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Challenges for off-grid electrification in rural areas. Assessment of the situation in Namibia using the examples of Gam and Tsumkwe

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Abstract Access to electricity is vital for the social and economic development of a country. Nevertheless, electrification is still a major challenge, especially for countries in sub-Saharan Africa (SSA). Growth in access to electricity in total numbers has slowed down in recent years. Namibia in particular appears to be in a predicament, since a large portion of its widespread population cannot be connected to the main grid at reasonable costs. Furthermore, Namibia relies heavily on imports of coal-based electricity, which limits the country's ability to achieve its pledged sustainability goals. This is quite paradoxical as Namibia has one of the highest solar irradiation levels in the world, providing the possibility to generate large amounts of solar electricity at very low costs and to electrify rural areas through solar off-grid systems. These favorable conditions should be exploited, not least in view of the growing demand for energy, which potentially exacerbates the present situation. This paper therefore presents firstly general challenges for off-grid electrification and subsequently illustrates the effects in Namibia on the example of two off-grid areas in Gam and Tsumkwe. Several deficiencies within the country's current off-grid approach are revealed, most notably the one-sided off-grid legislation and the neglect of educational outreach to the local community.

Keywords Rural electrification · Electrification challenges · Renewable energy · Mini-grid system · Namibia

1 Introduction

Sustainable Development Goal (SDG) 7 aims to achieve universal access to affordable, reliable, sustainable and modern energy by 2030 (IEA et al. 2020). In 2020, however, 789 million people worldwide still lived without access to electricity (United Nations 2020). Due to this deficit, necessary sustainable development in these mostly rural regions is stagnating. Indeed, a more reliable power supply has been shown to improve the overall situation of remote communities. Above all, hard-to-reach population groups, especially in sub-Saharan Africa (SSA), count among them (Gonzalez Sanchez et al. 2021; IEA et al. 2019). The benefits range from improved health care and education quality to income generation and thus poverty reduction (Kyriakarakos et al. 2020).

Off-grid solar systems present a promising solution to electrify these remote areas by closing the access gap as well as featuring lower costs and shorter waiting times until being connected, in comparison with grid extensions. Broadly defined, a mini-grid system includes a power generation as well as a distribution system that delivers energy to isolated loads, which can be complemented by a storage system for the generated energy (Mbinkar et al. 2021). Mini-grids are capable of operating independently, either through a single or multiple generation sources (hybrid systems), and thus can provide electricity, particularly to underserved populations in rural areas (Louie 2018).

Based on 5,544 investigated mini-grids in the course of the global mini-grids market report 2020, the generation source primarily used was solar power (see Fig. 1), which is indeed the most cost-effective and efficient renewable solution for developing countries (Eras et al. 2019).

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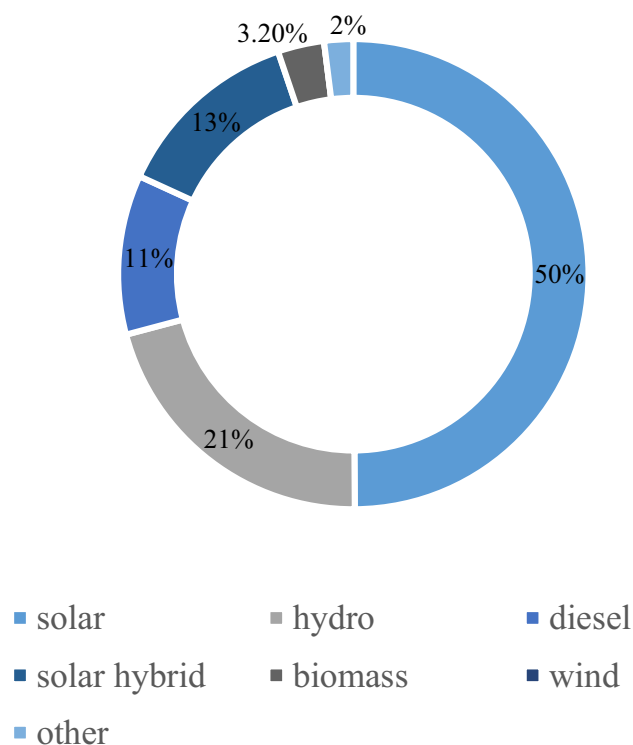


Fig. 1 Installed mini-grids by generation source (basis: 5,544 projects in Sub-Saharan Africa, Asia and small island nations incl. some in Latin America) (SEforALL and BloombergNEF 2020)

Various sources already outline the importance of a supportive regulatory framework, access to finance as well as socioeconomic and technical considerations for the implementation of off-grid solutions (Electricity Control Board 2017a; IEA et al. 2019; Tenenbaum et al. 2018). Nevertheless, the increase in access to electricity (in total numbers) has decreased in recent years (IEA 2020; Corfee-Morlot et al. 2019). This publication therefore seeks to delineate the current challenges for off-grid electrification in a concise manner in order to halt the downward trend. The literature-based first part of this paper is complemented by a case study of the electrification sector in Namibia. Both national and regional challenges are exemplified by two off-grid locations in northeastern Namibia: Gam and Tsumkwe.

2 Key challenges for off-grid electrification in rural areas

While challenges are described in detail in the following sections, a general objection is maintaining balance between the triangle of government, community and investors. Albeit investors focus on the investments return that result from a viable system management, the community desires a low or rather affordable tariff and reliable electricity supply. The

government, as the third stakeholder, aims at creating a just environment for urban and rural populations, which includes a fair tariff regulation that therefore might depend on subsidies. An overview of identified off-grid electrification challenges is presented in Table 1.

2.1 Challenges in regard to policies

Policy support is of great importance for the dissemination of off-grid electrification (Eras et al. 2019; Tenenbaum et al. 2018). This starts with a holistic, long-term electrification strategy, including an energy access plan, which should categorize different areas in a country in accordance with the possibility of being reached by the grid at reasonable costs. Areas that are not reachable require off-grid solutions. This information is essential for stakeholders to decide on off-grid projects. In fact, a key impediment in emerging countries is the lack of complete and accurate information targeted at businesses and investors (SEforALL and BloombergNEF 2020). As payback periods for mini-grids easily exceed several years, it is an essential task of the government to create a regulatory environment including agreements or subsidies, which are valid for ideally ten years or longer to mitigate risks for investors (Reber et al. 2018). The overarching off-grid strategy should be complemented by monitoring tools that continuously track progress (GOGLA 2019). There is a risk of overlap and duplication of effort if the monitoring tasks at hand are not coordinated and managed by a cross-government task force. Various issues even call for the additional integration of the public sector, civil society organizations, microfinancing companies and other stakeholders (Bhattacharyy and Palit 2016; Eras et al. 2019; GOGLA 2019).

Besides missing governmental planning of off-grid areas, specifically the lack of a grid arrival policy hampers investments in off-grid electrification (IRENA 2019). According to a World Bank Report, mini-grids were regularly abandoned once a village was connected to the national grid (Tenenbaum et al. 2018). Hence, a regulatory framework that ensures investors that mini-grids are retained and continue to be used after the grid is extended needs to be implemented (Antonanzas et al. 2021). There are, in fact, no reasonable obstacles when connecting the mini-grid to the national grid as long as adequate compensation and technical arrangements have been defined (Franz et al. 2014). Still, governments regularly fear losing flexibility. Changing domestic needs or innovations might affect expansion plans and eventually render mini-grids useless (Reber et al. 2018). Despite this, some countries have already implemented regulations in that regard. For example, the Nigerian government offers a range of solutions for operators when the grid arrives: receiving compensation, continuing running and deriving revenue from

Table 1 Summary of off-grid electrification challenges

Policies	Licensing	Tariff setting	Financial	Social	Technical
No long-term electrification strategy	Complex and bureaucratic licensing process	Tariffs unaffordable for rural communities (demand risk)	Short-term financing schemes	Lack of productive-use cases	Lack of technical standards
No energy access plan marking off-grid areas	High costs for licenses	Economic viability of mini-grids not ensured	Financing programs disregard small projects	No educational measures for communities (e.g., related to energy efficiency awareness)	No recognition of future demand when dimensioning
Short-term, volatile regulations	No distinction between project sizes	No adequate payment system	Absence of fiscal incentives		Components incompatible with conditions
Isolated coordination, no involvement of external stakeholders		Strict tariff standards, no differentiation between project sizes	Low expected return on investment	No community involvement in the planning phase	No monitoring system, no responsible qualified staff
No clear definition of stakeholder responsibilities involved in mini-grid projects			High upfront investment costs	No technical know-how to employ local staff	Lack of adequate regulations to ensure dependable operation and maintenance
Lack of main-grid arrival policy					

the mini-grid including receiving compensation for only operating the distribution system or operating alongside the main grid (SEforALL and BloombergNEF 2020).

The absence of clear information concerning licensing, technical system design, financing and tariff setting in the regulatory framework is moreover hampering particularly private sector involvement in the off-grid sector. Most of these issues are addressed in the course of this paper. Generally, information on processes and procedures should be easily accessible to inform the population and potential investors (IRENA 2016a). An example for this is Tanzania's online information portal exclusively for mini-grids (minigrids.go.tz).

2.2 Challenges in regard to licensing

Complex, costly and time-consuming retail or generation licensing procedures discourage investors or businesses from initiating mini-grid projects (Come Zebra et al. 2021). Countries that do not distinguish between small-scale projects and utility-scale projects thus reduce the chances for smaller projects to be established. This is critical given that the need for hundreds of mini-grids over the next few years is prevailing in most emerging countries (SEforALL and BloombergNEF 2020).

Moreover, bureaucratic hurdles for acquiring a proper license can be reduced by establishing a “one-stop shop” that issues all needed permits that are required along the

timeline of a project. This approach eases the burden on governments as well as prevents duplication of work (SEforALL and BloombergNEF 2020). Tanzania provides an exemplary solution for a smooth licensing process. A capacity carve-out is applied, since mini-grids with a capacity of less than one MW do not need a generation license at all (IRENA 2016a). Further, Tanzania allows developers to obtain a single license for multiple specified sites. Similarly, Sierra Leone is another example where a single license allows developers to generate, distribute and sell electricity (SEforALL and BloombergNEF 2020). In Rwanda, mini-grids with a capacity of less than 50 kW are exempt from licensing, while systems between 50 and 100 kW are subject to a simplified procedure (Come Zebra et al. 2021).

2.3 Challenges in regard to tariff setting

Tariff design is a regularly occurring source of conflict. This is particularly due to the fact that off-grid system developers must charge considerably high tariffs to cover investment and operational costs, in comparison with cheaper grid-based electricity (Lukuyu et al. 2020; Franz et al. 2014). As off-grid electricity is needed especially in places where people are destitute, the quandary becomes apparent. The unaffordability of access to electricity causes, in some cases, illegal usage by community residents, which leads to financial losses for the operator, not least

due to the overload that occurs. Common strategies include installing illegal connections, tampering with meters, the occurrence of billing irregularities, and the simple non-payment of bills (Bhatia and Angelou 2015). Moreover, high tariffs lead to a demand risk for the operator. Accordingly, rural areas are less attractive than urban areas from an economic point of view. However, the emergence of pay-as-you-go (PAYG) systems increasingly prevents illegal activities from happening and, at the same time, enhances the demand planning of the operation.

Apart from this, the government, in particular, has the obligation of safeguarding the economic viability of mini-grids, while ensuring that tariffs are not overly high for underserved communities—the tariff has to satisfy both the investor and the consumers (IRENA 2019). Hence, the government has options to intervene in the tariff structure. In the case that countries decide on uniform national utility tariffs, for example based on grid rates, it is clear that tariffs have to be cross-subsidized or directly subsidized by the government to ensure economic viability (Reber et al. 2018). The German Renewable Energy Act of 2002 serves as a precedent with regard to the installation of a support system for renewable energies. All end consumers of electricity must pay a renewable energy levy that depends on the number of renewable energy systems installed in a given year. This levy is set once a year and distributed to renewable energy operators to ensure that they remain competitive in the long term. Albeit in this scenario, customers gain unrealistic expectations of tariffs, since the true cost of service is obscured. Furthermore, the fact that capital expenses are not reflected deters investors. The other rather drastic option for the government is to deregulate completely and leave developers the choice to set their own cost-reflective tariffs. Following this scenario, mini-grid tariffs would outreach grid tariffs. Although this would attract investors, politicians are reluctant to adopt this scheme in consideration of the arising inequality between urban and rural populations. It is furthermore likely that customers will generate their own (not clean) electricity for less (e.g., wood). Tanzania addresses this issue by giving communities in remote and unregulated areas the opportunity to disapprove tariffs. The tariff will be reviewed when 15 percent of customers in the respective areas officially make a complaint to the authority (Reber et al. 2018; Babatunde et al. 2020). Between these two alternatives are various other schemes to find—cost-reflective tariffs with governmental approval, cost-reflective tariffs with grants and subsidies, national utility tariffs based on higher off-grid tariffs or size thresholds (Reber et al. 2018).

Especially for small-scale projects it is advantageous to let developers set their own tariffs. The Nigerian government, for example, allows operators with a distribution

capacity under 100 kW to define their own rates, which have to be calculated with the help of a standardized tool issued by the government (Antonanzas et al. 2021). In the case of interconnected mini-grids, the tariff has to be jointly agreed upon by the developer, the distribution company and the community (IRENA 2019).

2.4 Financial challenges

Financing mini-grids is challenging, especially in developing countries. The required long-term financing for mini-grid projects is often challenging to obtain. Banks in developing countries are particularly hesitant, either because of a lack of funds or because of the high risk of loss caused by high or uncertain inflation (USAID 2018). Furthermore, the power demand in rural areas is relatively low and unstable, which makes it difficult for operator to recover costs. Based on the rather limited demand, the sizes of rural mini-grids are rather small, ranging from 10 to 100 kW. Therefore, many private investors find the investment unattractive, given the time and effort required for due diligence. Private financiers typically prefer larger deals, which allow them to amortize transaction-related costs over larger volumes of capital and, in many cases, earn larger fees (SEforALL and BloombergNEF 2020). Hence, it is crucial to implement schemes that target smaller projects. This is, however, challenging for local banks, since they are unable to assess the risk of small-scale projects (USAID 2018).

Given the wide range of subsidies that have been implemented for mini-grid markets, two main types of support currently drive project development most: upfront capex subsidies and results-based financing (RBF). Upfront capex subsidies provide developers with the financial backing to cover some portion of the total capital expenditure (capex) of their projects before construction begins. This typically involves issuing grants or concessional loans to cover upfront capital costs. Disadvantageous for developers is that this process tends to be administratively complex. Further, upfront capex subsidies could set wrong incentives during the operation. The operator could delay necessary investments, as there is no cost pressure to pay back the grant. Generally, upfront capex-based subsidies are not contingent on how successful a project proves to be. This has led private investors and developers to call for schemes that grant rewards based on the results achieved. RBF involves payment of specified sums when projects achieve specific criteria, e.g., providing a fixed sum for each completed connection. Implementing RBF can come with challenges, but its introduction is usually simpler and faster than up-front proposals based on capex subsidies. As the success of RBF payments is back-loaded, RBF puts developers at greater risk if they are unable to move a

project forward as quickly as originally planned (Vivid Economics 2013; SEforALL and BloombergNEF 2020).

An example for upfront capex subsidies provides Uganda. Developers have the possibility to have 50% of the initial capital expenditure covered by the government. Notably the upfront capex subsidies include the distribution network; thus, these incentives lead immediately to the construction of distribution infrastructure. Concessions are issued to developers for 10-year periods on a build-own-operate-transfer basis through which the mini-grid's distribution network is eventually transferred to the government. Nigeria, on the other hand, provides an example for a successful RBF scheme, following the approach of a performance-based grant program. Grants of USD 350 per new connection are provided. A minimum total grant request of USD 10,000 has been set per mini-grid. Projects are restricted to solar hybrid mini-grids in off-grid regions (SEforALL and BloombergNEF 2020).

Another measure that potentially increases the amount of mini-grid projects is fiscal incentives, such as import duty waiver and value added-tax exemptions (Come Zebra et al. 2021; GOGLA 2019). One of the first following a coordinated approach was the East African Community adopting an import duty exemption. Notable is that tax waivers on a range of project components were removed in 2016, leaving only modules and batteries exempt (IRENA 2019).

2.5 Social challenges

The electricity generated from mini-grids remains expensive for clients from rural areas (SEforALL and BloombergNEF 2020). The lack of productive-use customers, who could generate revenue with the electricity generated during the day, brings economic pressure to the continuity of the system. Both of these issues are closely related to educational measures. Capacity building, which begins during the planning phase of a project, involves different areas such as strengthening technical or managerial capacity of public and private companies, educating villagers about productive-use cases for income generation, training staff of the rural electricity companies as well as private and public sector support (Sovacool 2012). While the simple coverage of energy demand was traditionally on top of the agenda, recent research has revealed that it is of utmost importance to combine these efforts with educational measures to advance socio-economic development. In particular to name are positive impacts on health, education and gender equality (Bahaj et al. 2019; Eales et al. 2018).

Beyond that, low demand and high default rates under optimistic demand scenarios are among the other key challenges of rural electrification (Peters et al. 2019),

which is strongly connected to the employment and income level of the clients. It is essential to not just focus on lightbulbs, but to identify where power can particularly help people to increase their income, which simultaneously helps mini-grid operators to ensure a reliable revenue collection and to recover investment costs. While a reduction of capex depends on external factors (technology and regulation), operational expenditure (opex) can be minimized through the stimulation of power demand, which, in turn, is achieved through education. Thus, building up local skills and ideally increasing entrepreneurial activities, tackle challenges that are related to unreliability of rural customers, which represents one of the biggest obstacles to mini-grids becoming economically viable without subsidies (Ngowi et al. 2019; Kanagawa and Nakata 2008; Ramchandran et al. 2016).

Various support schemes, for example the Key Maker Model, could support the development of a sustainable market for off-grid solutions. In accordance with this model, the operator integrates an anchor customer that processes raw materials from the local community with electricity from the mini-grid and eventually sells the final products to customers in urban areas (Ramchandran et al. 2016; IRENA 2019).

2.6 Technical challenges

While technical equipment has advanced over time, which is particularly noteworthy in regard to the decreasing investment costs, some technical regulations or supporting systems have not managed to evolve at the same pace. Particularly the lack of an appropriate regulatory framework consisting of technical standards for off-grid systems is a major challenge to allege, which usually causes an increase in costs and reduces the quality of the systems (Eras et al. 2019). To mitigate this risk, Kenya for example, has adopted regulations specifically for PV systems that aim to standardize the quality of components and business practices in the solar energy sector (IRENA 2020). In the worst case, resulting poor quality of supply (e.g., due to voltage fluctuations) affects the performance of applications. In particular, fluctuating temperatures negatively influences productive-use cases that require high-temperature levels (Bhatia and Angelou 2015). Thus, inferior systems installed due to a lack of technical standards would further hinder vital productive-use cases necessary for economic development in rural areas. A common challenge in the system design of a mini-grid occurs in the course of planning, dimensioning, and budgeting (Hartvigsson et al. 2021; Mbinkar et al. 2021; Cicilio et al. 2016). Thus, features such as (future) local energy needs, load demands, time of use, time for development and budget limitations need to be considered in beforehand. In the best case, a

standard that comprises the outlined elements exists (Dauenhauer et al. 2013). The dimensioning of the system is particularly significant, since a constantly overloaded system causes damage in the long term due to the under dimensioned premises. Load profiles should therefore be roughly forecasted in advance (Bhatia and Angelou 2015). It is furthermore essential to account for future electricity demand throughout the planning phase, which tends to increase as prosperity within a community increases. A main factor in terms of budgeting is the choice of battery, as the batteries are the most expensive parts of the system. While lead-acid station batteries are relatively affordable, they must be adequately taken care of. Their lifespan can be overestimated, causing them to drop out earlier than expected, resulting in additional costs for replacement (Dauenhauer et al. 2013).

Once the system is implemented, facilitating monitoring and maintenance is essential for ensuring reliable and long-lasting availability (IRENA 2016b). The lack of well-trained technical staff is consequently a severe challenge, as repairs cannot be carried out and regular monitoring of the system is most likely to be neglected (Hubble and Ustun 2018).

3 Off-grid electrification in Namibia

Although the majority of Namibia's renewable electricity generation comes from hydropower resources, this paper focuses on two hybrid diesel-photovoltaic (PV) powered mini-grids. Wind and solar power generation currently accounts for 24 percent of the country's total energy generation (Bloomberg Finance L.P. 2020), albeit research has shown that PV in fact is the most cost-effective and efficient renewable solution for developing countries (Eras et al. 2019). That is especially the case for Namibia, as having the second highest level of solar irradiation in the world (United Nations 2017). Despite good preconditions, oil that is imported from neighboring countries still accounts to the largest part of the overall energy supply, while solar power lags behind (see Fig. 2).

In Namibia's Vision 2030, the government declared to adopt sustainable energy policies with the intention of accelerating urban and rural development. The same was stated in the Strategic Plan 2017/2018—2021/2022 devised by the Ministry of Mines and Energy (MME) (Ministry of Mines and Energy 2017a). This appears to be a valid strategy, considering the above outlined potentials of solar energy in Namibia and the great dependence on imports of fossil fuels from neighboring countries (GIZ 2020; Electricity Control Board 2017a). Fostering current endeavors to increase the dissemination of solar energy supply through the uptake of off-grid solutions is therefore an

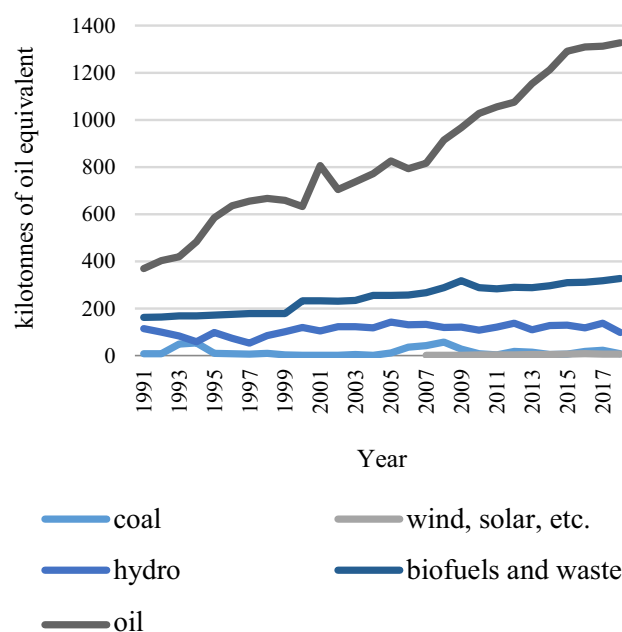


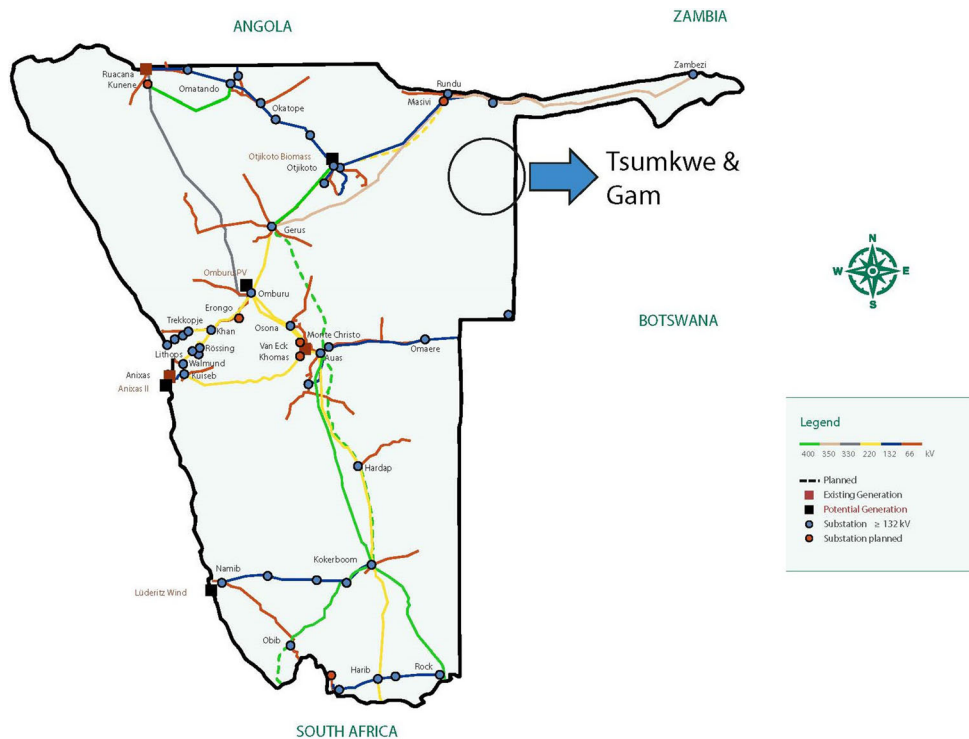
Fig. 2 Total energy supply by source, Namibia 1990–2018 (IEA 2021)

essential step not only toward greater energy independence, but also toward lower national electricity prices.

3.1 Structure of the Namibian Energy Sector

The Namibian electricity supply industry started a transformation process in the 2000s. Initially, the state-owned national power utility 'NamPower' had a quasi-monopoly in the market, being responsible for the generation, transmission, and distribution of electricity (Hauser 2018). While NamPower alone had been authorized to provide electricity to farms and mines, Local Authorities (LA) and Regional Councils (RC) were responsible for supplying electricity to residents and businesses (Electricity Control Board 2019a; Hauser 2018). In 2000 the Electricity Control Board (ECB) adopted the role as market regulator, which is stated in the *Electricity Act of 2007* (formerly: *Electricity Act of 2000*), while the MME remains to be responsible for developing the industry itself and ultimately acts as policymaker (Ministry of Mines and Energy 2017a). Since 2002, regional electricity distributors (REDs) have been conquering the market, which has stimulated liberalization. This development has also opened up the market for private Independent Power Producers (IPPs). However, sales to end customers continue to be handled exclusively by NamPower, the REDs and municipal utilities (Hauser 2018). The current institutional landscape of the electricity sector in Namibia is, however, still structured in a rather hierarchical way. It might therefore be expedient to decentralize the sector and vertically integrate a dedicated body responsible for off-grid electrification. This approach

Fig. 3 Namibia's electricity infrastructure (off-grid not included). [Adapted from NamPower (2020)]



would reduce the burden on the MME and increase flexibility and speed to continually develop new policies to respond to new challenges, thus adapting to market developments. A good example of such a structure provides Nigeria (IRENA 2018).

Most un-electrified areas in Namibia are far away from the national grid and considered to have low population densities or highly dispersed settlements. Hence, it is often neither technically nor economically viable to provide access to modern energy services using the utility grid connection (Ministry of Mines and Energy 2017a). It is therefore crucial to look at other ways of electrification that are not provided by the utility grid connection. In order to assess what that means for these particular off-grid areas in Namibia, two of such locations are presented in this paper. Both are settlements in the northeast of Namibia, situated in the center of the Tsumkwe Constituency in the Otjozondjupa Region, thus in the middle of the Nyae Nyae Conservancy area (see Fig. 3) (Hays et al. 2014).

3.1.1 Tsumkwe

The settlement of Tsumkwe is 735 km away from Windhoek and 304 km from Grootfontein, the nearest town where community members have access to basic services. According to the rural electricity distribution master plan (REDMP), it is considered an off-grid settlement (Republic of Namibia 2011), while Tsumkwe has a diverse

population including residents from San, Kavango, Herero, Damara>Nama, Owambo and Zambezi¹ ethnic groups (Zongwe et al. 2017), it is particularly known to be the San capital of Namibia, receiving many initiatives that aim at improving their lives, as being considered the most marginalized and vulnerable ethnic group in Namibia. In 2001, a total number of approximately 9,000 people lived in the Tsumkwe constituency, according to the Namibia Population and Housing Census Report of 2001—out of these, estimated 3,800 live in the Tsumkwe settlement (Ashton et al. 2012). Only slightly less than half of the local population in working age is in gainful employment (Namibia Statistics Agency 2019), which reflects the prevailing poverty.

The electrical infrastructure in Tsumkwe has its origin in Namibia's pre-independence period. Back then, Tsumkwe served as a military post established by the South African government to control Namibia (Zongwe et al. 2017). After Namibia's independence in 1990, the government funded the construction of a school, a clinic and a police station for the community and the population continued to use the diesel generators left behind by the South African Government (Ashton et al. 2012). Eventually in 2005, the Councilor of Tsumkwe called for an improvement of the electricity situation; thus, NamPower investigated the cost of connecting Tsumkwe to the national grid system.

¹ Until 2012 named Caprivi.

However, being located about 270 km from the main grid (see Fig. 3), a grid connection for Tsumkwe would cost more than N\$ 150 million (Zongwe et al. 2017). Subsequently, the MME commissioned a small team of experts through the Desert Research Foundation of Namibia (DRFN) to evaluate the current energy situation in Tsumkwe. The group was precisely instructed to assess whether a hybrid mini-grid energy supply system using solar energy and diesel would be a feasible long-term electrification approach for Tsumkwe. Based on good experience with a project at the Gobabeb Training and Research Centre, which ensured a reliable electricity supply through the same approach, it was decided to also use it for Tsumkwe.

In 2011, the existing infrastructure was indeed upgraded into a solar-diesel hybrid mini-grid by the DRFN, funded by the European Commission (75%), NamPower (14%) and the Otjozondjupa RC (OTRC) (11%) with a total budget of 2.99 million Euro, which corresponds to N\$ 30.8 million (Ashton et al. 2012). The installed mini-grid consisted of PV panels with 202 kW_p, complemented by a diesel generator with 650 kVA. The battery had a capacity of 766 kWh. While the ownership was transferred to the OTRC, operation and maintenance was under the responsibility of the Department of Works residing in Tsumkwe. In 2017, ownership of the systems was shifted to the Central North Regional Electricity Distributor (CENORED) by the MME, along with the responsibility for the operation, maintenance and possible expansion of it.

3.1.2 Gam

The Gam settlement is currently the second largest off-grid settlement after Tsumkwe and one of the furthest settlements located 112 km Southeast of Tsumkwe and about 416 km from Grootfontein. The livelihood of Gam residents is divided into cattle farmers and government employees from different ministries such as the Ministry of Agriculture, Water and Forestry, police station, clinic, a primary and secondary schools. Based on a survey conducted in 2012 in Gam, 5% San and 95% Ovaherero resided in the village (Zongwe et al. 2017).

Driven by concerns about climate change and the widening energy gap between supply and demand in Namibia, the Government of Namibia joined others in concerted efforts to attain the SDGs. At the same time, the Gam Development Organization requested the MME to electrify Gam to reinforce its development. Thus, Gam was provided with access to electricity in 2014 through a stand-alone hybrid mini-grid consisting of a 292 kW (peak) solar PV generator, a 180 kW, 3-phase inverter/charger, a lead-acid battery bank and two diesel generators, which are used as a standby generator. The system was funded and

commissioned by the MME (Zongwe et al. 2017). Once the project was completed, the Ministry handed over the mini-grid to the RC, which began to collect fees from consumers, while operation and maintenance was carried out by the Tsumkwe-based Department of Works. Similar to Tsumkwe, operation and maintenance of the mini-grid in Gam was handed over to CENORED in 2017.

When CENORED took over, the two diesel generators were moved to Tsumkwe, as the mini-grid drew about 28% of its daily power from the generator. The technology there was in poor condition due to lack of maintenance. Opposed to that, the PV Power Plant in Gam produced a surplus of electricity. The reason for this was because only a first part of the community, consisting of about 200 households, was connected to the mini-grid in 2014 (not including the school, police station and clinic). With the completion of Phase 2 in November 2020, an additional 400 new households were connected.

3.2 Adopted national policies

It is essential to accelerate the deployment of presented off-grid solutions that provide rural areas such as Tsumkwe and Gam decentralized access to electricity. That mini-grids are indeed acknowledged as a valid option for energy generation by the government is highlighted in the *Renewable Energy Policy* (Ministry of Mines and Energy 2017b). The framework that focuses on off-grid electrification is the Off-Grid Energisation Master Plan for Namibia (*OGEMP*). However, the document does not entirely address the above-outlined challenges. Even though the Namibian government provides a rough time frame for planned grid connections in the latest version of the *OGEMP*, uncertainty remains, particularly in pre-grid areas. Despite the first Policy Statement (P1) of the *National Energy Policy* that declares to “create opportunities for mini—and micro-generators to feed into the national grid and off-grid mini-grid networks” (Ministry of Mines and Energy 2017a), a comprehensive main-grid policy is missing.

This deficiency reflects the fundamental disregard of long-term planning in the regulatory framework, which is also evident in the case of the mini-grid systems discussed in this paper. As outlined above, two diesel generators were relocated from Gam to Tsumkwe. This may be reasonable in the short term to meet demand in Tsumkwe, but in the long term, more households will be and have already been connected to the mini-grid in Gam (phase two ended in November 2020). Therefore, the system in Gam now urgently needs at least one generator back. The *OGEMP* secondly misses the chance to give an overview of off-grid possibilities, such as mini-grids, in general. Transparent information on the different solutions for off-grid energy

generation could reduce barriers to market entry (Come Zebra et al. 2021). Indeed, disclosure of domestic costs of mini-grids and corresponding rules for their construction could facilitate the involvement of stakeholders such as REDs and IPPs. Furthermore, there is no online portal for information on processes and procedures. Energy4Impact and INSENSUS for SE4All established a ‘Green Mini-Grid Help Desk’, hosted by the African Development Banks and funded through the bank’s Sustainable Energy Fund for Africa (SEFA). This tool is designed to provide practical information on mini-grids policies and regulations for various African countries—including Namibia. While the idea is essentially good, documents and information for Namibia on the website are scarce. The third point of criticism is the exclusive ‘energy shop approach’. In reality, very few energy shops have sufficient expertise about funds and respective mechanisms (Stockmayer et al. 2015). As an energy shop does not exist in Tsumkwe, residents are forced to travel to Grootfontein or Windhoek to purchase necessary equipment or obtain advice and assistance.

The ECB published technical standards in 2004, which intend to provide guidance for license applications, monitor performance of licensees and assess customer complaints (Electricity Control Board 2014b, c). Particularly regulations and guidelines for dealing with conflicts are provided in more detail with the *Complaints Handling Procedure*, *Customer Service Charter* or *Mediation Procedure*, helping to conciliate investors and customers by issuing standards on which penalties can be imposed. Technical assistance for third parties (e.g., IPPs) is provided by the *Grid Codes* for Namibian Solar Energy Technologies, specifying requirements for both distribution and transmission of electricity. Both documents intend to foster liberalization endeavors. Furthermore, the *Namibian Electricity Safety Code*, established in 2009, governs the standards concerning safety for operating, maintaining, constructing and installing power systems in Namibia. Although the entirety of the procedures, codes and standards gives the impression of being comprehensive, the African Development Bank rated the technical regulations for Namibia as moderate under the Electricity Regulatory Index (ERI) for Africa 2019 and 2020 (African Development Bank 2020, 2019). There is a continuing lack of guidelines, which are directed not only at private investors, but also at REDs by means of providing training material on the installation and maintenance of mini-grids. The precise implications of this for the Tsumkwe and Gam sites are discussed in Sect. 3.7.

3.3 Licensing regulations

The *Electricity Act* of Namibia stipulates that a proper license is needed in order to establish and manage the

generation, transmission, distribution, supply, trade, import or export of electricity. In the case that electricity is generated in an area that has no connection to the interconnected power transmission grid or if electricity is exclusively used for self-consumption and the installed capacity does not exceed 500 kVA, a license is not necessarily required. (Parliament of the Republic of Namibia 2007). *The Rules on Unlicensed Generation (draft)* further regulate the systems that belong under above definition (on-grid, off-grid, as well as small-scale in-fee generator) from both a technical and economical perspective (Electricity Control Board 2011a). This approach is indeed favorable, due to the positive impact on development costs, supposedly attracting investors. However, a streamlined licensing framework for off-grid systems is not available, which could “reduce[s] the regulatory process involved in obtaining licenses or permits, reducing costs for off-grid operators” (African Development Bank 2019). In fact, even the mini-grid in Gam was operated without a license at times (Zongwe et al. 2017), which underlines the need to shed light on license applications for off-grid systems.

The general licensing process is rather centralized. The ECB makes recommendations to the MME concerning licenses for electricity generation distribution, trade, and transmission (Electricity Control Board 2019a). While the legal rights to generate, distribute and sell electricity to consumers have been transferred to the private sector in light of the market liberalization (Hauser 2018), the transmission of electricity is still solely permitted for NamPower (Ministry of Mines and Energy 2017a).

The licensing procedure, which takes with 60 days quite a reasonable amount time, when compared to Kenya’s 90 days, for example (Osawa and Telep 2015; GIZ 2020). The application fee for issue, renewal, amendment or transfer of a license amounts to N\$ 2,500, and the ultimate fee for the issue, renewal or transfer of a license total up to N\$ 10,000 (Electricity Control Board 2011b). This is complemented by a comparatively high degree of transparency. For example, the evaluation process of applications to obtain a license is depicted in the *Electricity Regulations: Administrative*. Section 18 of the *Electricity Act*, moreover, deals with the objections procedure. The application is followed by public hearings, which are described and monitored through the *Public Hearing Rules*.

3.4 Tariff regulations and applied payment solution

Based on the Namibian *Electricity Act*, tariffs are generally determined² by the specific entity (e.g., RED) that wants to

² In a manner specified by the ECB, thereby including demand-related costs, asset-related costs, energy-related costs, customer-specific costs and shared customers-related costs.

be licensed to distribute and supply electricity to end-users and subsequently have to be approved by the ECB (Parliament of the Republic of Namibia 2007). Moreover, tariffs are cross-subsidized in subject to the ‘category’ of electricity user (tariff option). These groups are domestic (households/residential), commercial (business and light industry connections), and large power users (industrial) (Electricity Control Board 2017a). A general standard is defined in the *Electricity Distribution Grid Code*, stating, “distribution tariffs should be sufficient to allow the necessary investments in the networks to be carried out to ensure the long-term viability of the network.” (Electricity Control Board 2018). This is underlined within the *ORM User Guide and Tariff Rulebook*, stating that “tariffs and the associated tariff structures must be cost reflective” (Electricity Control Board 2019b).

Prevailing tariff differentiation between the different REDs is mainly due to the Local Authority Surcharge (LAS), which is added to each tariff and is collected by the licensee on behalf of the LA as an electricity-service provision tax (Electricity Control Board 2017a). LASs were initially introduced to financially subsidize the regional districts by “raising additional revenue to be applied for general public purpose” (Parliament of the Republic of Namibia 2019) after the electricity supply structure was amended through the integration of REDs (see 3.1) (Electricity Control Board 2017b). The thereby generated tax amounts to about N\$ 250 million per year, thus contributing as a major source of revenue (SAD-ELEC 2006). Prior to establishing REDs, LASs used the revenues from electricity sales to cross-subsidize other municipal services (Electricity Control Board 2016). Other levies are the ECB, NEF and long-run marginal cost (LRMC) levies. The latter one was, for example, introduced to avoid future price shocks (NamPower 2020). The legal right for electricity levies is manifested in the *Electricity Bill* as well as in the *Economic Rule Gazette*.

The *Report on: Implementation of a Local Authority Surcharge in Namibia*, which analyzed the economic impact of LASs, however, underlines the need for eradicating the subsidy, concluding that “any deviation from cost reflective tariffs, such as the introduction of a levy or surcharge, is likely to result in (or permeate) sub-optimal economic efficiencies.” (SAD-ELEC 2006). Likewise, in the *Namibia IPP and Investment Market Framework Technical Assistance* the “Local Governance reliance on electricity surcharge” was identified as one of the key barriers that impedes the development of an IPP industry (CORE International and Emcon Consulting 2006). On the other hand, in the *National Electricity Support Mechanism*, it is asked: “If tariffs in off-grid localities are to be set below cost reflective levels, how and by whom will such shortfalls be funded?” (Electricity Control Board 2014a). Off-grid tariff mechanisms are

generally not included in the document, as it is solely “based on information of grid-connected utilities” (ibid.). Cost-reflective tariffs still have not been established, although the ECB constantly works toward this goal. However, the conflicting arguments in the guidelines presented illustrate the prevailing dilemma, which can also be observed in the cases of Tsumkwe and Gam.

In 2010, the cost-efficient tariff in Tsumkwe was 6 NAD/kWh, which was heavily subsidized as not affordable by many residents and eventually resulted in a tariff of 1 NAD/kWh for households and 1.90 NAD/kWh for commercial and institutional customer. The expensive subsidies resulted in a deficit for the OTRC, not least because of unpaid bills for electricity. With the introduction of the hybrid system, it was suggested to adopt a stepped tariff structure “whereby institutional and high-level commercial users cross-subsidize poorer households and smaller businesses.” Based on a report commissioned at that time, this proposed scheme would lead to an eradication of the needed subsidy over time, when being complemented by gradually increasing tariffs (5% p.a.) as well as an annual extension of PV and batteries (using revenue generated) to reduce fuel costs (OneWorld Sustainable Investments 2010). In reality, however, no such scheme was implemented. Even though the generation cost of electricity was reduced from 6 NAD/kWh to 3.50 NAD/kWh, the tariffs were kept similar.

To enable the collection of money in the later years of operation, a prepaid payment system was introduced. An electricity token for the prepaid electricity could be bought from the vending points in both Tsumkwe and Gam, and was also possible through the mobile and online payment options of the banks in Namibia. The prepaid system has been made available for both residential and business users. In addition to the prepaid system, conventional meters have kept providing service for business institutional users. The bills have been paid through the regional offices’ of the institutions. As of 2020, the prepaid and conventional institutional tariffs are the same for both Tsumkwe and Gam. The prepaid residential users pay 2.22 NAD/kWh, and the prepaid business users pay 4.07 NAD/kWh including fixed charges to CENORED.

As a result, the prepaid payment solution for the mini-grids in Namibia has created a regular cash flow that is necessary for the operation of the mini-grids. It has also enabled the operator to better project the demand from the local community, while it allowed people to become more aware of their electricity consumption.

3.5 Available financial instruments

Support and funding measures to enlarge solar energy diffusion have been implemented by the Namibian government.

Net Metering can be utilized by RE plants less than 500 kW. This is declared in both the *National Renewable Energy Policy* as well as in the *Net Metering Rules*. The *Electricity Distribution Grid Code* regulates so-called microrenewable infeed connection conditions. Some of the electricity distributors (e.g., Windhoek or Erongo RED) started limiting the construction of solar plants, arguing that the grid will become instable if too many systems are integrated (Buijs 2018). The *Renewable Energy Policy* addresses the issue by recognizing that “(...) some distribution utilities view net metering as a threat to their revenue (...)” and clarifies that corresponding regulations have been introduced (CORE International and Emcon Consulting 2006).

The REFiT Program, managed within the *REFiT Rules*, moreover, proposes feed-in-tariffs for RE-based plants greater than 500 kW and less than 5 MW (Ministry of Mines and Energy 2017b). The Namibian government, however, limits the allocation of licenses under REFiT. System operators, therefore, have to apply for a power generation license under the program (Hauser 2018). Ultimately, RE auction schemes or tender processes have been designed for systems greater than five MW (Ministry of Mines and Energy 2017b).

The government has, furthermore, established two funds to facilitate a larger uptake of renewable energies in the country: the Solar Revolving Fund (SRF), which is an element of the *OGEMP*, and the Environmental Investment Fund (EIF) (Stockmayer et al. 2015). Although only a small portion is used for off-grid development, it is an essential instrument for increasing rural electrification (Ministry of Mines and Energy 2017b). The SRF, administered by the Energy fund division of the MME, provides loans to households and communities for solar water heaters, solar water pumps and solar home systems at an interest rate of five percent during the loan period of five years. The loan amount ranges from N\$ 6,000 to N\$ 50,000, depending on the underlying technology. However, little funding is available for mini-grids (Ministry of Mines and Energy 2017b). The EIF is financed by a government allocation that includes the mandate to access local conservation fees and environmental levels. It either funds projects that aim at environment protection with all its different facets or issues loans to ‘green’ companies or individuals, offering interest rates of up to prime minus 4.27%, long repayment periods of up to 10 years as well as grace periods of up to 12 months.

As the mini-grids in Tsumkwe and Gam have been financed through funds, this section is not applicable to the systems.

3.6 Social situation

Kanagawa and Nakata (2008) pointed out that energy influences the socioeconomic condition of developing

countries in relation to health, education, income and the environment and improves the quality of life. In the cases of Tsumkwe and Gam, the number of electrified households and commercials through the mini-grid shows the interest of people in connecting to electricity. Tsumkwe settlement accounted for 206 clients at the beginning of the mini-grid connection in 2011 that reached 363 clients in 2020, whereas Gam reached from 200 to 614 clients including the expansion realized in 2020.

The design of an educational component within the management of mini-grid systems is essential for the sustainability and the durability of the system. Alongside guidance and training materials for REDs and other parties with an interest in a sustainable operation of off-grid systems, training materials for residents to encourage entrepreneurial activities ought to be provided (Mudi et al. 2019). More established businesses lead to an increase in demand, which increases the economic viability of the system while enhancing the community’s quality of life. Particularly local San people residing in Tsumkwe are having an unique entrepreneurial culture, which could be additionally supported by advancing possibilities to co-partner with San people and supporting an active participation in Namibian markets, cultural or traditional festivals, business forums and trade fairs (April and Itenge 2020).

Inglesi-Lotz and Diez del Corral Morales (2017), moreover, suggest that improved awareness in the society through education will result in more informed customers, who eventually make better energy purchasing and utilization decisions, which may, in turn, reduce the energy consumption levels (Inglesi-Lotz and Diez del Corral Morales 2017). Hence, greater understanding can potentially encourage people to replace inefficient appliances, which will help them save electricity costs in the long term. Furthermore, this will enable the development of energy literacy from a “social energy systems” approach (Cloke et al. 2017). Based on the results of field research in Tsumkwe in 2020, only 3 out of 56 interviewees are, in fact, aware that their prepaid electricity tokens payments include fees for service, maintenance and a levy for authorities. The rest of the respondents were convinced that they only pay for electricity or stated that they do not know what they are paying for. In general, the electrified houses were satisfied to have uninterrupted electricity, although they do not consider the unit prices to be justified. A field trip to Gam, which was conducted in 2016, presented similar results. A considerable number of people were unaware of solar energy and what it entails. Solely business people and those who already installed small solar panels on their rooftop were sufficiently informed (Haingura et al. 2016). This is a disappointing finding considering that some measures were indeed implemented to involve the

local community in Tsumkwe in the installation of the hybrid system. Local people were hired for construction to create a sense of ownership of the infrastructure. In addition, educational campaigns were organized that concentrated explicitly on informing the community about the project itself, maintenance of the stoves/solar water heater and energy efficiency. This was complemented by distributing informative flyers that educated residents on how to save money through energy-efficient measures, among other things.

3.7 Technical situation

As discussed in 3.2., the government of Namibia already provides various documents and codes to ensure an equal technical standard, although the African Development Bank assessed the technical regulations for Namibia as insufficient (African Development Bank 2019). Resulting lack of maintenance is therefore partly caused by the government's insufficient commitment to promoting and supporting off-grid systems. This shortfall can be seen in both investigated cases. During the time when the mini-grids were owned by the RC, they were not operated as designed and not maintained at all (Zongwe et al. 2017). Since the takeover was planned, NamPower and several REDs have been immensely reluctant to inherit the responsibility of operating and managing the mini-grids, due to the "lack of viability, relevant expertise, and regulatory uncertainty" (Stockmayer et al. 2015). As a consequence, the mini-grids are still not effectively taken care of (Zongwe et al. 2017). Research trips uncovered a severe lack of maintenance (Wagemann and Manetsgruber 2019). For example, a thick layer of dust covered the PV modules in Tsumkwe, which significantly reduces solar yield. Moreover, a stone chip damaged one PV module, which led to a hot spot. Such damage is very likely to result in a module failure and, consequently, in a failure of the entire PV string, which is why the research team had to bypass the defective module as an immediate action. Apart from that, PV inverters were also found heavily soiled with dust, which affects heat dissipation. The resulting overheating, in turn, leads to a reduced inverter output and service life. In the case of Gam, two of three air conditioner units were out of function and a filter mat was clogged by dust; thus, cooling was not possible. The resulting high temperature led to poor efficiency of the inverters as well as reduced the average lifespan of inverters in general. To conclude, regular preventive maintenance, which can only be accomplished with a trained team, ensures the optimized operation of the power plant, thus enhancing its technical sustainability. Consequently, education and training of operating personnel is essential to ensure the (techno-economic) lifespan of the equipment for better service.

In most cases, the technical staff additionally bears the responsibility for the regular monitoring of the system, which was due to the lack of information and clear structure of responsibilities not feasible in the hereby described use cases. In fact, a password required for the remote monitoring was not provided to CENORED by the contractor who installed the systems. Consequently, in-depth monitoring is still not possible at this point in time, which is needed to understand the current operation better. Apart from the apparent need for monitoring, this highlights the necessity to define clear responsibilities and roles during the planning and construction phase of such projects.

4 Findings from the use cases

The use cases shed light on the outlined existing trilemma of maintaining a balance between the triangle of government, community, and investors. Since the systems in Gam and Tsumkwe are donor funded, the role of the investor in these cases is replaced by the responsible energy distributor. Nonetheless, the importance of clearly defined roles for all stakeholders becomes evident to ensure a sustainable operation of these systems.

Different owner experiences have led to various mini-grid operations, all of which have demonstrated the significance of regular monitoring of the mini-grids in conjunction with required and planned maintenance to ensure uninterrupted operation of the systems. The parties responsible for the systems did not contractually define the responsibilities involved in operation and management. As a result, even today essential information is missing, which impedes the monitoring of the system. Furthermore, it has been illustrated in this paper how community involvement from the mini-grid planning phase through system design and operation is essential to ensure proper system sizing, appropriate rate and payment solutions and ultimately the long-term operation of mini-grids. In this context, it is imperative to highlight the vital role of educational measurements both for the community and for the technical staff of the operator. Sufficient training in the context of entrepreneurial activities of Namibian communities could have led to a more profitable operation of the mini-grid through better use of daytime solar power and better use of energy-efficient equipment.

Despite the admittedly transparent and relatively stable national regulatory environment in Namibia, which is important when seeking to attract investors, the use cases further demonstrated the significant need to transfer regulatory knowledge, technical guidelines and issued codes from large energy projects to smaller off-grid initiatives. In general, many policies target grid-based power generation, while off-grid regulations are scarce. Therefore, the design

of the guiding principles for off-grid installations under off-grid policies will play a crucial role in the future development of new mini-grids in other remote areas of Namibia. This will contribute to Namibia's efforts to reduce the number of non-electrified regions in the country, thus advancing toward SDG 7. The development of productive-use cases eventually represents a critical strategy for boosting and restoring the local economy.

5 Conclusion

While it is clear that off-grid electrification is essential to achieve SDG 7—affordable and clean energy for all—the realization is still challenging. This paper, therefore, investigated the optimal design of an environment that supports off-grid electrification in rural areas through a top-down discussion of two different communities in Namibia. The main objective was to discuss the most important features and concurrent challenges in terms of off-grid policies, licensing, tariff setting, socio-economic and technical implications generally and particularly for the two selected off-grid sites in Namibia. The communities of Tsumkwe and Gam served as representative examples to elaborate the key challenges for off-grid electrification, which is essential for providing access to affordable and reliable electricity for remote areas.

Major challenges were found to be the involvement of communities in the design phase of a mini-grid, which includes the sizing and evaluation of future demand. Lack of standards and regulations issued by the government endangers a safe and just implementation of off-grid systems. Alongside a main-grid arrival policy, tariff methodologies deserve special mention in this context. In fact, tariff guidelines that impede the possibility of private investors to recover their costs deters them and thus is rightly considered an essential obstacle for electrification. Missing education among the off-grid electrified population hampers the dissemination of productive-use cases, which is a vital element in order to sustainably operating such a system. A distinct focus in such projects must be on the end-user and not just on mere power generation.

Improving the deficiencies outlined in this paper, thus creating an environment in which off-grid systems can thrive, will not only have a positive impact on social and socioeconomic progress in rural areas, but will also contribute to the overall economic development of respective countries.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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