Bachelor Thesis

In the bachelor program

Information Management and Corporate Communications

at University of Applied Sciences Neu-Ulm

Financial Viability and Business Models for mini-grid projects in Namibia and Tanzania

1st examiner: Prof. Dr. Elmar Steurer

2nd examiner: Prof. Dr. Erik Rederer

Supervisior: Kerii Tjitendero

Author: Lydia Adane Kassa (289177)

Topic received: 01.06.2024

Work submitted: 01.10.2024

Table of contents

List of figures III
1 Introduction 4
1.1 Background and Motivation 4
1.2 Research objectives / goal 5
1.3 Company introduction 5
1.4 Methodology 6
2 State of Art 7
2.1 Definition and concept of mini-grids 7
2.2 Overview of Mini-Grid Market in Namibia 9
2.2.1 Socio-Economic and Geographical Factors 9
2.2.2 Regulatory Factors 12
2.3 Overview of Mini-Grid Market in Tanzania 17
2.3.1 Socio-Economic and Geographical Factors 17
2.3.2 Regulatory Factors 20
3 Business Model Assessment 24
3.1 Financial viability 24
3.2 Recommended Business Model 29
3.2.1 Anchor-Business-Community (ABC) Model 30
3.2.2 Public-Private Partnership (PPP) Model 31
3.2.3 Keymaker Model 32
3.2.4 Energy-as-a-Service (EaaS) Model 33
4 Discussion of use cases 35
4.1 Rafiki Power 35
4.2 Cenored 37
5 Conclusion 39
Bibliography 40
Statutory declaration 43

List of figures

Figure 1: A mini-grid system (World Bank, 2019, p. 5) 7
Figure 2: Battery prices (BloombergNEF, 2020)........ 8
Figure 3: Number of people without access to electricity by region, 2010-2023 (IEA Access to electrici-ty database, 2023)........ 8
Figure 4: Photovoltaic Power Potential Namibia (Global Solar Atlas)........ 11
Figure 5: Namibian Electricity Supply Industry (GIZ, 2022)........ 13
Figure 6: Import vs. Export of Electricity (ECB Statistical Bulletin, 2021)........ 13
Figure 7: IPP involvement in Namibia's Electricity Sourcing (ECB Statistical Bulletin, 2021, p. 37)15
Figure 8: Photovoltaic Power Potential Tanzania (Global Solar Atlas)........ 18

1 Introduction

1.1 Background and Motivation

The goal of achieving universal energy access is urgent, as millions of people in Sub-Saharan Africa still lack access to electricity. Mini-grids have emerged as a promising solution to this challenge, offering distributed energy systems that can systems for reliable power supply in rural and remote areas. Mini-grid deployment is especially important in Namibia and Tanzania due to geographical and infrastructure constraints that make traditional grid extension economically unfeasible.

There are a multitude of factors that contribute to the implementation of mini-grid projects. The relationship between energy access and socioeconomic development is a significant driver. Energy access is a prerequisite for socioeconomic development, and thus, it is a fundamental aspect of any energy strategy. Electricity promotes improvements in education, healthcare, and economic productivity, thereby helping to alleviate poverty. For example, the World Bank and ESMAP report emphasizes that mini-grids can serve as an instrumental function in achieving universal energy access by 2030, highlighting their potential to drive rural development

(cf. ESMAP, 2022).

Second, the decreasing costs of renewable energy technologies, such as solar photovoltaic (PV) systems, have made mini-grids more economically viable. This has resulted in increased investments and a proliferation of mini-grid projects throughout the region. According to reports, the cost of electricity generated by renewable energy technologies has steadily decreased, making these technologies comparable to or less expensive than fossil-based power. (cf. International Renewable Energy Agency [IRENA], 2020). Furthermore, there has been a significant shift from diesel to solar hybrid systems in mini-grids, which supports their financial viability. (cf. ESMAP, 2022).

It can thus be concluded that community participation is an indispensable factor in the success and sustainability of mini-grid projects. Engaging local communities in the planning and operational phases ensures that projects are tailored to their specific requirements, fostering a sense of ownership and acceptance. This participatory approach not only improves the project outcomes but also strengthens the social fabric of the communities involved (cf. Hoeck et al., 2021).

1.2 Research objectives / goal

This thesis aims to explore the financial viability and business models of mini-grid projects in Namibia and Tanzania. The specific objectives include:

- To analyze the regulatory and financial frameworks that support mini-grid projects in both countries.
- To evaluate the economic feasibility of different mini-grid configurations, including solar PV and hybrid systems.
- To identify the challenges and opportunities for scaling mini-grid projects in rural areas.
- To provide recommendations for optimizing the financial sustainability of mini-grid projects based on case studies and existing literature.

1.3 Company introduction

Off-Grid Europe is a leading renewable energy solutions provider specializing in off-grid systems with a focus on solar technologies. Founded in 2011, the company initially positioned itself as the largest solar cell retailer in Europe and has since grown to become a significant player in the off-grid energy sector. The company's mission is to improve energy access in underserved areas, particularly in Africa, through the use of innovative and sustainable energy solutions (cf. Off-Grid Europe, 2024).

The company has significantly expanded its operations since its inception and has implemented projects in several countries. In particular, in 2019, Off-Grid Europe was awarded the Senegal ASER300 Rural Electrification Project, which aims to provide electricity to more than 200 villages.

Off-Grid Europe provides a comprehensive range of services, including the engineering, production, and installation of mini-grids. The mini-grid solutions offered by the company are distinguished by their rapid installation times, sophisticated monitoring and control systems, and the utilization of lithium iron phosphate (LFP) battery technology, which enhances safety and longevity. Furthermore, the company places significant emphasis on the significance of local community engagement and capacity building, with the objective of ensuring that local populations are empowered to manage and maintain the energy systems effectively (cf. Off-Grid Europe, 2024). The leadership team at Off-Grid Europe, comprising co-founders Christiane Kragh and Mark Kragh, possesses considerable expertise in the field of renewable energy systems and project management. Their proficiency is pivotal in advancing the company's objective of facilitating access to contemporary energy resources, which are vital for human welfare and economic advancement (cf. Off-Grid Europe, 2024).

By leveraging innovative technologies and fostering partnerships, Off-Grid Europe aims to create sustainable energy access solutions that not will not only improve electricity access but could also contribute to the socio-economic development of rural areas in Namibia, Tanzania, and beyond.

1.4 Methodology

To accomplish the goals outlined in section 1.2, this study takes a methodical approach. The first part of the study investigates the idea of mini-grids in relation to Tanzanian and Namibian rural electrification. It lists the main obstacles that mini-grid initiatives must overcome, such as unclear regulations, operational inefficiencies, and financial constraints.

The thesis also looks at a variety of business models and their financial feasibility, focusing especially on integrating energy-efficient usage to promote regional economic growth. The optimal utilization of mini-grid systems and the variety of approaches used by these businesses to address shared obstacles are demonstrated through the use of case studies involving Rafiki Power and Cenored.

2 State of Art

2.1 Definition and concept of mini-grids

Mini-grids are small, decentralized electricity networks that are mostly used in rural areas that are geographically isolated and lacking access to the national electricity grid. They provide a versatile solution for electrification in areas without a network connection by incorporating alternative energy resources like solar and wind power or conventional diesel generators. As estimated by the World Bank, until 2030 some 500 million people might be supplied with electricity through mini-grids, underscoring their crucial role in the global electrification effort (cf. ESMAP, 2022, p. 2). Besides their significance for general electrification, mini-grids are being used in other business models, such as electric transportation, agricultural devices, refrigeration systems, etc.

<u>Technical Mini-Grid Components</u>

Mini-Grids consist of a generation unit, a distribution network, and a control system (cf. figure 1). The energy source can be photovoltaic, wind, or waterpower plants; in hybrid systems, these power plants are frequently combined with diesel generators (cf. IRENA, 2020, p. 20).

Looking back in time, the initial generation of mini-grids was dependent on diesel fuel, whereas the second-generation incorporated renewables alongside diesel. Finally, the recent third generation have evolved to mini-grids with a particular emphasis on fully renewable technologies with advanced battery storage (cf. ESMAP, 2022, p. 151).

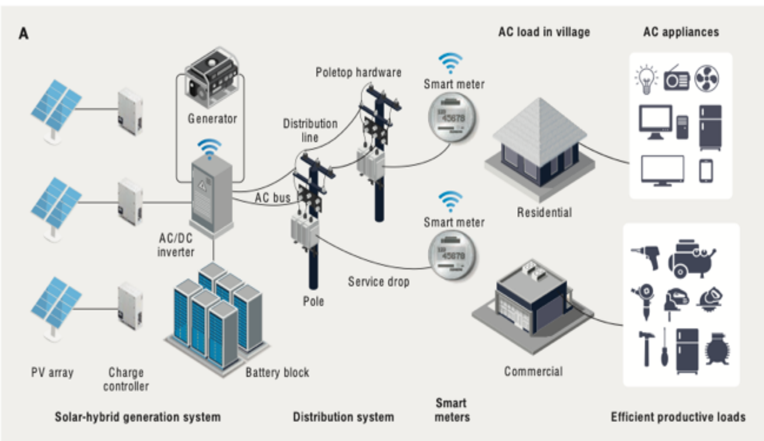

Figure 1: A mini-grid system (World Bank, 2019, p. 5)

The energy storage system is an essential element, which is often made of batteries to store excess energy. As depicted in figure 2, the declining costs of lithium-ion batteries—which have decreased by 89% since 2010—have made the use of renewable energy sources in mini-grids more appealing from an economic standpoint (cf. BloombergNEF, 2023). The substantial drop in lithium-ion battery prices reduces capital expenses and enhances the economic viability and flexibility of mini-grid systems, promoting greater use of renewable energy and innovation.

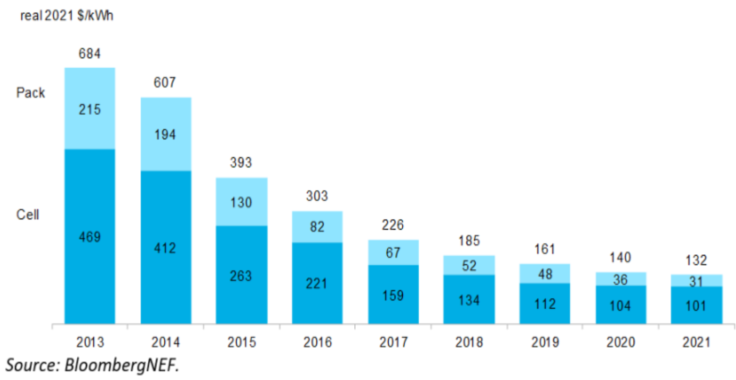

Figure 2: Battery prices (BloombergNEF, 2020)

Types and Importance of Mini-Grids

Mini-Grids come in two main varieties: network-connected (on-grid) and network-independent (off-grid) systems. Network-connected systems augment the national network, whereas off-grid systems are deployed in remote locations, where connecting to the national network is impractical (cf. ESMAP, 2022, p. 27). In Sub-Saharan Africa, where around 600 million people are without access to electricity, off-grid mini-grids are essential (cf. figure 3).

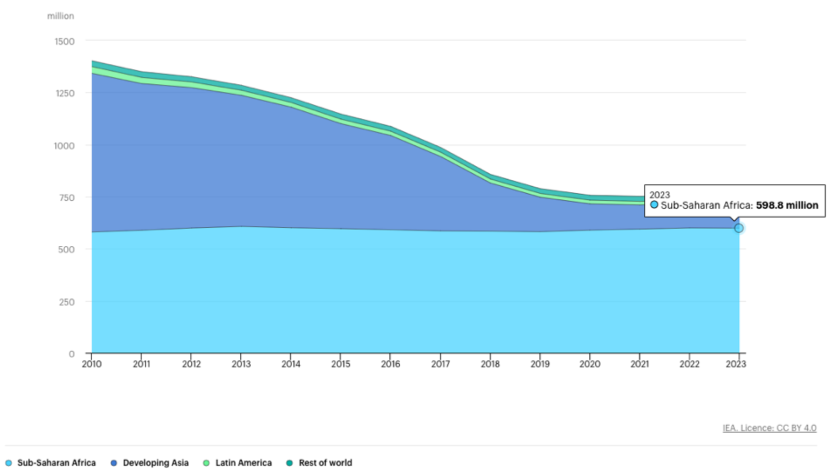

Figure 3: Number of people without access to electricity by region, 2010-2023 (IEA Access to electricity database, 2023)

According to the World Bank, as of 2023 approximately 3,000 mini-grids have been installed in that region, providing electricity to millions of people. However, a large scale-up is needed to achieve the target of ensuring universal access to energy by 2030. The World Bank estimates that the construction of more than 160,000 mini-grids will be required in order to provide electricity to 380 million people in Africa by 2030. The total cost of this infrastructure development is projected to be approximately $91 billion (cf. ESMAP, 2019, p. 2).

2.2 Overview of Mini-Grid Market in Namibia

2.2.1 Socio-Economic and Geographical Factors

Namibia has one of the world's smallest populations. With a population of about 2,6 million and a land area of 823.290 km², the population density is just 3 people per quadrat kilometers (cf. Statistisches Bundesamt (Destatis), 2024a). Approximately half of the population lives in urban areas, while the remaining 48% is concentrated in rural areas (cf. World Bank, 2023). This distribution presents a significant challenge for the electrification of rural areas because of the large distances between the settlements and the dispersed population.
The population of urban areas has grown faster in the last few decades due to migration to cities like Windhoek, Swakopmund, and Walvis Bay.

Despite this urban growth, a large portion of the rural population still relies on traditional energy sources like biomass for cooking and heating, which contributes to indoor air pollution and forest fires. The health of rural areas is negatively impacted by this.

In 2023, Namibia's annual population growth rate was approximately 1.4 percent, with 36.7 percent of the population under the age of fifteen (cf. *Population Growth (Annual %) - Namibia*, 2023; *Youthful Population Dominates Namibia’s 2023 Census Preliminary Results*) This points to a moderate but steady population growth that will continue to put pressure on the country's infrastructure in the years to come, particularly on the efforts to electrify the land. The education and employment systems will also be impacted, especially in rural areas where opportunities for employment are limited. Mini-Grids provide a solution by creating access to electricity and opening up new opportunities for health, education, and economic development.

Economic activities and industries

Namibia's economy is heavily dependent on natural resources, specifically tourism, agriculture, and mining. The GDP of Namibia was 12,31 billion USD in 2021, with a GDP per head of 4.842 USD (cf. Statistisches Bundesamt, 2022). The construction industry, which includes iron, steel, and diamonds, is a significant economic sector and contributes 11.1% of the GDP. However, the sector is very capital-intensive and employs a relatively small percentage of the population (cf. Namibian National Planning Commission (NPC), 2021, p. 2).
While agriculture (excluding the fishing industry) contributes just around 4% of the national GDP, it is the primary source of income for many people living in rural areas (cf. GIZ Sector Brief Namibia: Agriculture, 2022). Here, livestock farming, and subsistence farming are the main industries, however productivity is frequently low due to a lack of dependable energy sources. The availability of mini-grids might significantly increase land-based productivity by facilitating automation, mechanization, and refrigeration. This could increase farmers' income and decrease losses after extinction (cf. Hauser, 2018, p. 31).

The tourism industry is another significant sector that contributes over 3.5 percent to the GDP and employs a sizable portion of the population. More than 100,000 Namibians work in the tourism industry, and 1,681.336 million visitors visited the country in 2019. Numerous tourist lodges and camps are located in remote, hilly areas like the Namib-desert and Etosha National Park (cf. GIZ, 2022). Mini-Grids that run on renewable energy sources like solar or wind power provide a sustainable way to supply the necessary electricity for the gas plant (cf. Ministry of Mines and Energy, 2020, p. 14). The expansion of energy access in these areas may also promote eco-tourism.

Energy needs and access

Namibia's electrification rate lags overall at 56% in 2022, with only 35% in rural areas (cf. GIZ, 2022). This gap between urban and rural areas highlights the need of decentralized energy systems such as mini-grids, particularly in remote areas where the extension of national networks is not economically feasible. In Namibia's sparsely populated rural areas, infrastructure costs are high, making network expansion prohibitively expensive.

Namibian’s energy sector is dominated by NamPower, the governmental utility company with responsibility for the generation, transmission, and distribution of the majority of the country's electricity. Namibia imports over 60% of its electricity from neighboring South Africa, Botswana, and Sambia, which makes it vulnerable to regional power outages (cf. Government of the republic of namibia & ministry of mines and energy, 2016, p. 11).

Renewable energies, particularly solar energy, have a significant potential in Namibia. The country is distinguished by a particularly high level of solar radiation, with an average of 5-6 kWh/m²/day, which is among the highest values observed globally. This makes solar-powered mini-grids a very appealing option for electrifying rural areas (cf. SOLARGIS, 2019). Wind energy also offers opportunities, particularly in coastal areas such as Lüderitz, where wind speeds average between 7 and 9 m/s, making it perfect for commercial wind power plants (cf. Ministry of mines and energy & Government of the republic of namibia, n.d.).

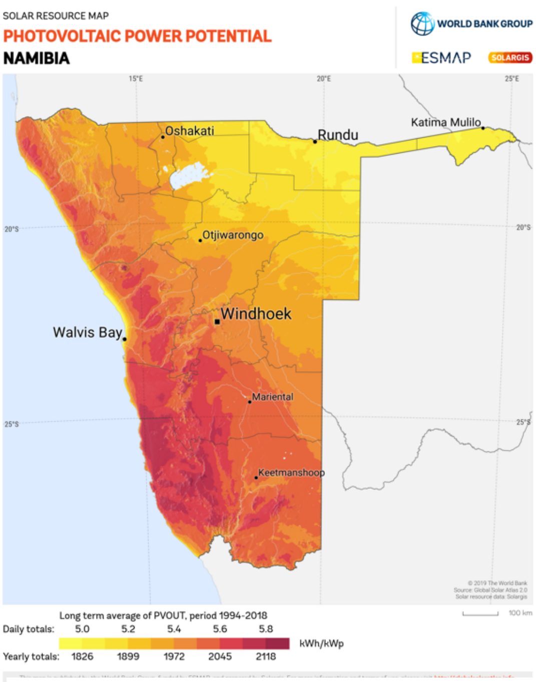

Figure 4: Photovoltaic Power Potential Namibia (Global Solar Atlas)

Namibia's diverse geography presents both challenges and opportunities for energy development. The country includes a variety of landscapes, ranging from the dry Namib Desert along the Atlantic coast to the semi-arid Kalahari Desert in the east. These areas are sparsely populated, with many settlements located far from the national power grid, making them perfect candidates for decentralized mini-grid solutions. The Namib Desert, one of the world's oldest deserts, receives little precipitation (about 13 mm per year in certain areas). Your proximity to the coast, however, provides ideal conditions for wind energy generation. The coastal city of Lüderitz, for example, has some of the highest wind speeds in the region, making it an excellent location for wind-powered mini-grids (cf. Hauser, 2018, p. 33).

In contrast, the Kalahari Desert in the eastern part of the country is more suited for solar energy projects (see Figure 4). This region receives between 150 and 700 mm of rainfall per year and has rather high solar radiation values despite the dry weather. Because of the dispersed population and difficult infrastructure conditions, decentralized energy supply is often the only economically viable solution (cf. Ministry of Mines and Energy, p. 5).

Namibia's rural infrastructure is underdeveloped, with poor roads and limited access to services. This presents logistical challenges for the construction and maintenance of mini-grids. Nonetheless, the abundance of the country's natural resources, particularly sunlight and wind, make decentralized, renewable energy projects both feasible and economically appealing.

2.2.2 Regulatory Factors

Namibia's energy sector is well structured and governed by several actors and regulators. The Ministry of Mines and Energy establishes the energy policy and defines the long-term goals. The ECB not only oversees the regulatory landscape but also plays a role in facilitating financial mechanisms like subsidies and concessional financing in line with the National Integrated Resource Plan (NIRP). The NIRP serves as the strategic guide for Namibia’s energy future, promoting the integration of renewable energy solutions like mini-grids to achieve the **70% renewable energy target by 2030**. Mini-grids, including solar and wind-powered systems, are an important component of the NIRP, particularly for the electrification of rural areas. The Electricity Control Board (ECB) serves as the central regulatory authority, responsible for granting licenses, establishing tariffs, and enforcing legal requirements. NamPower, the national utility that both produces and distributes electricity, is at the centre of the power generation and distribution process. Regional Electricity Distributors (REDs) play an important role in distribution, delivering power to various regions and integrating independent power producers (IPPs) into the network. This structure enables efficient distribution of electricity, particularly in remote areas, and supports the development of decentralized mini-grids (cf. Government of the republic of namibia & ministry of mines and energy, 2016, pp. 7; 22).

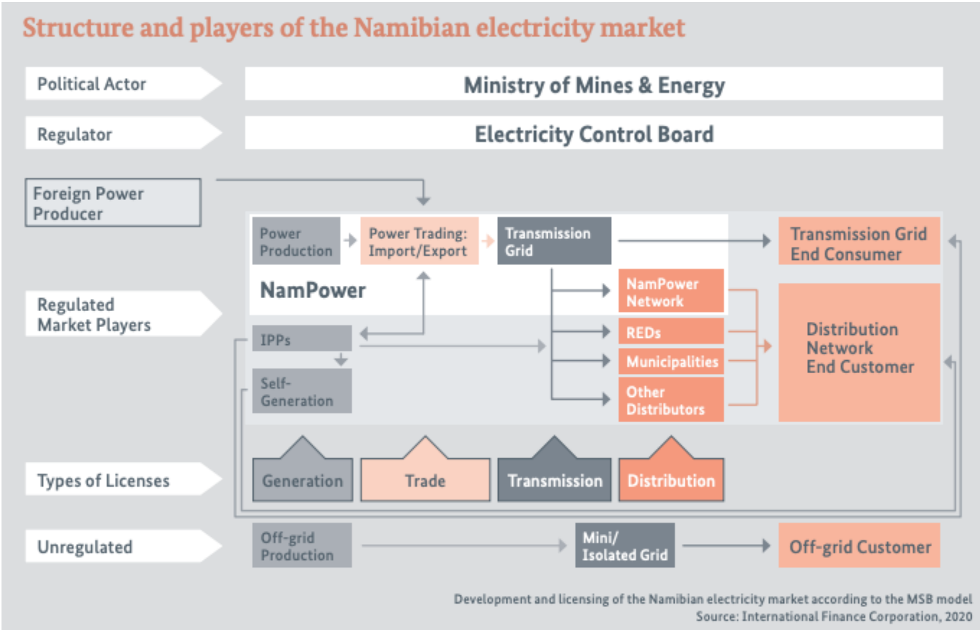

Figure 5: Namibian Electricity Supply Industry (cf. GIZ, 2022)

Financial Instruments

Namibia is heavily reliant on energy imports, particularly for fossil fuels. Despite the fact that the electrification rate is just 56%, the country will have to import around 60% of its electricity in 2020. Namibia has a peak load of 630 MW and an installed capacity of 610 MW, with NamPower providing 459.50 MW and IPPs operating 150 MW, mostly from photovoltaic plants.

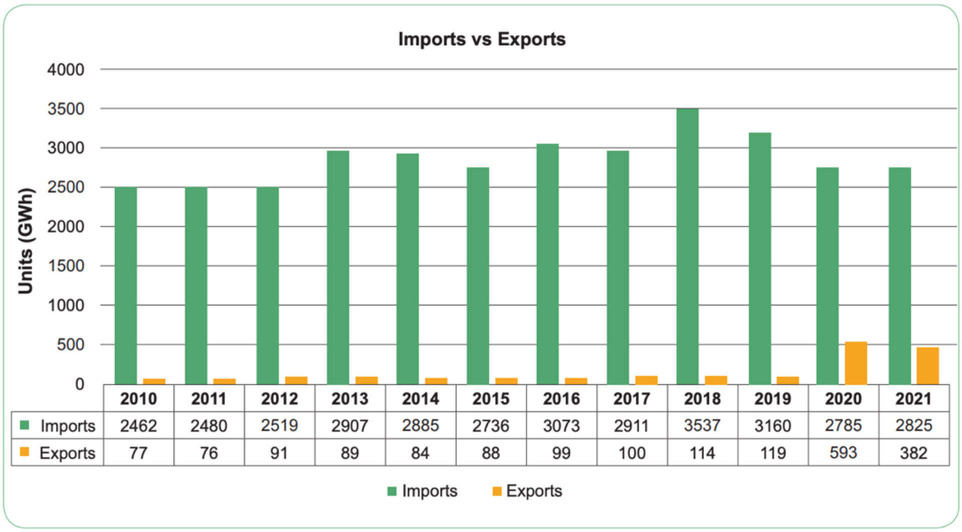

Figure 6: Import vs. Export of Electricity (ECB Statistical Bulletin, 2021)

This reliance on imports results in high electricity prices. The basis tariff for large consumers was 1.70 NAD/kWh in 2021/22, which has doubled since 2011. In practice, end-user prices are frequently higher due to additional costs incurred by regional providers. Commercial consumers may expect an average price of 2.40 NAD/kWh. In order to reduce imports and meet the rising demand for electricity, Namibia has set a goal of increasing its power capacity to 1,677 MW by 2035. Of this new capacity, 60% is to be derived from renewable energy sources (cf. GIZ, 2022, pp. 2–3). The following initiatives are designed to facilitate the accelerated electrification of rural areas and reduce the reliance on imported electricity.

1. **Net-Metering**
   Net-Metering is a key strategy for promoting renewable energy, particularly in urban areas and for projects under 500kW. It permits consumers to generate electricity from renewable sources, channel surplus power into the national grid, and secure the requisite approvals. This is ideal for smaller projects aiming to reduce operational costs by utilizing renewable energy generation on-site (cf. Electricity Control Board, 2023, p. 4).

2. **Renewable Energy Feed-in Tariff (REFiT)**
   The REFiT program has been constructed to encourage IPPs to generate renewable energy in projects larger than 500 kW and sell it to the national grid. It includes a variety of sustainable energy sources, including solar, wind, and biomass, and offers long-term contracts to reduce financial risk for investors. The objective of the program is to diversify the country's energy portfolio, diminish reliance on electricity imports, and expand local renewable energy generation (cf. NamPower Integrated Annual Report 2023, 2023, p. 26).

   REFIT has successfully enabled 14 IPPs to produce and supply 364 GWh of clean energy to Namibia’s national grid by 2023, demonstrating the program’s viability and effectiveness in promoting renewable energy (cf. NamPower Integrated Annual Report 2023, 2023, p. 27). This achievement shows that private sector participation under REFIT is feasible and profitable. Recently, the Ministry of Mines and Energy announced plans for a

300 MW accelerated feed-in-tariff program to speed up Namibia's path to energy self-sufficiency (cf. Ministry of Mines and Energy, 2024, p. 3). Figure 7 by the ECB shows the increasing involvement of IPPs.

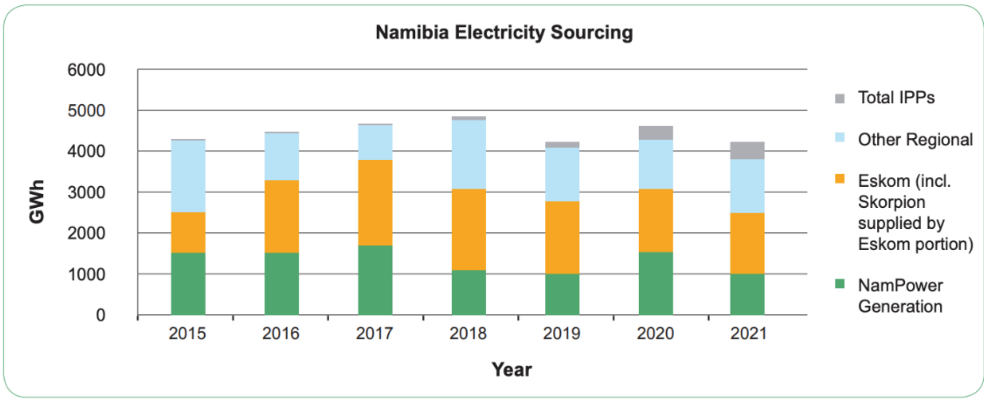

Figure 7: IPP involvement in Namibia's Electricity Sourcing (ECB Statistical Bulletin, 2021, p. 37)

The program offers long-term power purchase agreements (PPAs) with stable, guaranteed tariffs, significantly reducing investment risks. Namibia's rural and areas present significant opportunities for mini-grid solutions, especially given the country's ongoing electrification challenges (cf. NamPower, 2023, p. 26). Namibia's energy strategy, backed by REFIT, aligns with the national goal of achieving 70% renewable energy by 2030.

3. **Auction Schemes**

For renewable energy projects larger than 5 MW, auction schemes provide a competitive tender process for contracts. These auctions are ideal for larger-scale projects where developers can bid for long-term contracts and potentially secure more favorable terms (cf. Hoeck et al., 2021, p. 4).

4. **Solar Revolving Fund (SRF)**

The Solar Revolving Fund (SRF) provides loans range from N$ 6,000 to N$ 50,000 with an interest rate of 5% over five years. Though focused on smaller projects, installation of solar home systems and small photovoltaic systems in remote areas, the SRF also supports community-based mini-grid systems. This encourages the electrification of rural areas and reduces reliance on traditional energy sources (cf. Government of the Republic of Namibia Ministry of Mines and Energy, 2017).

5. **Environmental Investment Fund (EIF)**
   The EIF provides concessional loans with interest rates of up to prime minus 4.27%**,** repayment periods up to 10 years, and grace periods of up to 12 months. This fund is ideal for mini-grid projects with a strong environmental focus, offering long-term financing on favorable terms (cf. Government of the Republic of Namibia Ministry of Mines and Energy, 2017, p. 53; Hoeck et al., 2021, p. 4).

Non-financial instruments

Namibia's regulatory framework for off-grid electrification includes several key non-financial instruments that have been developed over the years to support mini-grid projects. Established primarily between 2004 and 2016, these instruments aim to ensure technical, safety, and service quality while facilitating market entry for smaller renewable energy projects.

The *Quality of Supply Standard (NRS048)* and the *Quality-of-Service Standard (NRS047)* were both introduced in 2004, adapted from South African standards. The Quality of Supply Standard regulates the reliability and stability of electricity, ensuring proper voltage and frequency, while the Quality-of-Service Standard defines service parameters like response times and complaint handling, ensuring consistent customer service from mini-grid operators. In 2009, the *Namibian Electricity Safety Code* was established to set safety guidelines for the installation, operation, and maintenance of electricity systems, protecting both workers and consumers.

In 2016, Namibia introduced the *Namibian Distribution Grid Code*, which outlines the rules for integrating distributed energy systems like mini-grids into the national grid. This code regulates governance, planning, and technical requirements for connection, facilitating the smooth integration of mini-grids with existing infrastructure.

Licensing

Namibia has established a relatively simple licensing procedure to lessen the administrative load on small renewable energy projects. According to the GIZ Sector

Brief Renewable Energy (2022), the licensing procedure typically takes around 60 days. This is considered efficient compared to other countries, such as Kenya, where the procedure might take up to 90 days (cf. Osawa & Telep, 2015, p. 25). Projects generating less than 500 kVA are excluded from licensing requirements, encouraging the development of smaller off-grid systems by lowering costs and regulatory delays (cf. Parliament of the Republic of Namibia, 2007, p. 11).

While this approach has proven effective for smaller projects, a clear licensing framework for larger off-grid installations remains a significant unmet need. This presents possible challenges for operators of bigger mini-grid initiatives. The Electricity Control Board (ECB) is in charge of recommending licenses to the Ministry of Mines and Energy (MME) for the generation, distribution, and sale of electricity, with specific objections processes established in the Electricity Act (cf. Parliament of the Republic of Namibia, 2007, p. 10).

2.3 Overview of Mini-Grid Market in Tanzania

2.3.1 Socio-Economic and Geographical Factors

Tanzania ranks as one of the countries with the highest population density in East Africa, with an estimated 67.4 million people living there in 2023 (cf. Statistisches Bundesamt (Destatis), 2024b, p. 5). Approximately 65% of the population inhabits in rural regions, where distributed residential areas and the high cost of grid extension pose major challenges to electrification (cf. Statistisches Bundesamt (Destatis), 2024b, p. 5). Tanzania's rural areas, like those in other sub-Saharan nations, still primarily rely on biomass for heating and cooking, such as wood and charcoal. 76.4% of rural households are using biomass, which puts women and children in particular at serious risk for health problems due to indoor air pollution and deforestation (cf. Ahamad et al., 2021, p. 4).

The young population - roughly 44% of the population is under 15 years old - offers a large potential labor pool for future development, especially in the energy industry (cf. Statistisches Bundesamt (Destatis), 2024b, p. 6). Nonetheless, the 2.8% annual population growth rate of the nation puts a significant amount of strain on the infrastructure already in place, this is particularly the case in rural areas with restricted access to electricity (cf. World Bank Group, 2023). In light of the ongoing expansion of the global population and the comparatively slow pace of electrification in rural areas, it is imperative to make substantial investments in energy infrastructure to meet the rising levels of demand for electricity.

Mini-grids are a practical and cost-effective way to close this gap, improve access to power in rural areas, and promote overall socioeconomic development. Tanzania's reliance on hydropower to produce electricity presents additional challenges because the country is vulnerable to seasonal variations and climate risks that can impact hydropower output (cf. Contejean & Verin, 2017, p. 13). In rural areas where centralized infrastructure is not economically feasible, mini-grids—particularly those fueled by solar and wind energy — offer a more adaptable, scalable, and reliable way to meet the nation's energy needs.

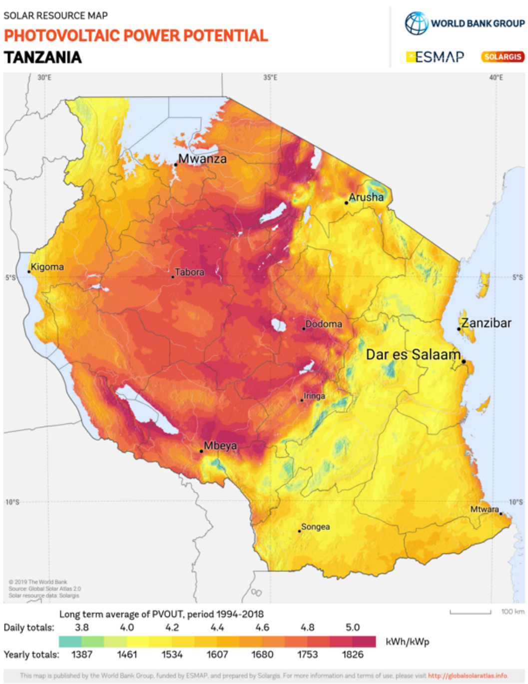

Figure 8: Photovoltaic Power Potential Tanzania (Global Solar Atlas)

Northern regions receive solar radiation levels between 4.5 and 5.0 kWh/m²/day, making solar-powered mini-grids ideal for rural electrification (cf. *Photovoltaic Power Potential - Tanzania*, 2019). Wind energy potential is also significant, especially in regions like **Singida** and the **Makambako Pass**, where wind speeds range from 7 to 9 m/s (cf. *Global Wind Atlas*, 2023). The development of mini-grids in these regions could drastically improve energy access, reducing reliance on expensive and polluting diesel generators while promoting the use of renewable energy to meet local energy demands.

Tanzania's diverse geography presents both challenges and opportunities for decentralized energy development. The country's geography includes coastal lowlands, islands like Zanzibar and Pemba, highlands, and vast interior lakes like Lake Victoria and Lake Tanganyika. The geographical diversity of the country has an impact on the expansion of the national grid, particularly in rural and sparsely populated regions where the construction and maintenance of grid infrastructure is costly and challenging. (cf. Pueyo et al., 2022, p. 14).

Economic Activities and Industries

The primary drivers of Tanzania's economy are the **mining, fishing, tourism, and agriculture** industries, all of which are essential to the nation's economic expansion. With almost 66% of the workforce employed and contributing 28% of the country's GDP, agriculture is the largest industry (cf. Statistisches Bundesamt (Destatis), 2024b, p. 8). But inadequate access to contemporary energy services lowers agricultural productivity. Power shortages for irrigation, mechanization, and cold storage are common among rural farmers, which lead to large losses after harvest and decreased profitability. By providing dependable energy to isolated farming areas, mini-grids may help overcome these difficulties and increase productivity as well as farmers' incomes (cf. Contejean & Verin, 2017, p. 7).
Another significant driver of Tanzania's GDP, employing over 1.5 million people and making almost 10% of the country's GDP, is tourism (cf. Tanzania Investment Centre, n.d.). Every year, millions of tourists go to the nation's well-known tourist spots, like Zanzibar, Mount Kilimanjaro, and Serengeti National Park. In these isolated areas, many vacation lodges and campgrounds are not connected to the national grid and depend on expensive, environmentally damaging diesel generators. Mini-grids powered by renewable energy provide a more environmentally friendly option by lowering operating expenses and encouraging eco-tourism, both of which are in line with worldwide sustainability trends.
Due to ongoing government efforts to improve industry revenue, Tanzania's mining sector—which accounts for 9.1% of the country's GDP—continues to grow (cf. Ministry of Minerals, 2024). Tanzania is the only country in Africa that produces tanzanite, a unique gemstone. It is also the 4^{th} largest producer of gold on the continent. Numerous mining operations are situated in isolated locations that frequently have inadequate access to energy (cf. International Trade Administration, 2022).
Fishing is another significant industry in Tanzania, especially in the areas surrounding coastal towns like Pemba Island and Zanzibar and inland lakes like Lake Victoria and Lake Tanganyika. Millions of Tanzanians depend on the fishing sector for their livelihoods and food security, yet significant post-harvest losses

occur due to unreliable electricity for cold storage and processing facilities. Fish spoilage is common in areas without proper refrigeration, which reduces the amount of fish that can be exported and used to generate cash. By supplying cold storage facilities with electricity, mini-grids might offer a solution that would lower spoilage and enhance the standard of living for fishing villages (cf. Dittmeyer & Pflomm, 2024, p. 12). These regions could benefit from increased fishing sector GDP contribution by electrification with renewable energy, which would assist both local exports and imports.

Tanzania's economy is more diverse than Namibia's, which relies heavily on natural resources. Due to its lengthy coastline and massive inland lakes, it has a significantly larger tourism sector and a more developed fishing business. These qualities highlight the increased possibility for renewable energy-powered mini-grids to address critical gaps in electricity availability, unlocking these industries' economic potential and significantly contributing to Tanzania's overall economic development.

2.3.2 Regulatory Factors

Tanzania’s regulatory framework is designed to attract private investment into rural electrification projects. This section addresses key regulators and key actors, followed by the regulatory components: licensing, tariffs, environmental compliance, and grid integration.

The **Ministry of Energy** is responsible for the establishment and enforcement of Tanzania's energy policies. It manages the National Electrification Plan, which aims to improve rural access to electricity by integrating decentralized solutions such as mini-grids, with a particular emphasis on renewable energy resources like solar and hydropower. Energy and Water Utilities Regulatory Authority (**EWURA**) is the main regulatory authority with responsibility for overseeing tariffs, issuing licenses, and ensuring compliance with national standards (cf. Nagpal & Parajuli, 2018, p. 49). The Rural Energy Agency (**REA**) promotes rural electrification by supporting the development of off-grid solutions through grants and concessional loans, especially to mini-grid developers focused on renewable energy. Tanzania Electric Supply Company (**TANESCO**) is the state-owned utility which is responsible for on-grid electricity generation and distribution in Tanzania.

Even though TANESCO mainly deals with on-grid power, its pricing and policy decisions influence mini-grid operators (cf. Nagpal & Parajuli, 2018, p. 46).

<u>Financial Instruments</u>

The *Rural Energy Agency* (REA*)* in Tanzania was established in 2007 under the Rural Energy Act of 2005. The organization's fundamental objective is to encourage and facilitate access to contemporary energy services within rural communities.

1. REA manages the *Rural Energy Fund (REF)* as well as the *Results-Based Financing (RBF)* Mini-Grid Program, which finance projects aimed at increasing electrification in underserved regions, including mini-grid developments, through subsidies, technical assistance, and partnerships with private developers. Projects ranging from small-scale (under 1 MW) to larger ones (up to 10 MW) are eligible. The RBF program, supported by Sida and DFID, issued its first call for proposals in 2016, and 22 projects received grants by 2018 (cf. USAID, 2018, pp. 1–6).

2. The *Tanzania Rural Electrification Expansion Program (TREEP)* is supported by the World Bank and launched in 2016. Under this program, capital subsidies are provided to mini-grid developers, although the percentage of project cost coverage varies depending on project specifics and location. It focuses on expanding rural electrification, increasing renewable energy supply, and building institutional capacity. It helped electrify over 4,300 villages, 1,600 healthcare facilities, and 6,000 education centers, significantly reducing energy costs for local businesses (cf. World Bank, 'Changing Lives and Livelihoods in Tanzania, One Electricity Connection at a Time', 2022).

3. *Feed-in Tariffs (REFiT*) are a key financial instrument under the *Small Power Producer (SPP) Framework*, especially for renewable energy projects like solar, hydro, and biomass. REFiTs provide a guaranteed price for electricity sold to the national utility (TANESCO) or mini-grids. For projects under 1 MW, developers can access predetermined tariffs without

the need for competitive bidding. Projects between 1 MW and 10 MW can also participate but may be subject to a bidding process to ensure competitive pricing (cf. USAID, 2018, p. 11).

<u>Non-financial instruments</u>

1. The *Small Power Producer (SPP) Framework* facilitates the licensing of projects generating up to 10 MW, allowing these projects to supply electricity to off-grid areas (cf. Nagpal & Parajuli, 2018, p. 48).

2. The *Power Africa Transactions and Reforms Program (PATRP)* and initiatives led by the *Rural Energy Agency (REA)* provide technical assistance and capacity-building to local mini-grid developers. These programs help developers navigate the complex regulatory landscape and offer support for project feasibility, design, and financial structuring. From 2014 to 2019, PATRP played a crucial role in assisting small developers with business development and securing financing, helping local stakeholders overcome capacity gaps (cf. USAID, 2018).

3. Licensing: In 2019, the Electricity (Development of Small Power Projects) Rules mandated formal registration for all mini-grid projects, regardless of size. Prior to these rules, projects generating less than 100 kW were exempt. However, now even Very Small Power Producers (VSPPs) must go through a full registration process. VSPPs, despite their smaller size, must follow EWURA's licensing procedures and tariff guidelines. This regulatory change seeks to ensure compliance and improve oversight in the rapidly expanding mini-grid sector (cf. Pueyo et al., 2022, p. 34). For mini-grids ranging from 1 MW to 10 MW, the registration process becomes more involved, requiring technical, financial, and environmental assessments. Small Power Producers (SPPs) can sell electricity directly to consumers or in bulk to distributors, whereas larger producers (over 10 MW) are subject to stricter regulatory requirements and more complex tariff agreements (cf. The United Republic of Tanzania, 2019).

4. Tariff regulation represents a significant aspect of concern for those engaged in the operation of mini-grids. Cost-reflective tariffs enable developers to recover their expenses while ensuring the financial viability of their projects. However, government interventions have the potential to disrupt this balance. In 2020, the Tanzanian government required mini-grid operators to align their tariffs with the lower rates of the national utility, TANESCO. This policy put significant financial strain on mini-grid developers, such as JUMEME, whose revenues dropped by 90% due to the imposed tariff reductions (cf. Pueyo et al., 2022, p. 34). Although the regulatory structure permits operators to propose tariffs based on cost-reflective models, the government's decision to reduce tariffs demonstrates the potential for instability in tariff-setting (cf. ESMAP, 2022, pp. 240–244). A streamlined tariff structure applies to mini-grids under 1 MW, lowering regulatory complexity and allowing for faster deployment (cf. The United Republic of Tanzania, 2019, p. 13).

3 Business Model Assessment

3.1 Financial viability

In recent years, the implementation of mini-grid projects in remote African regions has emerged as a promising solution for electrification, particularly in Namibia and Tanzania. The configuration of these mini-grids often includes the integration of solar photovoltaic (PV) technologies with battery storage solutions, in addition to diesel generators, to guarantee a dependable and consistent energy supply in areas with limited or no access to conventional electricity sources. The levelized cost of energy (LCOE) is a significant metric for evaluating the long-term financial viability of energy projects. It represents the average electricity consumption costs over the lifetime of a system and provides a comprehensive understanding of the economic implications of energy production and utilization strategies. In this chapter, we will examine the LCOEs of four Namibian and Tanzanian regions that were studied previously: West Tanzania, East Tanzania, Namibia North, and Namibia South. The focus is on technological differences, geographical factors, and their respective effects on the financial feasibility of proposed projects in these regions.

LCOE Definition and Calculation

The Levelized Cost of Energy (LCOE) represents a significant metric for the calculation of costs per kilowatt-hour (kWh) associated with the generation of electricity over the lifetime of a mini-grid system. The LCOE calculation takes into account both capital expenditures (CAPEX) and operating expenditures (OPEX) and divides them by the total amount of electricity produced. The Formula is as follows:

$$LCOE = \frac{Gesamtkosten\ (CAPEX\ +\ OPEX)}{Gesamte\ Stromproduktion\ (kWh)}$$

This analysis is about four regions with 300 kWp solar photovoltaic systems and various battery storage and diesel generator components. Solar radiation (kWh/kWpa), operating costs, and installation costs vary by region, resulting in differences in LCOE values.

1. **Western Tanzania**
   Installed solar capacity: 300 kWp
   Solar Radiation: 1.650 kWh/kWpa
   Annual electricity production: 495,000 kWh.
   LCOE Solar: 3.6 cents per kWh.
   LCOE of batteries: 27.4 ct/kWh.
   LCOE Diesel: 3.0 ct/kWh.
   Total system LCOE: 31.0 ct/kWh.

West Tanzania has a solar output of 1.650 kWh/kWpa, which is lower than Namibia's. This results in a Solar-LCOE of 3.6 ct/kWh, which is in the middle of the range when compared to other regions. The relatively high reliance on batteries is particularly noteworthy, as it has a negative impact on overall system costs. The LCOE of batteries is 27.4 ct/kWh, which is the largest cost driver. Diesel generators have low costs of 3.0 ct/kWh, however they contribute only little to electricity generation due to the low operating hours. The overall system LCOE of 31.0 ct/kWh is the highest in the analysis, owing to lower solar production and increased reliance on storage.

2. **Eastern Tanzania**
   Installed solar capacity: 300 kWp
   Solar Radiation: 1.450 kWh/kWpa
   Annual electricity production: 435,000 kWh.
   LCOE Solar: 3.4 ct/kWh.
   LCOE of batteries: 27.4 ct/kWh
   LCOE Diesel: 3.0 ct/kWh.
   Total system LCOE: 30.8 cents per kWh.

East Tanzania has the lowest solar radiation of all the regions studied, resulting in the highest solar LCOE of 3.4 ct/kWh. The low annual electricity production of

435,000 kWh is a direct result of the low solar radiation of 1.450 kWh/kWpa. This results in an overall system LCOE of 30.8 cents per kWh.

As in West Tanzania, battery storage remains the most expensive option at 27.4 ct/kWh. The increased reliance on batteries and low solar production makes this region one of the most expensive in the analysis. The potential for optimization lies primarily in the more efficient use of storage systems and the reduction of diesel dependence.

3. **Namibia North-West**

   Installed solar capacity: 300 kWp

   Solar Radiation: 1.800 kWh/KWpa

   Annual electricity production: 540.000 kWh.

   LCOE Solar: 3.3 cents per kWh.

   LCOE of batteries: 27.4 ct/kWh

   LCOE Diesel: 3.0 ct/kWh.

   Total system LCOE: 30.7 cents per kWh.

The North-West region of Namibia is distinguished by an exceptionally high level of solar radiation, with an estimated 1,800 kWh per kWp, which translates to a notable annual solar production of 540,000 kWh. This allows for a lower solar LCOE of 3.3 ct/kWh, which is advantageous in comparison to Tanzania. The whole system LCOE is 30.7 cents per kWh, which is somewhat lower than in the Tanzanian region. However, battery storage remains costly at 27.4 ct/kWh.

4. **Namibia South-West**

   Installed solar capacity: 300 kWp

   Solar Radiation: 2.000 kWh/kWPA

   Annual electricity production: 600.000 kWh.

   LCOE Solar: 2.5 cents per kWh.

   LCOE of batteries: 27.4 ct/kWh

   LCOE Diesel: 3.0 ct/kWh.

   Total system LCOE: 29.9 ct/kWh.

Namibia South-West had the highest solar radiation in the analysis, with 2.000 kWh/kWpa, resulting in a maximum annual solar production of 600.000 kWh. This enables the lowest solar LCOE of 2.5 ct/kWh. The high efficiency of solar energy in this region contributes to the lowest overall system LCOE in the analysis, which is 29.9 ct/kWh. The optimum use of solar resources makes Namibia's Southwest the most economically viable region in the analysis.

<u>Comparing and interpreting the LCOE values</u>

1. Differences in sunlight and solar-LCOE

The most obvious difference across regions is the amount of available sunlight, which directly influences the Solar-LCOE. Namibia's South-West region benefits from the highest solar radiation (2,000 kWh/kWpa) and so has the lowest solar LCOE of 2.5 ct/kWh. In comparison, East Tanzania has the lowest solar radiation (1.450 kWh/kWpa) and a higher solar-LCOE of 3.4 ct/kWh. These differences in solar radiation and the resulting solar-LCOE are reflected in the overall system-LCOE. While sunlight has the greatest influence on electricity production and hence system efficiency, the comparison shows that higher sunlight may contribute significantly to cost savings. Namibia South-West achieves the lowest electricity costs due to high solar radiation of 2,000 kWh/kWpa. With a total system LCOE of 29.9 ct/kWh, it compares favourably to the other regions. Despite somewhat higher diesel costs, the system remains competitive due to the outstanding solar performance.

2. Battery storage as a cost factor

In all regions, battery storage is a significant cost-driver. Regardless of solar radiation or geographical location, the battery LCOE in all regions remains constant at 27.4 ct/kWh. This high value indicates that batteries are now one of the more expensive components in hybrid mini-grid systems. While the solar modules themselves are quite inexpensive, and the diesel LCOE remains moderate in all regions, the high costs of battery storage significantly increase the overall system LCOE.

Particularly in regions like as East Tanzania, where solar radiation is not as strong, the increased reliance on batteries results in a total system LCOE of 30.8 ct/kWh. This is one of the higher values in the analysis, indicating that batteries are an area that need more optimization. Innovative storage options or advancements in battery technology might result in a significant reduction in total costs over time.

3. **Diesel Dependence and Cost Differences**

While solar and battery storage remain relatively constant across regions, there are notable differences in diesel LCOE. Diesel costs in Namibia South-West are the same as in other regions at 3.0 ct/kWh, but the overall system LCOE is the lowest due to the high solar radiation. This demonstrates that, even when diesel generators are used as backup systems, the total costs do not increase significantly when solar resources are optimally utilised.

4. **The effects of LCOE on the long-term economic viability**

The comparison of regions demonstrates that the economic viability of mini-grid projects is heavily reliant on solar radiation and efficient use of solar resources. Regions with high solar radiation, such as Namibia South-West and Namibia North-West, benefit from lower overall system LCOE, but regions like East Tanzania have higher costs due to their reliance on batteries and diesel generators. It demonstrates that Solar-PV in conjunction with batteries can provide a sustainable solution, however the high storage and diesel costs drive the total costs up. In regions such as East Tanzania, further optimisation through technological innovations, such as the integration of more efficient storage technologies or the increase of solar power, is required to reduce the LCOE over time and make the projects economically viable.

5. **Overall comparison of regions**

Namibia South-West has the lowest overall system LCOE of 29,9 ct/kWh because to the high solar radiation, which enables high solar production. Despite its dependence on diesel, the system remains competitive due to its perfect solar performance. Namibia North-West also has a low overall system LCOE of 30.7 ct/kWh, but with less solar production than Namibia South-West. This demonstrates that even with lower levels of sunlight, efficient use of solar resources is critical. West Tanzania has the highest overall system-LCOE at 31.0 ct/kWh, which is mostly due to lower solar radiation and the resulting increased reliance on battery storage. East Tanzania also has high overall system costs at 30.8

ct/kWh, which is caused by low solar radiation and the resulting need for more battery storage and diesel operation.

Concluding remarks and recommendations

Optimizing storage technologies

The analysis shows that battery storage is a significant cost driver in all regions. To reduce the levelized cost of energy (LCOE) and enhance the project's financial viability, further research and development in the field of energy storage technologies is imperative. This might take the form of novel battery systems or other storage technologies that reduce the high costs associated with lithium-ion batteries.

Focus on solar resources

Regions with high solar radiation, such as Namibia's south-west and north-west, benefit greatly from the use of solar energy. These projects can remain competitive for the long term by increasing solar production and reducing reliance on diesel. The development of tailored solar projects in optimally suited regions should thus be prioritized.

Long-term financial stability

The LCOE analysis shows that mini-grid projects in remote regions such as Namibia and Tanzania can be economically viable if properly optimized. The most significant challenges are lowering storage costs and reducing reliance on diesel. Through a combination of technological innovation, smart resource management, and strategic investments, these projects may provide long-term benefits to local communities while lowering energy costs.

3.2 Recommended Business Model

In order to establish sustainable and financially viable mini-grid projects, it is crucial to employ the appropriate business models that suit the regulatory framework, socio-economic conditions, and demand profiles of these countries. This chapter explores three effective business models for mini-grid projects: the Public-Private Partnership (PPP) model, the Anchor-Business-Community (ABC) model, the KeyMaker model and Energy-as-a-service model.

3.2.1 Anchor-Business-Community (ABC) Model

The ABC model is designed to ensure a stable and balanced revenue flow by serving three key consumer segments: **anchor clients**, **businesses**, and the **community**. The goal is to encourage productive use by businesses, which creates local economic development and increases the overall electricity demand over time.

- **Anchor Clients**: Secure long-term contracts with large energy consumers to stabilize revenue.

- **Businesses**: Encourage small businesses to use electricity for income-generating activities like food processing or refrigeration.

- **Community Engagement**: Community users benefit from affordable energy as the project scales, but their demand is lower and often subsidized by anchor customers.

The ABC model thrives in areas where there is a mix of industrial or commercial activity and residential needs, ensuring both financial sustainability and community impact. For example, PowerGen Renewable Energy operates successful mini-grids in Kenya and Tanzania, serving over 10,000 people. By focusing on anchor clients like schools, health centers, and businesses, PowerGen has ensured stable revenue streams while promoting productive energy use in rural areas.

In Namibia, this model is more applicable in regions with agricultural or mining activity. Mining sites or large agricultural cooperatives can serve as anchor clients, providing stable revenue while extending energy access to local communities (cf. Hauser, 2018, pp. 27–32). However, lower population density poses challenges, so careful market selection is key.

3.2.2 Public-Private Partnership (PPP) Model

The Public-Private Partnership (PPP) model leverages collaborative approach that involves government entities and independent companies for the financial and operational aspects of mini-grid systems. Governments usually provide initial funding, regulatory support, and subsidies, while private entities bring in technical know-how, investment, and operational management expertise. This shared responsibility helps mitigate the financial risks of rural electrification and promotes long-term sustainability.

- **Government Support**: Governments provide capital investment, regulatory support, and often subsidize tariffs to ensure affordability for consumers.

- **Private Sector Involvement**: Private companies invest in infrastructure, supply technical expertise, and handle day-to-day operations.

- **Risk Sharing**: Both government and private entities share the financial and operational risks. Government subsidies help offset the costs of infrastructure, while private companies focus on revenue generation and customer acquisition.

Tanzania's Rural Energy Agency (REA) has facilitated multiple PPPs by offering grants and technical support to private developers. For example, PowerGen Renewable Energy is one of the projects developed under this framework. With government backing, PowerGen has successfully expanded mini-grid operations in rural Tanzania (cf. SEforAll, 2020, pp. 95–100). It could also be used for coffee roasting for coffee cooperatives in specific regions where smallholder farmers can benefit from solar powered mini-grids.

In Namibia, NamPower has collaborated with independent power producers (IPPs) to develop large-scale solar and wind projects. Expanding this framework to mini-grid development could bring affordable energy to remote areas where the grid is uneconomical to extend (cf. ESMAP, 2022, pp. 223–225).

3.2.3 Keymaker Model

The Keymaker model is a unique approach that integrates the development of electricity infrastructure with local productive activities to generate additional revenue streams. The mini-grid operator partners with local businesses, enabling them to use electricity to grow their businesses. The model aims to increase the financial sustainability of mini-grids by stimulating local economic activities and, in return, generating a stable demand for electricity.

- **Revenue Streams**: The model creates dual revenue streams—one from electricity sales and another from income generated through value-added local businesses, such as agro-processing or fish farming.

- **Partnership with Local Businesses**: The mini-grid operator actively helps develop productive activities that rely on electricity, such as cold storage for fish or mills for grain.

- **Economic Growth**: The reliable supply of electricity helps local businesses improve their operations, leading to increased demand for energy, creating a positive feedback loop for both the businesses and the mini-grid operator.

In Tanzania, JUMEME implemented the Keymaker model on the island of Maisome in Lake Victoria. The company developed a 60kW solar-hybrid mini-grid, serving around 600 customers, with 21 productive users and 50 commercial users. One of the main productive uses was the commercialization of Tilapia fish**.** Local fishermen benefited from deep-freeze equipment powered by the mini-grid, which allowed them to preserve fish and access higher-value markets. This, in turn, increased electricity consumption, improving JUMEME’s revenue (cf. Pueyo et al., 2022, pp. 32–34).

Additionally, JUMEME introduced aquaculture activities, using electricity for water pumps and milling machines for fish feed production. However, despite initial success, the project faced setbacks due to a regulatory change in 2020. The Tanzanian government imposed national tariffs on mini-grids, slashing JUMEME’s revenue by over 90%, which halted many of the productive activities and led to the rationing of electricity. Unfortunately, the model's success depends on a stable regulatory environment that allows for cost-recovery tariffs (cf. Pueyo et al., 2022, p. 34).

The model is also well suited to the popular electric scooters (e-boda-bodas) because it could bring together mini-grid operators with local companies such as Ampersand to provide charging infrastructure in Tanzania. This stimulates local economic activity while ensuring stable electricity demand, creating a dual revenue stream from transport services and electricity sales.

In Namibia, this model could be applied in regions with significant agricultural activity. For example, mini-grid operators could collaborate with local farmers to provide electricity for cold storage, irrigation, or processing activities. Such integration would boost productivity and ensure the long-term sustainability of mini-grid initiatives. Namibia's population density may present a challenge in some regions.

3.2.4 Energy-as-a-Service (EaaS) Model

The Energy-as-a-Service (EaaS) model simplifies energy access for customers by focusing on essential services. EaaS ensures energy affordability and reliability, which is crucial in regions with limited access to traditional power infrastructure.

- **Service-Based Billing**: Customers subscribe to or pay per use of energy-powered services (e.g., lighting or refrigeration) rather than being charged for electricity usage.

- **Affordability**: By offering services instead of raw electricity, costs are predictable, making energy more accessible to low-income users.

- **Sustainable Revenue**: The operator benefits from predictable, recurring revenue through service fees, ensuring financial stability and scalability.

Pineberry, a German-Kenyan company, employs a Mini-Grid-as-a-Service (MaaS) model, delivering energy solutions tailored to rural communities' specific needs. Pineberry provides services like irrigation and cold storage, which increase productivity in agriculture. Customers pay for these services rather than electricity, ensuring they only spend on what they use, making it an affordable solution for smallholder farmers (cf. Pineberry, 2024). By focusing on productive uses like irrigation, Pineberry helps drive local economic growth, creating demand for energy services that support sustainability and financial viability.

BBOXX leverages the EaaS model to provide solar-powered services in off-grid areas of East and Central Africa. Supported by the Multilateral Investment Guarantee Agency (MIGA), BBOXX delivers energy services like lighting, refrigeration, and phone charging through a subscription model. This approach allows customers to access necessary services without needing to worry about electricity management, driving adoption in rural communities (cf. ‘MIGA Support Helps Bboxx Deliver Clean Off-Grid Solar Energy in Central and East Africa’, 2021).

In Tanzania, as well as in Namibia, the EaaS model is particularly beneficial in regions with a high demand for services. By offering these energy-powered services, mini-grid operators can enhance agricultural productivity and improve local businesses' efficiency. Off-grid farms and lodges can benefit from energy services which are essential for food preservation and guest accommodations.

4 Discussion of use cases

4.1 Rafiki Power

Rafiki Power, a subsidiary of E.ON Off Grid Solutions, is an innovative Tanzanian company specializing in the provision of off-grid energy systems. This entails the development of sustainable power solutions for rural areas and remote locations that lack grid connectivity, thus posing a challenge in terms of accessibility. Through the use of state-of-the-art solar technology, Rafiki Power provides clean, renewable energy customized to African communities and business's needs (cf. Smart Villages, 2017).

Energy is a key component for education, healthcare and job creation, and through its customized solutions, the company is making an important contribution to overcoming energy poverty. A particular focus is on the use of solar systems, combined with innovative battery storage technologies. Not only do these systems provide a stable and reliable supply of electricity, but also contribute to the mitigation in CO2 emissions and support the global energy transition. Rafiki Power adopts a holistic methodology that prioritizes not only the technical implementation of its projects, but also the social and economic integration of the communities that benefit from them. The company works in close collaboration with local partners, authorities and international organizations to guarantee the long-term sustainability and economic viability of its solutions (cf. Gründerküche, 2017)

<u>Business Model</u>

Rafiki Power operates in rural Tanzania through the Energy-as-a-service business model and the Pay-As-You-Go (PAYG) payment model, a system designed to offer off-grid solar energy to underserved communities. This model addresses the issue of energy poverty by providing access to affordable electricity without the necessity of upfront costs. These solutions provide energy for both residential and productive uses, including the operation of small businesses and micro-industries. By concentrating on local economic activities, Rafiki Power guarantees that the energy they provide helps drive local income generation and community development (cf. Adegoke, 2019; Smart Villages, 2017).

The inclusion of mobile money as a component of mobile payment integration represents a significant aspect of the PAYG model. In Tanzania and other parts of East Africa, platforms like M-Pesa are widely adopted for mobile payments, which offers customers a simplified process (cf. *Vodacom Tanzania : Mpesa*).

In terms of financing and partnerships, Rafiki Power initially received pilot funding from the parent organization E.ON which is one of Europe's largest energy companies. Over time, they expanded their operations through the formation of strategic alliances with non-governmental organizations (NGOs). However, as installation and transportation costs remain high, particularly in remote villages, Rafiki Power also relies on subsidies to offset these costs (cf. Smart Villages, 2017).

Unique Challenges and Solutions

Maintenance and Operational Costs

- Challenge: Cost of maintaining and operating a mini-grid system in remote areas. There are also logistical challenges, such as obtaining spare parts and skilled labor.
- Solution: Remote monitoring system to monitor operations, reducing the need for expensive technical site visits (cf. Battery Council International, 2020).

Customer Education and Engagement

- Challenge: The benefits of electricity or its efficient use is not fully understood, which leads to slow adoption.
- Solution: Investment in Community engagement and customer education program to increase understanding and adoption of mini-grid systems (cf. Battery Council International, 2020)

4.2 Cenored

One of Namibia's major regional energy distributors, CENORED (Central North Regional Electricity Distributor), was founded in 2003 as a part of the government's effort to enhance power supply and distribution in underserved areas. CENORED provides services to rural, peri-urban, and metropolitan communities in Namibia's north and center. The company's main goal is to supply towns that are not connected to the national grid with electricity that is both inexpensive and dependable. By putting creative ideas like hybrid mini grids into practice, CENORED is dedicated to helping the nation reach its electrification targets and providing energy access to isolated areas.

Business Model

By employing a public-private partnership (PPP) strategy, CENORED has developed a minigrid business model that allows the company to supply energy to isolated, off-grid neighborhoods such as Tsumkwe. The Tsumkwe mini grid was financed through a partnership between the European Commission (75%), NamPower (14%), and the Otjozondjupa Regional Council (11%) (Hoeck et al., 2021, p. 8). It combines solar PV with diesel generators. This enables CENORED to use prepaid metering to earn recurring revenue from consumers while covering the significant capital expenses associated with installation. Residential users pay NAD 2.22/kWh, whereas enterprises pay NAD 4.07/kWh, balancing affordability with cost recovery. In addition, CENORED teaches locals how to do simple maintenance duties, which lowers operating expenses and promotes community ownership. Mini-grids are guaranteed to be financially and operationally sustainable because of their reliance on outside grants and hybrid energy systems, which lessen dependency on fuel (Hoeck et al., 2021, p. 15).

Challenges

- High maintenance costs: Maintaining hybrid mini-grids in remote areas is expensive, with factors like dust on solar panels and manual battery/diesel switching increasing operating costs (Hoeck et al., 2021, p.6).

- Low demand and affordability: Demand for electricity is limited by rural households' inability to afford energy costs. High tariffs, especially for business customers, exacerbate the challenge of covering operating costs (Hoeck et al., 2021, p.3).
- Regulatory and operational barriers: CENORED faces stakeholder coordination challenges and high operational costs in managing minigrids, leading to advocacy for grid expansion (Hoeck et al., 2021, p.3).

Solutions

- Community Involvement: CENORED educates local residents to carry out basic preventive and operational tasks like cleaning solar panels and fixing minor technical problems, which reduces operating costs and promotes local ownership (Hoeck et al., 2021, p.12).
- Optimizing hybrid systems: Prepaid metering systems help improve cash flow and allow consumers to manage their energy consumption. This reduces the risk of non-payment. It is also planned to expand solar capacity to help reduce reliance on diesel (Hoeck et al., 2021, p.10).
- Long-term financial support: CENORED relies on Namibia's Off-Grid Energization Master Plan (OGEMP) and seeks additional national and international funding to ensure sustainability (Hoeck et al., 2021, p.8).

5 Conclusion

In conclusion, the economic sustainability of mini-grid projects in Namibia and Tanzania is dependent on a number of factors, including regulatory frameworks, technological advancements, and the implementation of sustainable business models. While both countries face similar socioeconomic challenges and energy access goals, geographical and resource differences necessitate tailored approaches. Mini-grids that are fueled by sustainable energy sources, including solar and wind, provide a scalable solution to rural electrification, assuming that advances in battery storage and reduced reliance on diesel can further reduce costs.

Mini-grid operators can ensure financial sustainability and promote local economic growth by utilizing models such as Anchor-Business-Community and Public-Private Partnerships. Continued investments in energy infrastructure, combined with supportive regulatory policies, will be critical for scaling these solutions and meeting long-term energy access targets in Namibia and Tanzania.

Bibliography

Access to electricity improves slightly in 2023, but still far from the pace needed to meet SDG7 – Analysis. (n.d.). IEA. Retrieved 7 September 2024, from https://www.iea.org/commentaries/access-to-electricity-improves-slightly-in-2023-but-still-far-from-the-pace-needed-to-meet-sdg7

Ahamad, M. G., Tanin, F., & Shrestha, N. (2021). Household Smoke-Exposure Risks Associated with Cooking Fuels and Cooking Places in Tanzania: A Cross-Sectional Analysis of Demographic and Health Survey Data. *International Journal of Environmental Research and Public Health*, *18*(5), 2534. https://doi.org/10.3390/ijerph18052534

Ahlborg, H., & Hammar, L. (2014). *Are mini-grid projects in Tanzania financially sustainable?* SpringerLink. Retrieved September 30, 2024, from https://link.springer.com/article/10.1007/springer123

Battery Council International. (2020). *Application Brief Rafiki Power*.

BloombergNEF. (2023, November 26). Lithium-Ion Battery Pack Prices Hit Record Low of $139/kWh. *BloombergNEF*. https://about.bnef.com/blog/lithium-ion-battery-pack-prices-hit-record-low-of-139-kwh/

Cenored. (n.d.). *Company Overview*. Retrieved from [Cenored Official Website](https://www.cenored.com.na)

Cenored. (n.d.). *About Us*. Retrieved September 30, 2024, from https://cenored.com.na

Contejean, A., & Verin, L. (2017, January). *Making mini-grids work: Productive uses of electricity in Tanzania. IIED, Working Paper.* IIED, London. http://pubs.iied.org/16632IIED

Dittmeyer, H., & Pflomm, G. (2024, March). *Tansania. Dezentrale Energieversorgung mit erneuerbaren Energien*. AHK Services Eastern Africa Ltd.

EEP Africa. (2019). *Scaling Up Mini-Grids: Policy and Financing for Sustainable Development in Sub-Saharan Africa*. Retrieved September 30, 2024, from https://eepafrica.org/wp-content/uploads/2019/11/EEP_MiniGrids_Study_DigitalVersion.pdf

Electricity Control Board. (2023). *Net Metering Rules: Electricity act,2007*.

Energy Sector Management Assistance Program. (2022). *Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers* (Washington, DC). World Bank. https://www.esmap.org/mini_grids_for_half_a_billion_people_the_report

Energypedia. (n.d.). *NAE Case Study: Tanzania, Mini-Grids Regulatory Framework*. Retrieved September 20, 2024, from https://energypedia.info/wiki/NAE_Case_Study:_Tanzania,_Mini-Grids_Regulatory_Framework

FairPlanet. (2019). *Pay-as-you-go models address energy poverty in Africa*. Retrieved September 30, 2024, from https://www.fairplanet.org/story/pay-as-you-go-models-address-energy-poverty-in-africa/

GIZ. (2022, July). *Sector brief Namibia: Renewable Energy*. GIZ.

Global Wind Atlas. (2023). https://globalwindatlas.info

Government of the republic of namibia & ministry of mines and energy. (2016). *Electricity-sector-national-integrated-resource-plan-nirp-2016*.

Gründer-küche. (2017). Gründerstory Rafiki Power - E.ON Ausgründung für Mini-Grids. *Gründer-küche*. Retrieved from https://www.gruenderkueche.de

Hauser, J. (2018, December). *Namibia. Erneuerbare Energien zur dezentralen Energieversorgung: Zielmarktanalyse 2019 mit Profilen der Marktakteure*. Southern African – German Chamber of Commerce *and Industry.*

Hoeck, I., Steurer, E., Dolunay, Ö., & Ileka, H. (2021). *Namibia's regulatory framework for off-grid electrification.*

Hoeck, T., Steurer, J., & Dolunay, S. (2021). *Challenges for off-grid electrification in rural areas: Assessment of the situation in Namibia*. PROCEED.

International Trade Administration. (2022, December 14). *Tanzania—Country Commercial Guide*. Tanzania - Mining. https://www.trade.gov/country-commercial-guides/tanzania-mining

IRENA (2016), Innovation Outlook: Renewable Mini-grids, International Renewable Energy Agency, Abu Dhabi.

Lee, A., & Usmani, F. (2018, August 28). *Pay-as-you-go solar could electrify rural Africa*. World Resources Institute. Retrieved September 30, 2024, from https://www.wri.org/insights/pay-you-go-solar-could-electrify-rural-africa

MIGA Support Helps Bboxx Deliver Clean Off-Grid Solar Energy in Central and East Africa. (2021, April 20). World Bank Group. https://www.miga.org/press-release/miga-support-helps-bboxx-deliver-clean-grid-solar-energy-central-and-east-africa

Ministry of Minerals. (2024, July 15). The Mining Sector, A Key Player In Tanzania's Economy. The Mining Sector, A Key Player In Tanzania's *Economy*. https://www.madini.go.tz/page/03cef72a-bdd3-41dc-ba84-40954095b835/

Ministry of mines and energy & Government of the republic of namibia. (n.d.). *Ministry of Mines and Energy—Wind Energy*. Retrieved 8 September 2024, from https://mme.gov.na/energy/ene_wind.php

Ministry of Mines and Energy. (n.d.). *National Electrification Policy—Final Draft*.

Nagpal, D., & Parajuli, B. (2018). *Policies and regulations for renewable energy mini-grids*. International Renewable Energy Agency (IRENA). https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Oct/IRENA_mini-grid_policies_2018.pdf

NamPower Integrated Annual Report 2023. (2023). https://www.nampower.com.na/public/docs/annual-reports/NamPower_Integrated_Annual_Report_2023.pdf

Osawa, B., & Telep, P. (2015, July). *How do we license it? A guide to licensing a mini-grid energy service company in Kenya*. GIZ.

Off-Grid Europe. About Us. Retrieved September 8 from https://offgrideurope.com/about-us

Parliament of the Republic of Namibia. (2007, September 26). *Electricity Act 2007*. https://media.namiblii.org/files/legislation/akn-na-act-2007-4-eng-2007-10-18.pdf

Photovoltaic power potential—Tanzania. (2019). https://globalsolaratlas.info/download/tanzania

Pineberry. (2024). *Mini-Grid-as-a-Service*. PineBerry. https://pineberry.services/mini-grid-as-a-service

Population growth (annual %)—Namibia. (2023). World Bank Open Data. https://data.worldbank.org

Power for All. (n.d.). *Insider Insight: Rafiki Power*. Retrieved from https://www.powerforall.org/resources/insights/insider-insight-rafiki-power:contentReference[oaicite:0]{index=0}.

Pueyo, A., Ngoo, G., Daulinge, E., & Fajardo, A. (2022). *The Quest for Scalable Business Models for Mini-Grids in Africa: Implementing the Keymaker Model in Tanzania*. Institute of Development Studies. https://doi.org/10.19088/IDS.2022.071

SEforAll. (2020). *State of the Global Mini-Grids Market Report 2020*. Sustainable Energy for All.

Smart Villages. (n.d.). *Rafiki Power and E.ON: Mini-grids for improved livelihoods in Tanzania*. Retrieved September 30, 2024, from https://e4sv.org/rafiki-power-e-mini-grids-improved-livelihoods-tanzania/?doing_wp_cron=1727647049.3762569427490234375000

SOLARGIS. (2019). *Photovoltaic power potential—Namibia*. Global Solar Atlas. https://globalsolaratlas.info/download/namibia

Statistisches Bundesamt (Destatis). (2024a, August 5). *Statistisches Länderprofil—Namibia*.

Statistisches Bundesamt (Destatis). (2024b, August 5). *Statistisches Länderprofil—Tansania, Vereinigte Republik*.

Tanzania Investment Centre. (n.d.). *Tanzania Tourism Performance Review*. Retrieved 28 September 2024, from https://www.tic.go.tz/sectors/tourism

Telecom Namibia, CENORED ink agreement for several new joint research initiatives. *Namibia Economist*. Published June 22, 2023. Available at: https://economist.com.na/80226/human-resources/telecom-namibia-cenored-ink-agreement-for-several-new-joint-research-initiatives/

The United Republic of Tanzania. (2019, June 21). *The Electricity Act, (CAP.131)*. https://www.ewura.go.tz/wp-content/uploads/2019/07/The-Electricity-Development-of-Small-Power-Projects-Rules-2019-GN-No.-462.pdf

Thomson, M. (2019, July 18). *Pay-as-you-go solar: A lifeline for electricity access in Africa*. World Economic Forum. Retrieved September 30, 2024, from https://www.weforum.org/agenda/2019/07/pay-as-you-go-africas-solar-energy/

USAID. (2018, April 30). *Tanzania Rural Energy Agency Transaction Advisor—Final Report*.

Vodacom Tanzania: *Mpesa*. (n.d.). Retrieved 30 September 2024, from https://vodacom.co.tz/mpesa

Waldron, D. (2018, December 17). *How PayGo transformed off-grid solar. Is consumer financing next?* Consultative Group to Assist the Poor (CGAP). Retrieved September 30, 2024, from https://www.cgap.org/blog/paygo-transformed-grid-solar-is-consumer-financing-next

World Bank Group. (2023). *Population growth (annual %)—Tanzania*. World Bank Open Data. https://data.worldbank.org/indicator/SP.POP.GROW?locations=TZ

World Bank. Changing Lives and Livelihoods in Tanzania, One Electricity Connection at a Time. (2022, June 28). *World Bank*. https://www.worldbank.org/en/news/feature/2022/06/28/changing-lives-and-livelihoods-in-tanzania-one-electricity-connection-at-a-time

World Bank. *Mini Grids for Half a Billion People : Market Outlook and Handbook for Decision Makers (English).* Energy Sector Management Assistance Program (ESMAP) Washington, D.C.: World Bank Group. http://docments.worldbank.org/crated/en/099635009232259510/P1751510dd4ab407e083a6098d1905fa94f

World Economic Forum. (2019, July 18). *Pay-as-you-go: How a solar energy model is empowering rural Africa*. Retrieved September 30, 2024, from https://www.weforum.org/agenda/2019/07/pay-as-you-go-africas-solar-energy/

World Resources Institute. (2017). *Accelerating mini-grid deployment in sub-Saharan Africa: Lessons from Tanzania*. Retrieved September 30, 2024, from https://www.wri.org/research/accelerating-mini-grid-deployment-sub-saharan-africa

Youthful population dominates Namibia's 2023 Census preliminary results: 71.1% of population is under age 35. (n.d.). UNFPA-Namibia. Retrieved 8 September 2024, from https://namibia.unfpa.org/en/news/youthful-population-dominates-namibias-2023-census-preliminary-results-711-population-under-age

Statutory declaration

I certify that I have prepared this bachelor’s thesis independently, that I have not submitted it for examination purposes, that I have cited all sources and aids used, and that I have marked verbatim and analogous quotations as such.

Wertheim, 01.10.2024

Location, date

Signature