Chapter

Advancing Off-Grid Electrification by Uncovering the Holistic Risk Landscape Using a Standardized Risk Management Procedure (SRMP)

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Abstract

Although it is now well known that access to electrification is a crucial prerequisite for ensuring sustainable development, rural households in sub-Saharan Africa in particular remain unelectrified. It is often not economically viable to connect these remote communities to the main grid. Therefore, mini-grid systems represent a promising alternative to ensure electrification even at long distances from the grid, backed by the fact that these systems are becoming cheaper with the advancement of integrated technologies. However, such systems are fraught with risk if various potential pitfalls are not considered upfront. This discourages investors and thus prevents the electrification rate to increase. The following chapter therefore aims to highlight the risk landscape for the deployment of mini-grid systems in order to assist investors in sustainably integrating mini-grid systems. The approach is illustrated using Namibia's largest mini-grid in Tsumkwe as an example. Through the application of the SRMP, it is revealed that the mini-grid is exposed to a moderate level of risk, mainly due to a lack of education and a replacement process.

Keywords: Rural Electrification, Risk Assessment, Off-Grid System, Mini-Grid System, Namibia

1. Introduction

Despite the fact that energy is undisputedly vital to generate economic growth and ensure a common social well-being, more than 780 million people worldwide still live without access to electricity [1]. Senegal's GDP increased by 1.7% when a 70 MW power plant was put into operation. The same was observed in Uganda, where GDP increased by 2.6% with the commissioning of a 250 MW hydropower plant [2]. However, sustainable development is stagnating in those regions without electricity access. This is particularly true for populations located in rural areas that are difficult to reach, especially in sub-Saharan Africa (SSA) [3]. While the access rate in SSA rose in the past years especially due to the achievements of a very few countries, the Covid-19 pandemic confound this development and added urgency to this topic [4].

Off-grid solar systems provide a feasible solution to electrify these remote areas by closing the access gap and offering reasonable costs and shorter waiting times compared to grid expansion [4, 5]. Apart from a sound technological concept, several other (risk) dimensions influence the reliability and long-lasting persistence of a mini-grid. This publication exemplifies the holistic risk landscape through the case of Tsumkwe, a settlement in the northeast of Namibia. For this purpose, a risk-rating model for mini-grids, based on the standardized risk management procedure (SRMP), is used. Steurer et al. (2017) provide a more detailed description of this model, which was refined in the course of this paper [6]. The risk evaluation comprises five categories: Regulation, Economy, Technology, Finance and Education, thus providing an indication of the multi-dimensionality of this subject. Being located in an economically disadvantaged rural area of Namibia, Tsumkwe relies on electricity from a mini-grid, which was set up in 2011 and is, therefore, well suited for the topical investigation.

2. The SRMP approach

2.1 The need for a holistic risk assessment

Mini-grids are exposed to various types of risks. It is therefore not unexpected that many of these projects have failed along the way. An aggravating factor certainly is the amount of different stakeholders that are involved in such projects with each following their own objective – electricity distributor, public and private investors, government and eventually the consumer or an enterprise. While the power supplier is usually striving to increase its profits, the government is committed to a just energy supply and the consumer, in turn, demands a relatively cheap and reliable energy supply. This altogether needs to be translated into a reasonable business story, comprising, for example, questions related to the overall organization, education, as well as the financial and economic feasibility (see **Table 1**). This results into a multi-dimensional and complex endeavor, which has to be planned in a thoughtful way. Due to this complexity, a holistic risk assessment tailored to the needs of mini-grids has to be in place. This is achieved with the standardized risk management procedure (SRMP) for mini-grids, which is considered a measure of the ability of a mini-grid to meet financial obligations and profitability expectations in the medium and long term.

Cluster	Question
Regulatory	Is the political situation stable?
	Is the mayor of the respective village accepting and supporting the development of a mini-grid system?
	Has a grid arrival policy been adopted?
	Are further information existent that relate to off-grid systems?
	What is the crime rate?
Economic	How does the tariff design look like?
	How is the billing process structured?

Cluster	Question
	How many commercial customers are connected to the mini-grid (in relation to connected households)?
	Can money be saved for potential repairs or extensions?
Technology	Who is taking care of maintenance and potential repairs?
	Is the used technology easy to maintain?
	Who is taking care of the operation management?
	What does the procurement process looks like?
Finance	Who is responsible for cost/result controlling?
	Who is responsible for Accounting and Budgeting?
	How is the reporting structure designed?
	How does the funding structure look like?
	Where to ask for funding?
Education	Who is responsible for training the (technical) staff? Is a training plan in place?
	Who is responsible for raising awareness and training the (rural) population?
	How can an increase of productive use cases be achieved?
	Is there a place people can approach for help/assistance?
	Are there funding opportunities for small business startups?

Table 1.
Uncertainties related to the five dimensions.

2.2 The structure of the SRMP approach

The SRMP, in general, weights factors related to the regulatory framework, economy, technology, finance and eventually education. These five categories are evaluated based on qualitative and quantitative data, resulting into a risk score that ranges from very low (1) to very high (6). The final score indicates the holistic risk level for implementing mini-grids in a specific region (here: Tsumkwe). Those marks than flow into a combined score (see **Figure 1**).

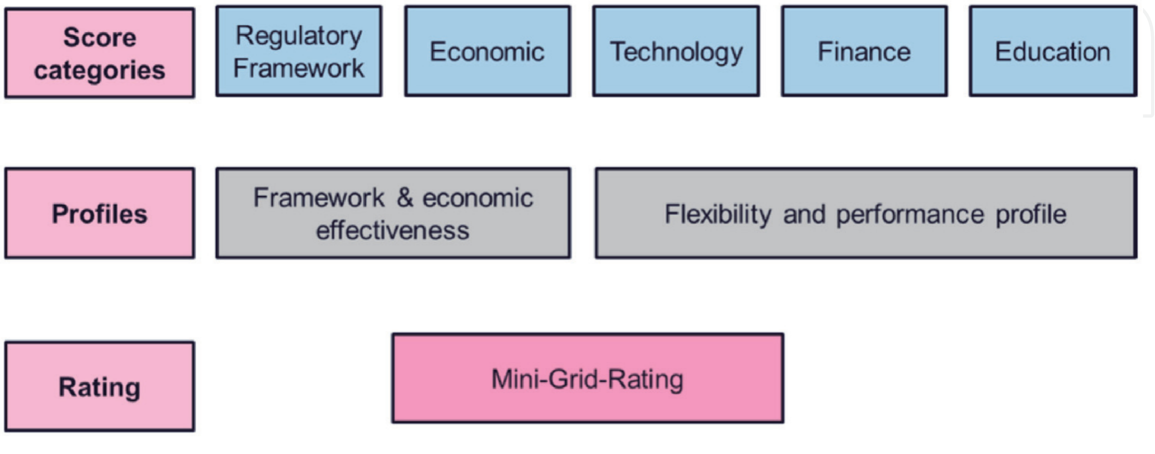

Figure 1.
Framework of the SRMP [6].

Each of the five criteria described previously is weighted individually to obtain a single score of the five criteria to form a profile. For example, the regulatory framework score is combined with the economic score at an equal weighting of 50%

to generate the overall "framework and economic effectiveness" profile. The scores from the remaining three criteria, i.e., the Technology, Finance, and Education scores, each account for 33% of the total "Flexibility and Performance Profile." The two scores from these intermediate profiles are then combined resulting in a rating level that represents the final, overall mini-grid rating (see **Figure 1**).

The overall rating of the mini-network is aggregated and expressed in the form of rating levels from AAA to D and is derived from an equal weighting of the intermediate profiles at 50% each. Consequently, the ratings obtained correspond to the credit ratings commonly used on the capital markets and published by the international rating agencies, e.g. Standard & Poor or Moody's and Fitch. The reason for this is to provide institutional investors with a decision-making tool with which they are familiar, one of the stakeholders in mini-grid projects.

3. Electrification in Namibia

The proportion of the Namibian population with access to electricity grew from 43.7% in 2010 to 57.4% in 2019 [4]. This might be surprising, as Namibia is frequently perceived as developed as South Africa when it comes to the electrification rate. Namibia, however, is in a somewhat more difficult situation, as being the second least densely populated country in the world [7]. The population is widely scattered, which makes it almost impossible to connect all villages to the main grid. Especially remote areas are unable to use electricity, which hinders the development. Thus, off-grid systems represent a great opportunity to enhance rural electrification. In particular, mini-grids based on solar energy provide great value in view of the potential of solar energy in Namibia, as the country exhibits the second highest level of solar irradiation in the world [8]. In addition, Namibia is today heavily dependent on fossil fuel imports from neighboring countries such as South Africa [9, 10]. Encouraging current efforts to increase the penetration of solar energy supply is therefore an essential step not only toward greater energy independence, but also toward lower national electricity prices and an overall reduction in CO2 emissions.

In the Vision 2030, issued in 2004, the Namibian government has already stated to pursue a sustainable energy policy in order to accelerate urban and rural development [11]. The same was declared in the Strategic Plan 2017/2018–2021/2022 devised by the Ministry of Mines and Energy (MME) [12]. This indeed appears to be a valid strategy, considering the above-mentioned predicament.

3.1 The electricity sector in Namibia

The Electricity Supply Industry in Namibia has started a transformation process in the 2000s. Prior to that, the state-owned national power utility 'NamPower' had a quasi-monopoly in the market, being responsible for the generation, transmission and distribution of electricity. While NamPower was the only entity authorized to supply electricity to farms and mines, Local Authorities (LA) and Regional Councils (RC) were exclusively liable for providing electricity to residents and businesses. [7] Starting in 2002, regional electricity distributors (REDs) have been conquering the market, resulting in progressive liberalization. This development also created a market for private Independent Power Producers (IPPs). However, sales to end customers continue to be handled exclusively by NamPower, the REDs and municipal utilities [7].

In 2000, the Electricity Control Board (ECB) took over the role of market regulator, which is defined in the Electricity Act of 2007 (formerly: Electricity Act of 2000). In this function, the ECB issues regulations and technical standards for the connection of renewable energy (RE) plants to the grid, while the Ministry of Mines and Energy (MME) is in charge of the development of the industry itself and ultimately acts as a policy maker [12].

3.2 State of electrification in Tsumkwe

Tsumkwe is located in the northeastern part of the Otjozondjupa Region in Namibia. The settlement is 735 km away from Windhoek and 304 km from Grootfontein, the nearest town where community members have access to basic services (e.g. banks or supermarkets). According to an observation trip conducted in 2005, the closest grid electricity access point from Tsumkwe is either in Maroelaboom, which is about 180 km to the west (33 kV connection) or at the Berg Aukas Distribution Station located about 240 km to the west (66 kV connection) [13]. Based on Namibia's Rural Electricity Distribution Master Plan (REDMP), Tsumkwe is considered an off-grid area and will not be connected to the grid in the near future [14]. This is mainly due to the high cost of N$150 million associated with the connection [15].

Prior to Namibia's independence, Tsumkwe served as a military base for the South African Army. The power supply was provided by means of two diesel generators connected to a micro-power grid with a small medium voltage of 11 kV [15, 16]. After Namibia's independence in 1990, the government funded the construction of a school, a clinic and a police station for the community, which could be utilized through the infrastructure left by the South African government [17]. However, power supply was unreliable and due to increasing costs of diesel, electricity supply started to be restricted, which inhibited the dissemination of businesses and had an adverse influence on livelihood in general. As the system generally was poorly maintained, diesel occasionally spilled and polluted the environment. The tariff was not affordable for residents until that time, although the government heavily subsidized it, leading to a tariff of 0.14 USD/kWh for private households and 0.27 USD/kWh for institutions and commercial customers (equivalent to 2 and 4 NAD respectively based on the exchange rate of 2014). The subsidies, furthermore, resulted into an annual deficit of NAD 1.2 million for the Otjozondjupa Regional Council (OTRC) [16].

Eventually in 2005, the Councilor of Tsumkwe called for an improvement of the electricity situation. Therefore, a small team of experts was commissioned by the MME through the Desert Research Foundation of Namibia (DRFN) to evaluate the current energy situation in Tsumkwe. The team 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 a solar PV system backed by a diesel generator, it was decided to use the same hybrid approach for Tsumkwe. The usage of solar power is not at all surprising, as Namibia exhibits the second highest level of solar irradiation in the world [8].

The European Commission, NamPower and the OTRC, funded the resulting project. The Namibian government's share thereby primarily benefited the introduction of energy efficiency appliances. For example, solar water heaters were substituted for electric water heaters, electric stoves were replaced with gas burners, and households were equipped with energy-efficient light bulbs. All this was done on the basis of the recommendations of the experts from the observation tour in 2005. Although the experts' advice was additionally to run the hybrid mini-grid system autonomously through an independent operator, who could collect revenue and take responsibility for maintaining the system and ultimately developing the village, ownership of the system was transferred to the OTRC. Operation and maintenance of the mini-grids was under the responsibility of the Department of Works residing in Tsumkwe [13, 15].

4. Risk assessment on the example of Tsumkwe

4.1 Regulatory assessment

This criterion mirrors the degree of impact that official bodies and authorities overseeing electrification have on a mini-grid. The transition to preferably RE based off-grid solutions indeed requires strong policy support [3, 9, 18] and as investments in off-grid solutions are largely driven by regulatory policies [5], the importance becomes apparent.

For the sake of comprehensibility, the criterion is divided into two factors. The primary factor assesses the effectiveness, stability, and predictability of political institutions. Particular attention is paid to the alignment of local bodies and the population with a mini-grid project. Therefore, the attitude of local mayors towards the electrification project is rated and the support of the local population is measured. Moreover, the community's crime rate is considered, as this poses the risk of ongoing conflicts with potentially negative impacts on an electrification project. Another key determinant in the evaluation of the regulatory framework is the degree of transparency, accountability, and process reliability of the various institutions involved. Simply put the extent to which local bodies take action to signal their accountability for their policy decisions and their outcomes. This area is captured by the secondary factor. Obvious conflicts of interest are one of the things that have to be taken into account. This requires critical scrutiny when analyzing the organizational structure of the mini-network. Further, generally unbiased enforcement of contracts and respect for the rule of law add to this.

4.1.1 Primary factor

It is essential to accelerate the deployment of solutions that provide Namibian rural areas decentrally with access to RE in order to, ultimately, facilitate the country's development. That mini-grids are acknowledged as a valid option for energy generation by the government is highlighted in the Renewable Energy Policy, outlining "(…) while some regions of Namibia are most optimally served through grid-connected, utility-scale renewables, other locations are well-suited to being powered by off-grid applications. Both approaches are complementary in nature and neither grid extension (with renewables integration) nor off-grid systems by themselves can provide a solution in isolation." [19]. Despite this, the regulatory framework in Namibia that addresses off-grid electrification, the OGEMP, shows a number of deficiencies.

The document fails to provide a plan for a possible grid expansion. Nonetheless, this is an essential piece of information, not least because mini-grids have been abandoned in recent years by the time a village was connected to the national grid [18], which certainly yields uncertainty amongst investors. Thus, policies are required that define rules for the further persistence of mini-grids and preferably ensure investors that mini-grids are retained and continued to be used to sell generated electricity to the grid after the grid is extended [20]. That is already underlined by the first Policy Statement (P1) of the National Energy Policy, which declares to "create opportunities for mini- and micro-generators to feed into the national grid and off-grid mini-grid networks." [12]. Moreover, in the latest version of the OGEMP, the government provides a rough time frame for planned grid connections in certain municipalities. Although this could reduce uncertainty and encourage investments in communities that have no perspective of being connected to the grid (such as Tsumkwe), uncertainty remains in pre-grid areas. Consequently, a comprehensive policy in that regard is yet missing. The OGEMP secondly misses the chance to explicitly present off-grid possibilities, such as mini-grid or stand-alone systems, although including clear and transparent information on the different solutions for off-grid energy generation, potentially reduces barriers to market entry. Lastly, the focus within the OGEMP is almost exclusively placed on an 'energy shop approach'. According to this approach, private households, businesses and institutions gain access to energy technologies through these shops, which are planned to be established in "reasonable distances" – corresponding to 10 km to 30 km [21]. Energy shop owners are also supposed to consult their customers regarding funding, assist by hiring technicians when needed and they are ultimately the ones who do not only receive loan payments, but also pursue missing or late payments [21]. Yet the document does not address a conceivable reluctance of storeowners to sell energy products, opting instead for the "over their heads" strategy. Past observation has demonstrated that owners do not necessarily stock up on energy equipment, in part because of a lack of capital. Moreover, in reality, very few energy stores have sufficient expertise in subsidies and relevant application mechanism [22]. Overall, there is a lack of policies, frameworks or even institutions specifically related to mini-grids, although the country convinces with a very transparent regulatory framework especially in the context of renewable energies [23]. This leads to a final rating of 3 (see **Table 2**).

As for the legal basis for the generation, distribution and sale of electricity, Namibia has already introduced a transparent licensing process, which takes about 60 days to be completed. In comparison, the process takes 90 days in Kenya [24]. As stated in the Namibian Electricity Act, an electricity generation license is not required for projects of 500 kVA or less, which reduces development costs and thus, attracts investors. A streamlined licensing framework for off-grid systems is not yet available, which potentially "reduce[s] the regulatory process involved in obtaining licenses or permits, reducing costs for off-grid operators" [25].

Apart from the national circumstances, other predominant conditions in Tsumkwe are included in the assessment that feed into the primary factor. For example, the relatively low crime rate and the affirmative attitude of the settlement mayor towards the mini-grid systems, which both affect the evaluation positively. The Tsumkwe community was partially involved in the planning and deployment phases of the mini-grid. Local employment for the construction was particularly important to establish a sense of ownership of the infrastructure. In addition,

Primary factor: The effectiveness, stability, and predictability of the policymaking and political institutions on community and block level		Secondary factor: The transparency, accountability and process reliability of the other involved institutions, especially the block and district	
Alignment major and local authorities	2	Obvious conflicts of interests	1
Crime rate in Tsumkwe	2	Generally unbiased enforcement of contracts and respect for the rule of law	2
National Policies	3	Significant and sustained issues between entities on state level and local level	3
Result	2.33		2.0
Final score	**2.25**		

Table 2.
Regulatory Framework scoring.

educational campaigns were arranged that focused specifically on informing the community about the project itself, how to maintain the stoves/solar water heater, and about energy efficiency. This included several informative flyers that educated residents on how to save money through energy-efficient practices, among other things [13]. Despite these efforts, the community was not engaged in the course of setting tariffs, which however is essential to ensure a sustainable management of the plant. Considering all this, the overall risk score of the primary factor is 2.33 (see **Table 2**).

4.1.2 Secondary factor

Moderately well documented are non-financial instruments, such as technical standards or grid codes for off-grid systems, which supposedly strengthens the emergence of IPPs by providing transparent information on market requirements. There is a continuing lack of guidelines in this context, which are directed not only at private investors, but also at the REDs by means of providing training material on the installation and maintenance of mini-grids. This can be seen in the case of Tsumkwe. During the time the mini-grid was owned by the RC, it has not been operated as designed and not been maintained at all [15]. Once the takeover was planned, NamPower and other REDs have been immensely reluctant to inherit the responsibility for the operation and management of mini-grids, due to the "lack of viability, relevant expertise, and regulatory uncertainty" [22]. As a consequence, the mini-grid is still not effectively taken care of [15, 26]. This reflects the insufficient involvement of the government in promoting and supporting off-grid systems as well as the persistent challenges between entities at the state and local levels.

Overall, the secondary factor performs slightly better. This can be traced back to the exceptional transparency of regulatory processes, apart from what has been described above. Deductions are made for the just moderate respect for the rule of law, experienced in Tsumkwe [15]. This generally leads to a result for secondary factor score of 2.0. Since the primary factor is weighted at 75 percent and the secondary factor at 25 percent, the final score is 2.25, indicating a rather low risk level.

4.2 Economic assessment

The economic score is derived by analyzing the purchasing power of the local population (retail score) and the diversity of the regional economic sectors (commercial score).

Both scores are averaged to generate the final economic score. To obtain the retail score, the per capita income of the locality is utilized. Hence, the average monthly income per person is compared to the corresponding average income level of a comparison group. The comparison group is usually dictated by the region. The variety and diversity of the pillars upon which the local economy relies is another critical determinant of the economic score and is illustrated by the commercial score. An economy that relies on different industries is able to withstand crises in one or more sectors of its economy, making its overall economic performance less volatile. Concentration in solely one sector is consequently perceived as a negative. Accordingly, in the case of rural mini-grids, a high share of agricultural activities results in a negative score. Because of this reasoning, the share of agricultural business is taken into consideration for the overall local economic performance. A higher share results in a higher risk for the mini-grid.

It is safe to say that an economically viable mini-grid operation is currently hardly possible in the case of Tsumkwe. Based on a conducted Levelized Cost of Energy (LCoE) calculation, which is backed by assumptions derived from findings of a research stay in 2019, the total costs for generating electricity in Tsumkwe amount to approximately 2.2 NAD/kWh. Revenues, on the other side, are 2.4 NAD/kWh when assuming a share of 80% private households and 20% commercial customers. This leads to a negative profit margin of 0.2 NAD/kWh, indicating a low profitability for potential investors (see **Table 3**).

The risk assessment itself is based on the two dimension outlined above, which are the income level as well as the economic diversification, which underlines the importance of engaging commercial customers.

Expenses	Income	
OPEX costs range from 2.2 NAD/kWh	Residential customers 80% @ 2 NAD/kWh	Average income 2.4 NAD/kWh
	Commercial customers 20% @ 4 NAD/kWh	
	Profit margin 0.2 NAD/kWh	

Table 3.
Profitability analysis (estimation).

4.2.1 Village income level

The village income level of Tsumkwe lies at around 4880 NAD monthly per household, which was elicited during a research trip in 2020. The land is not fertile enough to engage in subsistence or even commercial farming, thus the largest portion of household in the Otjozondjupa Region report salaries or wages as their main source of income [27]. The income is set in relation with the average income level in Otjozondjupa region as of 8317 NAD per household per month [28]. This ratio as of 58.3% corresponds to a risk sub-score of 3.5 (see **Table 4**).

Position	1	2	3	4	5	6	7	8	9
Average income village / avg. Income peer group	100%	90%	80%	70%	**60%**	50%	40%	30%	20%
Income score	1	2	2,5	3	**3,5**	4	5	5,5	6

Table 4.
Income score.

4.2.2 The importance of commercial customers

The electricity tariff for commercial customers is higher, than for private households. Further, commercial customers, as a standard, consume electricity mainly during the daytime, while the consumption of private households peaks in the morning and in the evening. The mini-grid operator benefits from higher daytime utilization of the solar mini-grid, since providing power directly from PV panels equals zero marginal costs. Batteries represent fixed costs, but are depreciated with each discharge. Diesel generators have high variable costs driven by fuel prices. Thus, for the operator, adding daytime demand reduces the overall levelized cost of electricity. Midday loads, as stated above, are more likely to consist of income-generating activities such as, for example, cold storage, processing of agricultural products or running small workshops. Evening loads are more likely to be residential. Having productive-use customers can, therefore, benefit residential customers, since the midday utilization lowers the overall price of electricity. In other words, the existence of more commercial customers, who buy power at zero marginal cost during the day, will lower the price for the electricity residential customers pay at night. In the case of Tsumkwe, however, the share of residential customers contributes the most to the revenues of the mini-grid. This leads to the assumption that the scarceness of commercial customers (among other factors) potentially causes the situation illustrated in the beginning.

The level of productive use in a local economy is, therefore, a crucial determinant for the economic score within the SRMP. A mini-grid that serves customers in the field of productive use can achieve a stable overall economic performance at lower prices for both commercial and retail customers. As a result, isolated concentration on the residential sector or a high share of household or residential activities lead to a negative assessment. Based on this, the share of residential customers feeds into the assessment – a higher share leads to higher risk for the mini-grid. Besides, the share of anchor customers revenues compared to the total revenues of the mini-grid is used for measuring the commercial strength. Anchor customer are, for example, larger enterprises or public institutions. The utilization profile of an anchor customer is rated as both stable and safe due to its high creditworthiness. A higher share of anchor customers to total commercial customers contributes to a lower risk for the mini-grid (**Table 5**).

		Economic diversification					
		Share of residential customers as % of total revenues (less than)					
		0%	**20%**	**40%**	**60%**	**80%**	**100%**
Share of anchor customers to total commercial customers (less than)	**80%**	2	2	3	3	4	4
	60%	2	3	3	4	4	5
	40%	3	3	4	4	5	5
	20%	3	4	4	5	5	6

Table 5.
Economic diversification.

In the case of Tsumkwe, the anchor customers are the police station, lodge, hospital and schools, contributing roughly 22% of the mini-grid's revenues as commercial customers. Together with the low share of existent commercial customers, an overall commercial score is derived [6]. The relatively high residential usage of 75% and the low share of anchor customers among commercial customers of 22%, combined with a medium average income level in Tsumkwe, ultimately lead to a moderate economic score of 3.75 (**Table 6**).

Components	**Score**
Income level	3,5
Economic diversification	4,0
Final Economic score	**3,75**

Table 6.
Economic score components.

4.3 Technological assessment

The technology score is intended to provide conclusions concerning the reliability and resource efficiency of the system. Therefore, the maintenance cost and the share of renewable energy are both chosen to measure how much attention is paid to providing a robust and reliable technology frame and to measure the resource efficiency of a mini-grid. The maintenance cost is put in relation to the investment, while the share of renewable energy is calculated by the energy generated annually from renewable sources compared to the total energy generated each year. However, any additional source, especially based on renewable energy, results in all probability in inefficient supply structures and additional sources of technical error. If that is the case, the value would be adjusted.

In 2011, the existing diesel-based mini-grid in Tsumkwe was upgraded with a 202 kW_p solar PV plant and a 1.93 MWh lead-acid battery system [15]. After some years of operation, the battery storage and PV panels were extended to 3.08 MWh and 303 kW_p, respectively, which made it the largest off-grid electricity supply system in Namibia. Besides the open-space PV generator and its inverters, the hybrid mini-grid has a diesel generator set to enable a 24-hour, uninterrupted electricity supply for the settlement. The diesel genset has a rated output of 300 kVA corresponding to a true power of 240 kW. As for the distribution side, the mini-grid in Tsumkwe consists of an 11-kV three-phase distribution grid separated into an essential and a non-essential line. This structure allows the consumers connected to the essential line - that is the water pumping station and the clinic - to be given priority in the event of a power or energy shortage. Zongwe et al. (2017) indicate the average daily electricity consumption in Tsumkwe to be about 2 MWh/d [15], which was confirmed during the first field trip within the research project in 2019. In the same period, PV production amounted to 1,618 kWh/d. The diesel genset contributed some 581 kWh/d of electricity, which corresponds to an average running time of about 2.4 hours per day. Hence, PV reached a share of approx. 69% of the total electricity generation in the mentioned period, which indicates an economically optimized mini-grid design: a renewable energy fraction of 60% was identified as cost-optimal for hybrid mini-grids in a publication of IRENA [29][1]. Overall, the general technical design of the mini-grid conforms very well to the present energy situation in Tsumkwe.

However, the research trips have also shown severe lack of maintenance. For example, the PV modules were covered by a thick layer of dust, significantly reducing the solar yield [26]. One PV module was even damaged because of a stone chip, which caused a hot spot. As such damage is very likely to lead to module failure and thus failure of the entire PV string, the research team had to circumvent the defective module. Moreover, the PV inverters were found to be heavily contaminated with dust, which impairs heat dissipation. The resulting overheating in turn reduces inverter performance and the overall lifetime of the system. [23] Besides these defects, the lead acid battery banks have proven to be the weakest part of the Tsumkwe mini-grid. Five defective battery cells were identified during a research trip. Since these battery cells were already short-circuiting due to electrode sludging and thus endangered the entire battery system, they had to be removed from the battery banks immediately. In early 2021, furthermore, the CENORED operations team detected that an inverter was defective and that the continuity of power supply was being affected. The request for support from CENORED Management to the research project team in Germany provided evidence that no replacement process is implemented.

The SRMP scheme combines the low maintenance level in terms of investment costs of 6% together with a share of 50% renewable energy in an initial score of 4 (see **Table** 7).

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[1] It is expected that the cost-optimal RE fraction may rise to 90% by 2025 as the costs of storage and control devices continue to fall.

		Maintenance costs / Investment costs			
		15%	**10%**	**5%**	**0%**
Share of RE (% of overall electricity generation)	**100%**	1	1	1	2
	80%	1	1	2	3
	60%	1	2	3	4
	40%	2	3	4	5
	20%	3	4	5	5
	10%	4	5	5	6
	0%	5	6	6	6

Table 7.
Technology score: Initial score.

Value		**Adjustment**
Procurement process for spare parts in place?	No	+1
Complex technology?	No	0
Adjustment total		+1
Total technology score		5

Table 8.
Technology score: adjustments.

In a second step, the technology score is adjusted if there are special technological risks in place (see **Table 8**). In case of the Tsumkwe mini-grid, the missing procurement process for spare parts leads to a negative adjustment by one score, resulting in a final technology score of 5.

4.4 Financial assessment

> The finance score is measured in two steps. First, two quantitative tables are used to obtain an initial score by applying a scoring grid. The initial score is based on a calculation of the average of the percentage of debt and the cost of debt over the last three years and can be improved in the case of a positive adjustment and worsened by a negative one. In this way, financial flexibility and independence is assessed by the amount of net debt as a percentage of total capital and interest expense as a percentage of revenue. The baseline can be changed by a positive or negative adjustment. The baseline could improve by one grade if a grant is awarded to finance the mini-grid. A grant in all probability affects the flexibility of a mini-grid in a positive way and allows the mini-grid's management to operate without financial pressure from investors for extended periods of distress. On the other hand, this must not lead to moral hazard or encourage development that disregards necessary structural investments. To cover this characteristic, the involvement of private investors is being examined. A private investor can be regarded as extremely relevant in order to avoid that profitability targets are undervalued. Therefore, a negative adjustment occurs if no share of a private investor is retained.

The financial score is calculated by combining quantitative and qualitative aspects. The proportion of debt and the cost of debt determine the initial quantitative score. Due to the fact that in the case of Tsumkwe no debt capital was used to finance the mini-grid, the scoring starts with the value of 1 (**Table 9**).

The initial score can be changed through two adjustments, which are qualitative aspects in terms of independence and efficient management based on the funding. Major emphasis is therefore placed on grant funding and private sector participation.

		Share of debt			
		30%	**50%**	**70%**	**100%**
Cost of debt/revenues	**0%**	**1**	1	1	2
	10%	1	1	2	3
	20%	1	2	3	4
	40%	2	3	4	5
	60%	3	4	5	5
	80%	4	5	5	6
	100%	5	6	6	6

Table 9.
Finance initial score: assignment.

Experience shows that a grant reduces the willingness of management to use financial resources efficiently - as demonstrated by the failure of socialist systems in the past. As a result, funding by a grant leads to an increase of the risk score by +1.

On the other hand, private sector participation enhances independence from political decisions and encourages efficient management of resources. A private investor can be regarded as vital to avoid underestimation of the profitability targets. Therefore, the risk score increases by +1 if no private investor is involved in the mini-grid project.

In the case of Tsumkwe, there is neither a grant, as explained in the introduction, nor a private investor with commercial objectives. This leads to an increase of the risk score by +2 (see **Table 10**), resulting in a total financial risk score of 2.0, which indicates an overall moderate level of risk.

		Adjustment
Grant?	Yes	1
Private Investor?	No	1
Total adjustments		**2**
Final Financial Score		**3**

Table 10.
Finance adjustment.

4.5 Educational assessment

> This criterion is perceived as an assessment of management's ability and willingness to coordinate, communicate, and implement educational goals in order to maintain continuous economic performance and mitigate technical failures. The assessment considers only quantitative data, i.e., no qualitative adjustments are made. Ultimately, it is imperative that the management of a mini-grid is able to actively manage and contribute to technical quality through a planned educational policy. The quality of educational efforts is evaluated by the number of educational activities and the cost of educational activities compared to the total cost on average over the last three years.

When new technologies are adopted, as in the case of Tsumkwe, the shift from a diesel-only generator to a solar PV-diesel hybrid mini-grid system demands a significant amount of training for various groups of people to achieve better technical proficiency due to emerging productive use cases among the community [23, 30]. In fact, in order to operate an economic viable mini-grid system, productive use cases and the commercial usage of electricity produced are urgently needed, thus the engagement of the local community is a key aspect that needs to be considered already in the planning and development phase. In addition, a better understanding of electricity generation and use can potentially encourage people to replace inefficient equipment, both helping to save electricity costs in the long run and stabilizing the system. A series of training/education activities should therefore accompany every mini-grid project by default. In the case of Tsumkwe, the community was indeed involved and employed in the construction of the mini-grid. In addition, educational campaigns have been organized, focusing particularly on informing the community about the project itself, maintenance of stoves or solar water heater, as well as energy efficiency. This was done by distributing several flyers that provided information on how to save money through energy efficient measures, among other things [31, 32]. However, it now became apparent that the approach was not successful or rather not sufficient. Based on the results of a research trip to Tsumkwe in 2020, relatively few community members were aware that their prepaid electricity payments contained charges for service, maintenance, as well as a levy for government agencies. The remaining respondents were convinced that they were only paying for electricity, or indicated that they did not know what they were in fact paying for [23]. A field trip to a neighboring village, which was already conducted in 2016, presented similar results. A considerable number of people was 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 [33]. This shows that the design of an educational component within the management of mini-grid systems is essential for the sustainability and the durability of the mini-grid system. As the case of Tsumkwe illustrated, this is not done by distributing informative material, but rather through direct contact with the community members, joint discussion about tariff considerations and training offerings.

From a technical point of view, regular preventive maintenance, which can only be accomplished with a trained team, ensures the optimized operation of a mini-grid and thus, enhances its technical sustainability. Apart from the educational requirements for community members, education and training of operating personnel is consequently essential to ensure the (economic) lifespan of the equipment for better service. At best, the responsible personnel is recruited locally. When the mini-grid system in Tsumkwe was expanded in 2011, two of twelve battery banks were obviously not properly connected to the other batteries. As a result, some of the additional battery capacity was unavailable. The fact that this problem was not identified until a research trip in 2019 clearly demonstrates the lack of knowledge and experience in operating off-grid power systems in the analyzed community.

The level of education proved to be a weak point within the five dimensions examined in the case of Tsumkwe. Based on our impression by a fact finding mission trip in July 2019 only one education measure per year was reported upon. Related to revenues expenses for education can be seen around 5% (**Table 11**). Due to the fact that in the municipality only very few educational measures were carried out that were useful in any way, combined with today's very low level of awareness regarding electricity among the population and poorly maintained facilities, this results in a value of 5 (**Table 12**), indicting a high risk level.

Component	Estimation
Number of educational measures p.a.	1
Cost of education	**5,0%**

Table 11.
Education score components.

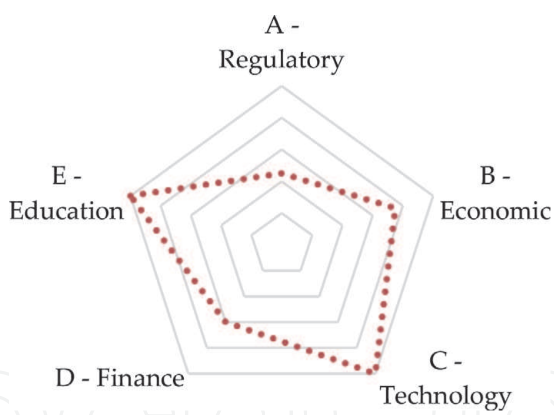
		Number of educational measures				
Expenses education/revenues		20	15	10	5	0
	0%	1	2	3	4	5
	5%	2	3	4	5	6
	10%	3	4	5	6	6
	15%	4	5	6	6	6

Table 12.
Education: Scoring grid.

4.6 The overall rating

As alluded at the beginning, the five key components of a mini-grid rating which have been distilled into two profile categories – the "Regulatory framework effectiveness and economic profile" and the "flexibility and performance profile" – will be summarized and combined to produce a final, overall mini-grid rating. The two aforementioned profiles that were created as an intermediate step are the base to attain the final, overall SRMP mini-grid rating.

The five factors of the SRMP mini-grid rating procedure are allocated to two categories – the 'regulatory framework effectiveness and economic profile' and the 'flexibility and performance profile'. These profiles are subsequently combined to receive a final, overall mini-grid rating. **Table 13** presents the results in the case of the Tsumkwe mini-grid.



Factor	Score
A - Regulatory Framework	2.25
B – Economic	3.75
C – Technology	5.0
D – Finance	3.0
E – Education	5.0
Profiles	**Score**
Regulatory framework effectiveness and economic profile (A&B)	3.0
Flexibility and performance profile (C&D&E)	4.33
Total Rating	**bb+**

Table 13.
Final risk rating for the mini-grid in Tsumkwe.

		Regulatory framework effectiveness and economic score (A&B)										
Flexibility and performance profile (C&D&E)	**Category**	**Superior**	**Extremely strong**	**Very strong**	**Strong**	**Moderately strong**	**Intermediate**	**Moderately weak**	**Weak**	**Very weak**	**Extremely weak**	**Poor**
Category	**Score**	**1,0**	**1,5**	**2,0**	**2,5**	**3,0**	**3,5**	**4,0**	**4,5**	**5,0**	**5,5**	**6,0**
Extremely strong	1	aaa	aaa	aaa	aa+	Aa	a+	a	a-	bbb+	N/A	N/A
Very strong	1,8	aaa	aaa	aa+	Aa	aa-	a	a-	bbb+	bbb	bb+	bb-
Strong	2,3	aaa	aa+	aa	aa-	A	a-	bbb+	bbb	bb+	bb	b+
Moderately strong	2,8	aa+	aa	aa-	a+	a-	bbb	bbb-	bb+	bb	bb-	b+
Intermediate	3,3	aa	aa-	a+	A	bbb+	bbb-	bb+	bb	bb-	b+	b
Moderately weak	3,8	aa-	a+	a	bbb+	Bbb	bb+	bb	bb-	b+	b	b
Weak	4,3	a	a-	bbb+	Bbb	**bb+**	bb	bb-	b+	b	b-	b-
Very weak	4,8	N/A	bbb	bbb-	bb+	bb	bb-	b+	b	b	b-	b-
Extremely weak	5,3	N/A	bb+	bb	bb-	b+	b	b	b-	b-	ccc/cc	ccc/cc

Table 14.
Final Investment grade.

Taking all of the above dimensions into account, the risk rating results in a "moderately weak rating" (bb+). While the overall result reflects the general tendency towards a rather challenging environment, the final evaluation also revealed strengths and weaknesses.

Table 14 clearly illustrates that Tsumkwe's mini-grid is exposed to high risk associated with a low level of technology maintenance and a widespread lack of education.

The economic environment is assessed by a moderate risk (economic score B). That is a typical outcome for remote areas with limited access to income generating activities. The (national) regulatory environment is admittedly transparent and relatively stable. A shortfall is outlined in the ERI 2019, as Namibian regulations do not necessarily have a convincing impact on consumers, but rather on power utilities [25]. The conducted analyses, moreover, uncovered the substantial need to translate regulatory knowledge, technical guidelines and issued codes from large energy projects to much smaller mini-grid initiatives. While many policies target grid-based power generation, off-grid regulations are indeed scarce. The Africa Minigrid Developers Association, moreover, ascertained that the digitization of relevant processes would potentially accelerate the development [34]. Apart from the digitalization of e.g. licensing processes to simplify the establishment of mini-grids for investors, this also corresponds to the above-mentioned finding that online portals are needed to disseminate information concerning off-grid possibilities among the population. As the mini-grid in Tsumkwe received funding from donors, the financial score is rated to be less strong. Private investors have inevitably a positive impact on the profitability due to allegedly commercial targets.

5. Conclusion

This paper has extended the rating model based on the standardized risk management procedure (SRMP) developed by Steurer et al. 2017 (for more information see [6]). The SRMP approach is applied for the mini-grid in Tsumkwe, Namibia. The findings result in an assessment of the mini-grid in Tsumkwe with a moderate level of risk. Important for the strategic management of the mini-grid are the identified strengths and weaknesses supporting long-term risk management. In this case, there main potential is given in the fields of technology and education. Reducing the share of diesel would lead to improved earnings. Further, a well-organized replacement process is needed to ensure long-term commercial profitability. Particularly, there is evidence to expose the true costs for off-grid electricity distribution as well as to issue a central guideline for particularly off-grid tariff setting. Developing productive use cases to boost and restore the local economy is, furthermore, crucial, which, however, needs to be complemented with comprehensive training offers targeting both operating personnel and the population.

Acknowledgements

The authors acknowledge financial support received from the German Federal Ministry of Education and Research (BMBF) via the PROCEED project. Furthermore, we would like to acknowledge the great collaboration in the PROCEED project, especially with Özge Dolunay and Sven Kühnel, who have contributed to the presented findings to a large extent.

Conflict of interest

Both authors declare that they have no conflict of interest.

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