper suggests future research into innovative financing models, scaling of mini-grid projects, and productive energy uses to drive rural development. The Kuruti Island case study provides practical lessons for similar electrification efforts in Tanzania and other developing regions, emphasizing the importance of tailored energy solutions that meet local socio-economic needs.

**Keywords:** Rural electrification, mini-grid systems, renewable energy, socio-economic impact, Tanzania, solar power.

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## **I. Introduction**

In recent years, substantial global progress has been made in expanding access to electricity. As of 2017, the number of people without access dropped below 1 billion for the first time (IEA, 2018). Despite this achievement, continued efforts are essential, as electricity access remains uneven across different regions. By 2017, 91% of the populations in Central and South Asia had electricity access, and the rate was as high as 98% in Latin America, the Caribbean, and East and Southeast Asia. In contrast, only 45% of the population in Sub-Saharan Africa (SSA) had electricity, leaving approximately 573 million people without access. Africa remains the epicenter of the global energy access challenge, with 14 of the 20 countries with the largest electricity deficits located in the region (IEA, 2021).

In SSA, average per capita electricity consumption remains critically low at 317 kWh annually—less than 1 kWh per person per day (IEA, 2020). This accounts for just 4% of global energy demand, despite SSA being home to 14% of the world's population (United Nations, 2022). These figures underscore the urgent need to address energy poverty in SSA to support economic growth and development. Access to electricity is essential for driving socio-economic development, improving quality of life, and fostering economic opportunities. However, in many developing countries, especially in Sub-Saharan Africa, rural areas remain largely underserved by national electricity grids. Tanzania is no exception, with significant portions of its rural population lacking reliable access to electricity.

## **The Importance of Rural Electrification in Tanzania**

Rural electrification is critical for improving living standards and achieving economic growth in Tanzania. Access to electricity in rural areas can enhance agricultural productivity, enable local businesses to thrive, and improve the provision of essential services such as healthcare and education. Furthermore, it helps to reduce reliance on traditional energy sources, such as kerosene and firewood, which contribute to environmental degradation and pose health risks due to indoor air pollution (IEA, 2021). For Tanzania to meet its development goals, particularly those outlined in the Tanzania Development Vision 2025 and the Sustainable Development Goals (SDGs), addressing energy poverty in rural areas is vital.

## **Mini-Grid Systems as a Solution**

Given the logistical and financial constraints of expanding the national grid, mini-grid systems have emerged as a viable solution for rural electrification in Tanzania. A mini-grid system is a decentralized energy generation and distribution network, typically powered by renewable energy sources such as solar, wind, or biomass, that provides electricity to off-grid communities. Mini-grids offer a flexible and scalable option for electrifying remote areas that are unlikely to be reached by the national grid in the near future (IRENA, 2018). In Tanzania, the government has recognized the potential of mini-grids in its Rural Electrification Strategy and Action Plan, which aims to increase rural electricity access through both grid extension and decentralized solutions like mini-grids (REA, 2020).

## **Current Status of Mini-Grid Electrification in Tanzania**

Tanzania is already home to several mini-grid projects, many of which are powered by renewable energy. According to the

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Tanzania Energy Access Situation Report (2019), there are over 100 operational mini-grids in the country, serving an estimated 184,000 households. These systems are primarily found in rural and peri-urban areas, providing power to households, small businesses, schools, and health facilities. Despite the growing presence of mini-grids, challenges remain, including high upfront capital costs, limited technical expertise, and the need for stronger policy support.

## **II. Objectives of the Review**

The primary objective of this review is to assess the socio-economic impacts and challenges associated with the electrification of remote rural areas in Tanzania through mini-grid systems. The paper will explore how access to electricity via mini-grids has contributed to improvements in economic development, health, education, and overall quality of life in rural communities. Additionally, it will address the obstacles faced in the deployment and sustainability of mini-grid systems, such as financial constraints, technical challenges, and regulatory barriers. By providing a comprehensive analysis, this review aims to inform policymakers, investors, and stakeholders about the potential of mini-grids to drive rural electrification in Tanzania and highlight the necessary steps for scaling up these initiatives.

### **Importance of Socio-Economic Analysis**

Understanding the socio-economic impacts of mini-grid systems is crucial for evaluating their effectiveness as a rural electrification solution. While electrification can bring numerous benefits, its success is contingent on various factors, including affordability, reliability, and community acceptance. A socio-economic analysis allows for a holistic evaluation of how mini-grids influence livelihoods, income generation, access to services, and social inclusion. Furthermore, examining the challenges faced by mini-grid projects—such as high costs, lack of technical capacity, and regulatory hurdles—can provide valuable insights into how these barriers can be overcome. This review, therefore, seeks to contribute to the growing body of knowledge on decentralized energy solutions in Tanzania and their role in achieving sustainable rural development. Explore into the specific socio-economic impacts of mini-grid systems in rural Tanzania, including their effect on agricultural productivity, small business growth, health services, and education. It will also identify the key challenges faced in deploying these systems and propose strategies for overcoming them to ensure the long-term sustainability of mini-grid electrification projects.

### **Overview of Minigrids in Tanzania**

Mini-grid systems have emerged as one of the most promising solutions for providing electricity to remote rural areas in Tanzania, where extending the national grid is either technically unfeasible or financially prohibitive. With growing participation from the government, private sector, and communities, mini-grids have already improved energy access for thousands of rural households. However, to realize the full potential of these systems, more needs to be done to streamline the regulatory framework, ensure financial sustainability, and promote the integration of renewable energy. In this section, we will explore the different types of mini-grid systems, examine ongoing initiatives, and analyze the policy and regulatory framework that governs the implementation of these systems.

### **Types of Mini-Grids**

Mini-grids are localized power systems that operate independently from the national grid, delivering electricity to off-grid communities. These systems generally include power generation units, distribution networks, and control systems to manage electricity supply. They can vary in size from micro-grids serving a few households to larger systems covering entire villages (Rao et al., 2020).

#### **Renewable Energy-Based Mini-Grids**

Renewable energy-based mini-grids are prevalent in Tanzania due to the country's significant renewable resources. Solar mini-grids, utilizing photovoltaic panels combined with battery storage, are widely adopted. Tanzania's high solar potential, with an average of over 2,500 hours of sunlight per year, makes solar mini-grids particularly effective (Norton et al., 2021). Solar mini-grids can provide reliable power during the day and store energy for nighttime use, thus enhancing energy access in remote areas.

Biomass mini-grids, which use organic materials like agricultural residues, are also prominent. These systems are especially beneficial in areas with substantial agricultural activity, where biomass resources are readily available (Ghimire et al., 2022). Additionally, small-scale hydroelectric mini-grids exploit local water resources to generate power, making them suitable for regions with reliable water flows (Hussain et al., 2021).

#### **Hybrid Mini-Grids**

Hybrid mini-grids, combining renewable sources with conventional generators like diesel, offer enhanced reliability by balancing the intermittent nature of renewables. These systems can operate on solar power during the day and switch to diesel generators during periods of low solar availability (Peters et al., 2019). Although costlier, hybrid mini-grids provide a stable electricity supply, which is crucial for ensuring continuous service to rural communities.

#### **Current Mini-Grid Initiatives in Tanzania**

Tanzania has made substantial strides in deploying mini-grids to improve rural electrification. According to the Rural Energy Agency (REA), more than 100 mini-grids are operational across the country, with a significant focus on renewable energy sources

(REA, 2020). This section explores the roles of government, private sector, and community-based initiatives in advancing these projects.

### **Government-Led Initiatives**

The Tanzanian government has been instrumental in promoting mini-grids through policies and programs aimed at increasing rural electricity access. The National Electrification Program Prospectus (2014) outlines strategies to leverage both grid extension and decentralized solutions like mini-grids (REA, 2020). The government supports mini-grid projects through financial incentives, such as subsidies and grants, to reduce the initial capital burden on developers.

### **Private Sector Participation**

The private sector has significantly contributed to the development of mini-grids in Tanzania. Companies like JUMEME Rural Power Supply Ltd have pioneered solar mini-grids, serving thousands of rural households. JUMEME's innovative business model includes pay-as-you-go (PAYG) systems, allowing users to pay for electricity in small increments, which enhances affordability (JUMEME, 2018). Similarly, Solar Tanzania operates several solar mini-grids and focuses on integrating energy storage solutions to enhance reliability (Karanja et al., 2021).

### **Community-Based Projects**

Community-based mini-grid projects have also proven effective. For example, the Mikoko Mini-Grid Project demonstrates successful community management and ownership. Initiated with donor funding, the project has become self-sustaining through revenue generation from electricity sales (GVEP International, 2020). These projects often involve local cooperatives in the planning and management stages, ensuring that the systems are tailored to community needs and supported by local stakeholders (Kigabo et al., 2022).

### **Policy and Regulatory Framework**

The Tanzanian policy and regulatory framework support mini-grid development, though challenges remain. The Electricity Act of 2008 and subsequent regulations provide a foundation for mini-grid operations, outlining roles and responsibilities for various stakeholders (Tanzania Electricity Regulatory Authority [TERA], 2021).

### **Tariff Regulation and Subsidies**

Setting appropriate tariffs is crucial for the sustainability of mini-grid projects. The Energy and Water Utilities Regulatory Authority (EWURA) regulates tariffs to balance affordability with operational viability. EWURA's guidelines allow for flexible tariff structures, particularly for renewable energy-based mini-grids, which typically have lower operating costs compared to diesel-based systems (EWURA, 2020). Financial support through the Rural Energy Fund (REF) helps to offset high initial costs and stimulate private investment (REA, 2020).

### **Challenges in the Policy Framework**

Despite these supports, the regulatory environment poses challenges. The licensing process can be cumbersome, and there is a lack of clear guidelines for integrating mini-grids with the national grid. These issues can hinder the expansion of mini-grids and their ability to scale effectively (Karekezi et al., 2020). Addressing these barriers is essential for maximizing the impact of mini-grids on rural electrification.

### **Socio-Economic Impacts of Electrifying Rural Areas Using Mini-Grid Systems**

Electrifying remote rural areas in Tanzania using mini-grid systems has significant socio-economic impacts. These impacts range from improving quality of life, economic growth, education, and healthcare to enabling new income-generating opportunities and promoting gender equality. This section delves into the detailed socio-economic benefits, challenges, and limitations, with a focus on research findings from other studies.

### **Improvement in Quality of Life**

Access to electricity is widely recognized as a key factor in improving the overall quality of life in rural areas. By providing reliable and affordable energy, mini-grids can have profound effects on households. Studies have shown that electrification leads to improved lighting, which enhances comfort and safety for families, particularly in the evening hours. As Kirubi et al. (2020) point out, rural electrification reduces reliance on traditional biomass energy sources, such as firewood and kerosene, which are not only inefficient but also detrimental to health due to indoor air pollution.

Additionally, electrification improves access to information and entertainment through radio, television, and mobile phones. In many rural Tanzanian communities, mini-grids have increased mobile phone usage and facilitated the operation of phone-charging businesses, contributing to local economies (Bensch et al., 2018). Access to electricity has also enhanced communication and connectivity with the outside world, further expanding rural residents' access to services and opportunities (Pueyo & DeMartino, 2019).

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**Economic Growth and Development**

One of the most significant socio-economic benefits of mini-grid systems in rural Tanzania is the promotion of local economic growth. Electrification facilitates the establishment of small and medium-sized enterprises (SMEs) that rely on energy for operation, such as welding shops, grain mills, and refrigeration services. These businesses create employment opportunities and increase household incomes (Fowowe, 2016). In an empirical study by Mahmood et al. (2018), villages with access to mini-grid electricity in Tanzania reported a 25% higher rate of business formation compared to non-electrified villages.

Electricity access allows agricultural processing activities to flourish. Electrified rural communities can engage in activities like milling grains and storing perishable crops using refrigerators, significantly reducing post-harvest losses. The ability to process crops locally increases their value and provides farmers with better market prices (Riva et al., 2020). Furthermore, as Bernard (2019) highlights, electrification contributes to rural productivity, enabling farmers to work longer hours and utilize electrically powered tools.

Moreover, rural electrification through mini-grids encourages the development of agro-processing industries, which play a vital role in local economies. These industries provide a stable source of income, fostering economic diversification away from purely agricultural activities (Gulagi et al., 2020).

**Impact on Education**

The introduction of electricity to rural areas also positively impacts education by extending study hours for students and improving access to modern educational resources. Electrified schools in rural Tanzania have experienced better academic performance as a result of longer study hours and access to computers and the internet (Kirubi et al., 2020). In non-electrified areas, students primarily rely on dim and hazardous kerosene lamps, which limit the amount of time they can study after dark (Grimm et al., 2016). With reliable electricity from mini-grids, students can study in well-lit environments, improving their academic success.

Schools with electricity can also benefit from modern teaching aids, such as projectors and computers, which contribute to better teaching methods and higher engagement levels. According to Abdulai & Owusu-Ansah (2020), access to electricity in schools has been associated with improved teacher retention rates, as teachers are more willing to work in electrified environments.

**Impact on Healthcare**

Healthcare delivery in rural Tanzania is often limited by the lack of electricity, which affects the functioning of healthcare facilities. Mini-grids have enabled significant improvements in healthcare by powering medical equipment, refrigeration for vaccines and medicines, and providing reliable lighting for nighttime operations (Samad et al., 2017). Research by Jimenez et al. (2020) revealed that health centers powered by mini-grids reported fewer vaccine spoilages and better service delivery.

The availability of electricity also allows healthcare facilities to operate equipment such as diagnostic machines, sterilization units, and incubators, all of which are essential for providing quality healthcare services. Furthermore, as noted by Nouni et al. (2017), electrified healthcare facilities can extend their operating hours, particularly in emergencies, thus improving overall health outcomes.

In addition, electricity access allows for the use of communication technologies like mobile phones and internet connections, which are crucial for telemedicine and other healthcare services that require remote consultation. This has been particularly beneficial in isolated rural areas where access to specialized care is limited (Gyamfi et al., 2020).

**Gender and Social Equity**

Electrifying rural areas through mini-grids also has substantial gender implications. Women in rural Tanzania often spend a significant amount of time performing household chores, such as collecting firewood and cooking. Electrification through mini-grids can reduce the time burden of these activities by providing clean energy for cooking and lighting, allowing women to engage in other productive activities (Toman et al., 2020). Additionally, with access to electricity, women can start small businesses, such as tailoring and food processing, contributing to household incomes and improving their economic standing (Peters et al., 2019).

Electrification also promotes gender equality by providing equal access to educational opportunities. Girls, who are traditionally more likely to be burdened with household chores, benefit from the extended study hours made possible by electric lighting. Studies by Dinkelman (2018) suggest that electrification contributes to higher educational attainment among girls, as they can spend more time on schoolwork in the evening. Access to electricity improves women's security and mobility by providing well-lit public spaces and homes, reducing the risks associated with gender-based violence (Gaye & Tindimugaya, 2019).

**Challenges and Limitations**

While mini-grids have the potential to transform socio-economic conditions in rural Tanzania, several challenges remain. The high upfront costs of installing and maintaining mini-grid infrastructure, particularly in remote areas, can be a barrier to widespread adoption. Although government subsidies and private sector investment have helped alleviate some of these costs, affordability remains an issue for low-income households (Yadoo & Cruickshank, 2019). According to Van der Zwaan et al. (2021), the cost of electricity generated from mini-grids is still higher compared to national grid electricity, especially in small-

scale systems that serve fewer households.

Another challenge is the sustainability of mini-grids in the long term. The financial viability of these systems depends on consistent and sufficient demand for electricity, which can be difficult to achieve in low-density rural areas with limited economic activities. Additionally, poor maintenance practices and limited technical capacity at the community level can result in frequent system breakdowns and service interruptions (Sovacool et al., 2020).

Lastly, while the socio-economic benefits of mini-grids are clear, there is a need for more comprehensive policy frameworks that facilitate their integration with the national grid. Mini-grid developers often face regulatory challenges, such as lengthy licensing procedures and unclear policies regarding tariff setting and grid interconnection (Bhattacharyya & Palit, 2019).

### **Challenges of Electrifying Rural Areas Using Mini-Grid Systems in Tanzania**

While mini-grid systems present a promising solution for electrifying remote rural areas in Tanzania, their deployment is not without challenges. These challenges are multifaceted and range from financial and technical constraints to regulatory and socio-cultural barriers. Understanding these challenges is crucial for developing effective strategies to improve mini-grid deployment and operation in Tanzania.

#### **Financial and Economic Constraints**

One of the most significant barriers to the widespread adoption of mini-grids in Tanzania is the high upfront capital cost required for infrastructure development. Installing mini-grids involves substantial investment in power generation units, distribution networks, and storage systems. A study by Bhattacharyya and Palit (2019) highlights that the capital costs of mini-grid systems in Sub-Saharan Africa can be as high as \$3,000 per kilowatt of installed capacity, which is prohibitive for many rural communities and small-scale developers. This is especially true for renewable energy-based mini-grids, such as solar or hydroelectric systems, which require significant initial investment despite their lower operational costs (Van der Zwaan et al., 2021).

In addition to high capital costs, the ongoing operation and maintenance expenses of mini-grids pose a challenge. The financial viability of these systems depends on the ability to generate sufficient revenue from electricity sales, which can be difficult in low-income rural areas. Many households in rural Tanzania have limited purchasing power and may be unable to afford the tariffs charged by mini-grid operators, especially when compared to the heavily subsidized tariffs of the national grid (Tenenbaum et al., 2014). As a result, mini-grid operators often struggle to recover costs, leading to financial instability and the potential for system failure.

Another economic constraint is the lack of access to affordable financing for mini-grid developers. Despite the presence of government subsidies and donor-funded programs, accessing credit remains a challenge for many small and medium-sized enterprises (SMEs) involved in mini-grid projects. According to Ahlborg and Hammar (2014), financial institutions are often hesitant to provide loans for rural electrification projects due to the perceived risks associated with operating in remote areas, where income levels are low and population densities are sparse. This limits the scalability of mini-grid systems and hinders the expansion of electrification efforts.

#### **Technical Challenges**

Technical challenges also hinder the effective deployment and operation of mini-grid systems in rural Tanzania. One major issue is the limited technical capacity for installing, maintaining, and managing mini-grid systems. Many rural communities lack the necessary technical skills to operate and maintain mini-grids, which can lead to frequent system breakdowns and prolonged downtime. A study by Blodgett et al. (2017) found that the lack of technical expertise is one of the primary reasons for the failure of mini-grid projects in rural Africa, including Tanzania.

Furthermore, the intermittent nature of renewable energy sources, such as solar and wind, presents a technical challenge for ensuring a stable and reliable power supply. Solar mini-grids, which are widely used in Tanzania, depend on the availability of sunlight, which can fluctuate due to weather conditions. During periods of low sunlight, energy storage systems, such as batteries, are needed to maintain power supply. However, the high cost and limited lifespan of batteries make it difficult for many mini-grid operators to provide consistent electricity, especially during cloudy or rainy seasons (Mandelli et al., 2016).

Grid integration is another technical challenge. Although mini-grids are designed to operate independently, there is increasing interest in integrating them with the national grid to enhance energy access and reliability. However, the lack of standardized technical protocols for grid interconnection and the high costs associated with upgrading mini-grids to meet grid standards create obstacles for such integration (Bhattacharyya, 2018). This can limit the potential for scaling up mini-grid systems and connecting them to the national grid, thereby reducing their long-term sustainability.

#### **Regulatory and Policy Barriers**

The regulatory environment in Tanzania, while supportive of rural electrification through mini-grids, poses several challenges for developers. One major issue is the complexity and length of the licensing process. According to the Energy and Water Utilities Regulatory Authority (EWURA), mini-grid developers must undergo a series of regulatory approvals, including environmental impact assessments, feasibility studies, and tariff-setting procedures (Mwihava et al., 2017). These processes can be time-

consuming and costly, particularly for small-scale developers with limited resources.

Inconsistent policies and unclear regulations regarding tariff structures also create challenges for mini-grid operators. While the Tanzanian government encourages private sector participation in rural electrification, there is often a lack of transparency and consistency in how tariffs are set for mini-grid systems. In many cases, tariffs must be approved by regulatory bodies, which can delay project implementation and limit profitability (Kirubi et al., 2009). Furthermore, the absence of clear policies on the integration of mini-grids with the national grid creates uncertainty for developers, who may be hesitant to invest in mini-grid projects without assurances of long-term viability (Van Ruijven et al., 2012).

### **Socio-Cultural Challenges**

Socio-cultural factors also play a role in limiting the success of mini-grid systems in rural Tanzania. Resistance to change and a preference for traditional energy sources, such as firewood and kerosene, can hinder the adoption of mini-grid electricity. Many rural households are accustomed to using these conventional energy sources, which are often cheaper and more readily available, even though they are inefficient and environmentally harmful (Grimm et al., 2017). Convincing rural communities to switch to electricity, particularly when it is more expensive, can be challenging.

Additionally, the lack of community engagement in the planning and implementation stages of mini-grid projects can lead to distrust and opposition. A study by Rolland and Glania (2014) found that successful mini-grid projects in Africa tend to involve local communities in decision-making processes, ensuring that the systems are tailored to meet the specific needs and preferences of the population. Without such involvement, there is a risk that mini-grid systems may be viewed as imposed solutions, leading to low levels of acceptance and usage.

### **Potential Solutions to Overcome the Challenges**

To overcome the challenges associated with mini-grid deployment and operation in rural Tanzania, several potential solutions have been proposed. These solutions focus on improving financing mechanisms, enhancing technical capacity, streamlining regulatory processes, and promoting community engagement.

#### **Improving Access to Finance**

Addressing the financial constraints of mini-grid systems requires innovative financing mechanisms that reduce the capital burden on developers and increase affordability for consumers. One potential solution is the establishment of more flexible financing models, such as pay-as-you-go (PAYG) systems. PAYG models allow households to pay for electricity incrementally, reducing the upfront cost of connection and making electricity more accessible to low-income families (Rolffs et al., 2015). Additionally, expanding the availability of concessional loans and grants for mini-grid developers can help mitigate the high upfront costs of installation and encourage more private sector participation in rural electrification efforts (Yadoo & Cruickshank, 2012).

Public-private partnerships (PPPs) are another promising avenue for financing mini-grid projects. By combining public sector support with private sector investment, PPPs can leverage the strengths of both sectors to improve project financing, risk-sharing, and long-term sustainability (Bhattacharyya, 2013).

Successful examples of PPPs in Tanzania include the JUMEME Rural Power Supply project, which has provided solar mini-grids to several remote communities through a combination of government subsidies and private investment (JUMEME, 2018).

#### **Enhancing Technical Capacity**

Building local technical capacity is essential for ensuring the successful deployment and long-term sustainability of mini-grid systems. This can be achieved through training programs and capacity-building initiatives that equip local communities with the skills needed to operate and maintain mini-grid infrastructure. According to Blodgett et al. (2017), providing technical training for community members can reduce system downtime and improve the reliability of mini-grids.

In addition to training, increasing access to affordable energy storage solutions, such as batteries, is critical for overcoming the technical challenges of intermittent renewable energy sources. Research by Mandelli et al. (2016) suggests that advancements in battery technology, coupled with falling costs, can enhance the performance of solar mini-grids by providing reliable energy storage, particularly during periods of low sunlight.

Standardizing technical protocols for grid interconnection is also essential for facilitating the integration of mini-grids with the national grid. Developing clear guidelines for mini-grid operators on how to upgrade their systems to meet grid standards can help streamline the integration process and reduce the costs associated with grid expansion (Bhattacharyya & Palit, 2019).

#### **Streamlining Regulatory Processes**

Simplifying the regulatory framework for mini-grid development is crucial for reducing the barriers to entry for developers and encouraging more investment in rural electrification. One potential solution is the introduction of a “light-touch” regulatory approach, where mini-grid developers are subject to fewer regulatory requirements for small-scale projects (Tenenbaum et al., 2014). This approach can reduce the time and cost associated with the licensing process, making it easier for SMEs and community-based organizations to establish mini-grids.

In addition, creating more transparent and consistent policies on tariff-setting can help ensure that mini-grid operators are able to recover their costs while providing affordable electricity to consumers. The Energy and Water Utilities Regulatory Authority (EWURA) could develop standardized tariff-setting guidelines for mini-grids, allowing for more predictable and transparent pricing structures (Mwihava et al., 2017).

### **Promoting Community Engagement**

Community engagement is critical for the long-term success and sustainability of mini-grid projects in rural areas. Mini-grid systems are more likely to succeed when local communities are involved in both the planning and operational stages. Studies have shown that community ownership or co-management of mini-grids enhances system reliability and community acceptance, as it fosters a sense of ownership and accountability among local users (Bhattacharyya & Palit, 2019). Engaging the community early in the project development process allows for the identification of specific energy needs, which can lead to tailored solutions that better serve local populations (Rolland & Glania, 2014).

One effective approach to promoting community involvement is through the establishment of community energy committees. These committees, comprising local stakeholders, can oversee the management and operation of mini-grid systems, ensuring that decisions are made in line with the needs and preferences of the community (Grimm et al., 2017). Such committees can also serve as a liaison between the community and project developers, facilitating communication and resolving potential conflicts. Involving women and other marginalized groups in these committees is particularly important, as it ensures that the benefits of electrification are shared equitably within the community (Ahlborg & Hammar, 2014).

Another strategy to enhance community engagement is through education and awareness campaigns. Many rural communities are unfamiliar with the benefits of electricity and may be hesitant to adopt new technologies. Educational programs can help raise awareness about the advantages of using electricity for various productive and household activities, such as lighting, irrigation, and refrigeration (Blodgett et al., 2017). These programs can also provide training on energy conservation and system maintenance, empowering communities to take an active role in sustaining mini-grid systems.

### **Socio-Economic Impacts of Electrifying Remote Rural Areas in Tanzania Using a Mini-Grid System**

Electrification of rural areas using mini-grid systems has a profound socio-economic impact on communities, particularly in developing countries like Tanzania. Mini-grids offer an affordable and decentralized solution to rural electrification, providing a reliable source of energy to regions far from the national grid. In this section, the socio-economic benefits of electrification via mini-grids will be discussed in terms of economic development, education, healthcare, and environmental sustainability.

#### **Economic Development and Livelihood Improvements**

One of the most immediate and observable impacts of rural electrification is the stimulation of local economies. Access to electricity enables small businesses to extend their working hours, improve productivity, and reduce operational costs by shifting from traditional energy sources such as diesel generators or kerosene. A study by Kirubi et al. (2009) found that rural electrification via mini-grids in Kenya led to a significant increase in income for small and medium-sized enterprises (SMEs), as they were able to adopt energy-dependent technologies, such as welding machines and milling equipment, which enhanced their productivity and income generation.

In Tanzania, the impact of mini-grids on rural livelihoods is equally significant. Electrification allows for the development of new businesses, including agro-processing, refrigeration for agricultural produce, and services such as hairdressing or tailoring. These enterprises not only generate income for the business owners but also create employment opportunities within the community (Yadoo & Cruickshank, 2012). In a survey conducted by Blodgett et al. (2017), businesses in rural Tanzania reported an average increase of 20% in revenue after gaining access to electricity from mini-grids.

Electricity also enables the mechanization of agriculture, which is the backbone of rural Tanzanian economies. Electrified irrigation systems, for instance, allow farmers to cultivate crops throughout the year, regardless of the rainy season, leading to higher crop yields and food security (Grimm et al., 2017). This not only improves household income but also enhances community resilience to climate variability. Furthermore, mini-grid electrification contributes to reducing post-harvest losses by enabling cold storage facilities, which preserve agricultural produce for longer periods.

#### **Education Enhancement**

Rural electrification through mini-grids plays a vital role in improving educational outcomes in remote communities. With access to electricity, schools can extend learning hours by providing lighting for evening classes and enabling students to study after dark. Ahlborg and Hammar (2014) reported that rural schools in Tanzania experienced improved student performance after being connected to mini-grids due to increased study time and better learning environments.

Moreover, electricity allows schools to use modern educational tools, such as computers, projectors, and internet services. These technologies provide students with access to a broader range of learning materials and expose them to digital skills that are essential in the modern workforce (Bhattacharyya & Palit, 2019). Teachers also benefit from electrification, as they can use computers for lesson planning, grading, and accessing online resources for professional development. In a study conducted by Rolland and Glania (2014), electrified schools in rural Tanzania showed significant improvements in both the quality of education

and student enrollment rates, as parents were more likely to send their children to schools equipped

### Healthcare Improvements

Access to reliable electricity is critical for improving healthcare services in rural areas. Electrified health centers can offer a broader range of services, including the use of medical equipment such as X-ray machines, refrigerators for storing vaccines and medications, and sterilization units. A study by Matinga and Annegarn (2013) found that rural electrification in Malawi led to a substantial increase in the quality of healthcare services, as health facilities could provide better maternal and neonatal care, emergency services, and surgery. Similarly, in Tanzania, mini-grids have enabled rural health centers to deliver more consistent and reliable services, particularly during emergencies when lighting and medical equipment are essential.

The electrification of healthcare facilities also contributes to improved maternal health outcomes. With electricity, health centers can ensure better conditions for childbirth, including lighting during night deliveries and the use of incubators for premature babies (Grimm et al., 2017). Vaccination programs benefit from electrification as well, as vaccines can be properly stored in cold chain systems, which are powered by electricity. Without these systems, vaccines could lose their efficacy, undermining immunization efforts in rural areas.

Additionally, access to electricity enables the use of information and communication technology (ICT) in healthcare, allowing for telemedicine services, electronic medical records, and better communication between rural health centers and regional hospitals. This improves patient outcomes by ensuring timely diagnoses and treatment plans, especially in remote areas where specialized healthcare services may not be available (Bhattacharyya, 2018).

### Environmental Sustainability

The environmental impact of rural electrification using mini-grids is generally positive, especially when renewable energy sources are utilized. Mini-grids powered by solar, wind, or hydroelectric systems help reduce reliance on fossil fuels, such as diesel and kerosene, which are commonly used in rural areas for lighting and cooking. The transition to renewable energy helps mitigate greenhouse gas emissions and contributes to global efforts to combat climate change (Van der Zwaan et al., 2021).

In Tanzania, where many rural households rely on biomass, such as firewood and charcoal, for cooking and heating, mini-grid electrification can reduce deforestation and improve air quality. A study by Mandelli et al. (2016) found that rural electrification projects in Sub-Saharan Africa that utilized renewable energy sources led to a significant reduction in local environmental degradation and indoor air pollution, which is a leading cause of respiratory illnesses in rural households. Electrification also contributes to the preservation of biodiversity, as communities rely less on natural resources for their energy needs.

Furthermore, mini-grids powered by renewable energy provide a sustainable energy solution that is less vulnerable to price fluctuations and supply chain disruptions associated with fossil fuels. This enhances the energy security of rural communities and ensures a more stable and reliable energy supply (Tenenbaum et al., 2014). The environmental benefits of mini-grids also extend to future generations, as they promote sustainable development practices that align with global environmental goals.

### Case Study: The Kuruti Island Mini-Grid System

Kuruti Island is found in Indian Ocean, Shungubweni ward in Mkuranga District Council, Coast Region. The Island is accessible 30 km by road from Mkuranga town and then by using a boat (about 15 minutes cruise), it serves as an insightful case study of rural electrification through a solar-powered mini-grid system. Like many remote areas in Tanzania, Kuruti Island had been without reliable access to electricity for decades, which severely limited the island's socio-economic development. The introduction of a decentralized mini-grid system, powered by renewable energy, has significantly improved the quality of life for the island's residents. This section examines the design, socio-economic impacts, challenges, and key lessons from the Kuruti Island mini-grid project. The mini-grid is DC coupled type with a PV array consisting of 36 pieces of 305 Wp Suntech solar modules, four 60A outback MPPT Charge controllers, 7 KW Outback Radian inverter and a 144 KWh OPZs battery bank.

Total island area is not quantified but the width span along the island is about 800 meter and that is where households are found. Most of the island's area is inhabited because people prefer to live on the village Centre for easy access to social service places like schools, dispensary and shops.



Figure 1(a): Location of Kuruti Island in Tanzania



Figure 1(b): 11KWp Mini-Grid Array in Kuruti Island



Figure 1(c): OPZs battery bank, Inverter and charge controllers in the Power House in Kuruti Island

Customers are connected through smart meters whereby electricity supply and uses are monitored and controlled through a web-based application provided by the meter supplier. The metering has features for load limiting and prepayment billing. Customers have an option to pay bills through their mobile phones.

The tariffs are set according to the customer's ability and willingness to pay for electricity. A preliminary survey in the island indicated that a household spends between USD 7.9 to USD10.6 on energy for lighting, phone charging and power for radio per month. This is equivalent to 7% of a typical household monthly income in the island. An average household is expected to consume 0.34 KWh a day for these energy applications and the tariff is set at USD 0.44 per KWh. Customers are encouraged to use LED lamps to get the most benefits out of the services.

### System Design and Implementation

The Kuruti Island mini-grid has installed an 11 KWp Solar mini-grid in Kuruti village, a small Tanzanian island located in Indian Ocean. The mini-grid serves 66 customers including households, small businesses, a school and a clinic in the island with an estimated population of 1213 and 192 households. Main applications of the power include lighting, phone charging, refrigeration of soft drinks and running Televisions. Prior to the introduction of the mini-grid, residents relied on costly and polluting sources of energy, such as kerosene lamps for lighting and diesel generators for limited electricity.

The mini-grid system on Kuruti Island is powered by solar energy. A solar photovoltaic (PV) array was installed as the primary energy source, accompanied by battery storage systems to ensure a stable supply of electricity even during cloudy days and at night. The distribution network connects households, small businesses, and public institutions, including schools and health centers. Energy-efficient appliances, such as LED lights and solar-powered refrigerators, were also introduced to minimize energy consumption while improving quality of life.

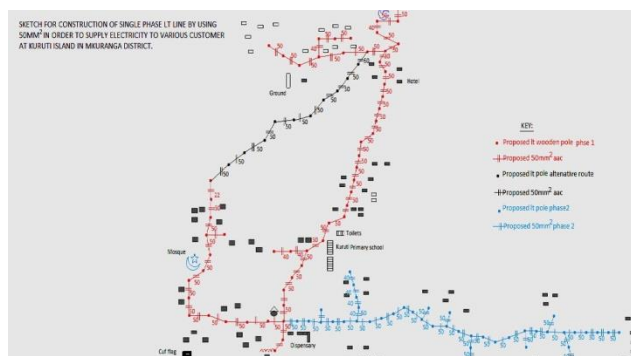


Figure 2: Distribution System Design Layout

The project was designed with scalability in mind, ensuring that the mini-grid could meet the island's growing energy needs in the future. In addition to providing electricity for basic household use, the system was designed to support productive activities, such as fish processing and refrigeration, which are vital to the island's economy. Kuruti Island has enough potential for solar energy as it has average of 4.87Kwh/m<sup>2</sup> solar radiation per year as shown in figure 3.

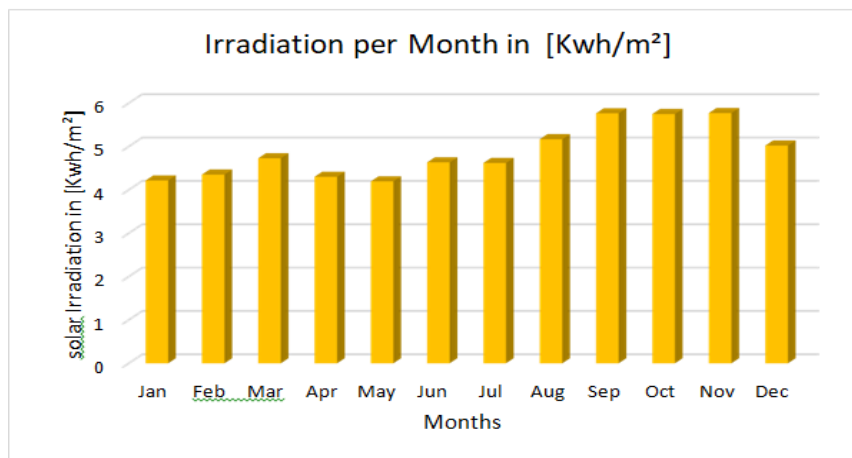


Figure 3: Solar Irradiation profile for Kuruti Island in a Year (*Global Atlas*)

### Socio-Economic Benefits

The electrification of Kuruti Island has had a transformative effect on the community, leading to improved livelihoods and economic growth. One of the most notable benefits has been the positive impact on the local fishing industry. Prior to electrification, fishermen were unable to store their catch for extended periods, resulting in significant post-harvest losses. With the availability of electricity, cold storage facilities were installed, allowing fish to be preserved for longer periods, thus reducing waste and increasing profitability (Blodgett et al., 2017).

The availability of electricity has also stimulated the growth of small businesses on the island. Shops, small restaurants, and mobile phone charging stations have emerged, and existing businesses, such as tailors and food vendors, have extended their operating hours. This has created new employment opportunities and increased household incomes, contributing to overall economic development (Yadoo & Cruickshank, 2012).

In addition to economic benefits, the mini-grid has significantly improved access to essential services. Schools on Kuruti Island now have lighting for evening classes, as well as the ability to use computers and other digital learning tools, which has improved educational outcomes. Healthcare facilities, previously limited by a lack of electricity, can now store vaccines in refrigerators, power medical equipment, and provide better care, particularly during emergencies and nighttime procedures (Ahlborg & Hammar, 2014).

### Challenges and Barriers

Despite the many benefits, the Kuruti Island mini-grid has faced several challenges. Affordability remains a key issue, particularly for low-income households. While the mini-grid has provided a more reliable and cleaner source of energy compared to diesel generators, some residents struggle to afford the connection fees and the ongoing costs of electricity (Grimm et al., 2017). The project developers have responded by offering flexible payment schemes and exploring subsidies for poorer households to ensure broader access to electricity.

Another challenge is ensuring the long-term maintenance and operational management of the mini-grid. Like many rural electrification projects, the technical capacity of local operators is limited, leading to concerns about system reliability. This highlights the importance of ongoing training and capacity-building for local technicians to ensure that they can maintain the system effectively (Bhattacharyya & Palit, 2019).

Environmental conditions also pose a challenge to the sustainability of the solar-powered mini-grid. Although battery storage helps mitigate issues related to solar intermittency, prolonged periods of cloudy weather can reduce the system's efficiency. To address this, future expansions could consider hybrid systems that incorporate other renewable energy sources, such as wind or biomass, to improve reliability (Rolland & Glania, 2014).

### III. Lessons Learned and Future Prospects

The experience of Kuruti Island provides several valuable lessons for future rural electrification projects in Tanzania and other developing regions. One key lesson is the importance of designing mini-grid systems that cater to the specific needs of the local population. In the case of Kuruti Island, focusing on productive uses of energy, particularly for the fishing industry, has maximized the economic benefits of electrification and improved local livelihoods.

Community involvement and ownership have been critical to the success of the project. By engaging local stakeholders in the planning and implementation stages, the project has been able to build trust and ensure that the system meets the community's needs. This sense of ownership has been instrumental in fostering user acceptance and encouraging responsible energy use (Bhattacharyya, 2018).

Looking ahead, the Kuruti Island mini-grid model could be replicated in other remote areas in Tanzania and beyond. The project demonstrates that decentralized renewable energy systems are not only viable but can also contribute to sustainable economic development and improved quality of life in rural communities. However, addressing challenges such as affordability and long-term system maintenance will be key to ensuring the sustainability of similar projects in the future.

#### **IV. Conclusion**

The implementation of mini-grid systems has demonstrated considerable potential in improving the socio-economic landscape of rural Tanzania, particularly in areas like Kuruti Island. By providing access to reliable electricity, mini-grids have positively impacted local businesses, education, healthcare, and the overall quality of life. The successful integration of solar-powered mini-grids highlights the importance of renewable energy solutions in addressing the energy access challenges in remote areas. However, despite the positive impacts, several challenges, such as financial constraints, technical capacity, and regulatory hurdles, continue to hinder the widespread adoption of mini-grids. For mini-grid projects to reach their full potential, it is crucial to implement strategies that address these barriers. Flexible financing models, community engagement, and ongoing technical training are essential to ensure the sustainability and scalability of these systems. Additionally, policy frameworks need to be refined to support the integration of mini-grids with the national grid, creating a more robust energy infrastructure in Tanzania.

Future research should focus on innovative financing solutions, the role of hybrid systems, and the integration of productive energy uses to further enhance rural development. By expanding the knowledge base and sharing lessons learned from successful projects, such as Kuruti Island, Tanzania can continue to make strides toward achieving its energy access and development goals, ultimately contributing to the country's socio-economic growth and sustainability.

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