Affordable and reliable mini-grids in Sierra Leone

Master thesis

Sjoerd Janse

TU Delft

Witteveen + Bos

Photo cover: Yele hydroplant ©Maarten Slooves

Affordable and reliable mini-grids in Sierra Leone

analysing and designing rural electrification from a socio-technical perspective

Master thesis submitted to Delft University of Technology
in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

in Complex Systems Engineering
at Faculty of Technology, Policy and Management
by

Sjoerd Janse

4036719 - sjoerd.janse@witteveenbos.com

Thesis committee:

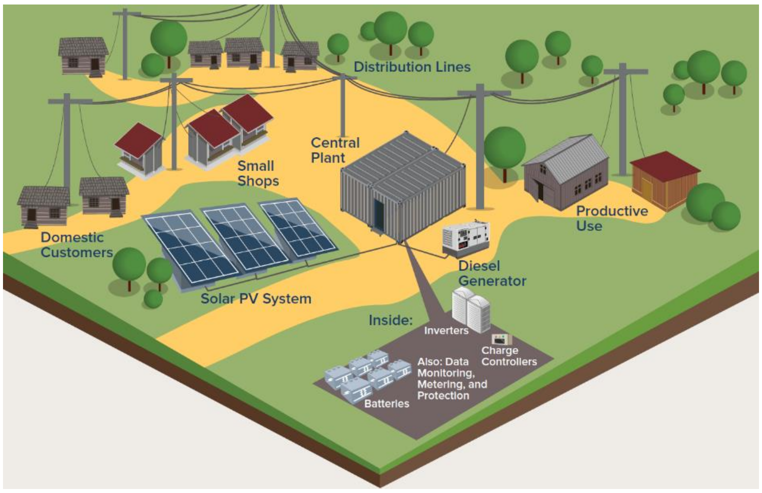
Prof.dr. K. Blok,
chair, section Energy and Industry
Dr.ir. B. Enserink,
first supervisor, section Policy Analysis
Ir. M.F.E. Wauben,
external advisor Witteveen+Bos

Management summary

In Sierra Leone the national electricity sector is small and the reliability of the power supply is low. About 97% of the rural population has no access to the electricity grid. There is a need for facilitating electricity access in these areas while electrifying these areas can stimulate socio-economic welfare. But electrifying these rural and local communities is challenging.

Mini-grids versus other options

Like other Sub-Saharan countries, the national electricity grid in Sierra Leone is very limited and have an unreliable power supply. (Sub)urban, highly populated areas have national utilities' priority over rural areas with lower population densities for central grid expansion. Smaller low-power solutions, like Solar Home Systems, are not fostering productive use of energy and are less affordable for most rural people in Sierra Leone. The emergence of mini-grids has provided an opportunity to supply rural customers with reliable and affordable electricity. Mini-grids can be defined as small scale electricity systems with local (modular) generation source(s) and a small distribution network that serves a number of connected customers. Mini-grids can operate autonomously without connection to the national transmission grid and are suitable at places where the costs of grid extension or Solar Home Systems are higher than a mini-grid.



Example of a mini-grid (1)

Holistic approach

There is little experience with mini-grids in Sierra Leone, but the country has a large potential for renewable mini-grids. The irradiation factor is sufficient to generate electricity by photovoltaic systems energy and several rivers in the country enable power generation by small hydropower systems. Nevertheless, the failure rate of mini-grid projects in Sub-Sahara Africa is high. Many mini-grids are not sustainable over the long-term. The emphasis is placed only on the technological aspects, where the socio-economic and institutional aspects are neglected. An approach in which social, technical, economic and institutional dimensions of mini-grids are included, can help to assess the long-term sustainability of mini-grids in Sierra Leone. Desk research, field visits and case study research of existing mini-grids have been used to answer the following research question:

> **How to achieve sustainable mini-grids in Sierra Leone that can give rural communities an affordable and reliable power supply?**

The study started with an extensive literature research to the characteristics and challenges of mini-grids. Based on academic literature and reports, 34 sustainability indicators have been listed. The indicators are grouped around key variables of some of the four sustainability dimensions. The indicators are used to discuss and assess the long-term sustainability of two mini-grids in Sierra Leone. The indicators have been assessed at a scale of 5 steps between 0 and 1. If the indicator has a higher the score, it is contributing more to the long-term sustainability of the mini-grid. In the table below the indicators are showed.

Social	*Community involvement*	Community education
		Support of local leaders and politicians
		Share of population with electricity access
		Training and employment of local people
	Ownership	Suitability ownership model
	Benefits & Acceptability	Allocation of electricity between customers
		Awareness about connection and consumption
		Availability of streetlights
		Ability to pay for electricity services
		Electricity access public facilities (schools, clinics, etc)
Technological	*Monitoring & management*	Metering system mini-grid
		Managing of electricity consumption
		Match of technical design with demand pattern
	Reliability & efficiency	Availability and utilization of services
		System efficiency
	Operation & maintenance	Availability equipment and spare parts in the country
		Dependency on foreign assistance
		Quality equipment and materials
	Modularity	Compatibility with future grid integration
		Adaptability and expandability
Economical	*Costs and investments*	Financial support government
		Operation and maintenance costs
	Productive use	Industrial/commercial customers with productive use
		Anchor client connections
	Financial	Non-payments or outstanding payments
		Tariff lag
		Micro-credit facilities
Policy / institutional	*Regulations*	National regulation on tariff setting and licensees
		Tax breaks on imported (spare) parts
	Organization	Capability of staff
		Long-term vision company
		Defining of responsibilities between stakeholders
	Enforcement & Security	Enforcement of local policy
		Security of electricity infrastructure

Case study research

In the research the current energy situation in Sierra Leone is described as well as rural electrification projects through mini-grids. Two mini-grids in Sierra Leone has been researched extensively: Yele and Segbwema. Yele is a village of 8000 people and located in the centre of Sierra Leone. The electricity is generated by a small hydropower plant, which is managed by the local company PowerNed. In Segbwema, located in the Eastern Sierra Leone, a solar photovoltaic (PV) system and distribution grid supplies a part of the 12.000 people in Segbwema. The grid is owned by a consortium of different

NGO's. The indicators mentioned above are used to discuss and assess the mini-grids. The assessment is based on interviews, discussions, observation and data review.

The outcome of the desk and case study research is contributing to knowledge about the success and failure factors of mini-grids. Lessons learnt can become essential to develop and build more mini-grids in the country, which have to be long-term sustainable. In this research the findings are applied for a potential mini-grid location in Sumbuya, in the South of Sierra Leone. This remote area welcomed in 2016 a large pineapple company, that is starting up his activities. The availability of a large electricity consumer can improve the feasibility of a mini-grid.

Indices	Yele	Segbwema	Sumbuya
Population	8000	12000	8000
Economic activities	Fishing and Farming: palm oil, cassava, potatoes, plantain, bananas, pepper		
Commercial activities	Welding, retail, palm oil processing, telecommunication tower, hospitals	Welding, retail, grain milling, processing, telecommunication tower, hospital	Large pineapple plantation and processing company, welding, construction companies, clinic
Households energy use	Electric bulbs, fans, radio sets, cell phones, refrigerators		
Technology	Mini-hydro (250kW)	PV (127kW)	?
Owner	PowerNed	WHH, COOPI	?

Lessons learnt

Below the lessons learnt are described. Each lesson learnt is substantiated with findings from the case study research.

1. **Site selection is crucial**, not each village is suitable for a mini-grid. Electricity cannot initiate socio-economic development; it rather stimulates the development. To maximize the financial viability, it is important to focus on medium-high densely populated villages with economic activities.

    Yele and Segbwema are two medium populated villages with an existing infrastructure (water, roads), economic activities and are centrally located. People are able to pay for electricity access, although their electricity consumption is low and fluctuates through a seasonal income flow. Both villages have public service facilities (hospitals, schools, etc.) and the potential to grow coming years. If the population density is too small, the success factor for economic viability is very low. However, clustering of mini-grid sites can help to benefit from economies of scale in construction and operation.

2. **Community involvement** supports the awareness of the customers and provides priceless information about customer needs. This should be done during the development phase, but also during the operation of the mini-grid

    This can be done by site visits, meetings with the community and councils, forming of an energy committee and radio-shows. To embed the mini-grid in the community, developers should pay attention to ideas and feedback of the community to increase and maintain customers interest and satisfaction. It is important to implement suggestions from local people to adapt the system to the local situation and respect local structures. Community meetings and radio shows can also be used to stimulate productive use of energy and a proper maintenance of the electricity connections and appliances.

3. **Capacity building** of local people is essential for the continuity of the mini-grid. The operation and maintenance require capable companies with a high level of technical and organisational knowledge.

Especially in Yele, the company paid attention to the capacity building of local people. Local people are attracted to become staff member and are trained as technician or financial employee. This creates social benefits for the community and priceless information for the company. Local people are familiar with the habits of the community and know inside information of households and villages.

4. **Stimulate of productive use of energy** by stimulating local businesses and working together with anchor clients.

   Stimulating productive use of energy during daytime can balance the demand load (in the evenings, households have a peak demand). It increases the utilization factor and electricity consumption of commercial and industrial customers. This is important, because the revenues of residential consumption are limited due to the low levels of consumption. Financing programs and micro-finance institutes can support commercial customers to buy new machinery. An anchor client with a high and stable load consumption can increase the cost-effectiveness of mini-grids substantially, because of the lower transaction costs. The base load can be guaranteed as well as a consistent income flow. Yele and Segbwema have both anchor customers (communication towers, hospitals, palm oil factory), but more anchor customer are welcomed. In Yele, there are more anchors customers than Segbwema. Moreover, an agro-industrial started up some activities in 2018, which can contribute to the minimum base-load of the electricity system.

5. **Flexibility** in the socio-technical design of a mini-grid is important to allow changes and improvements.

   It is difficult to forecast the demand loads and to foresee the practices of use. They are shaped during the time of operation. Expandability or modularity reduces overspending on capital and increase the reliability and viability of the system. In Yele, the consumption is growing each year, but the available power is limited. The generation capacity needs to be expanded. A second turbine in the hydropower plant is planned, but other additional generation capacity is required. For Segbwema, expandability through adding more PV-panels can be done easily.

6. **Load demand management** is essential for the sustainable operation of a mini-grid.

   Yele and Segbwema are both struggling with matching electricity supply and demand during peak hours. By managing the demand load properly though accurate monitoring and economic incentives (for example time-based tariffs) to structure customers behaviour, the system will achieve higher efficiencies and is economically more favourable. The mini-grid in Segbwema has a more advanced (remote) metering and management system, resulting in a higher technical sustainability of the mini-grid.

7. **Hybridisation** have positive impact on the reliability and cost-effectiveness of the grid.

   It is difficult to make purely solar-battery mini-grids reliable during peak loads. Using a diesel generator as backup can mitigate the power shortages, shutdown's and save battery capacity. Also, in Yele a diesel generator can mitigate the power shortages during peak loads and prevent black-outs (shut-down of the system) and brownouts (voltage drop). The rainy seasons make generation sizing challenging. In Segbwema, the generated potential is much lower than in the dry season. In Yele, the hydropower-plant is struggling with a backwater flow, resulting a too small head. Storage facilities and diesel generators can increase the reliability of the system and secure the customer loyalty.

8. **Strict enforcement policy** for cases of free-rider behaviour, theft or fraud is essential to prevent obviation of the rules and responsibilities.

   This enforcement needs to be done in close cooperation with the community council, because they are the traditional rulers of the villages. Working together with community councils and paramount chiefs make the company less vulnerable for blaming and shaming. Strict enforcement policy is required to stimulate regular payments and responsibility amongst the customers. There is a large preference to use prepaid metering systems, whereby people are only able to use electricity if they pay beforehand. Post-paid meters for residential customers didn't work due to the tendency to 'pay tomorrow' or 'pay later'. PowerNed cut off the electricity connection after some period of non-payment.

9. **Financing** should be done by a mix of grants, loans and local or private equity. The decreasing costs of generation technologies and battery system make investments in mini-grids more viable.

   It is not easy to cover the operational costs of a mini-grid. The tariffs should not exceed the ability of pay, but must have a minimum price to stress the economic scarce. In Yele and Segbwema, the management is continuously working on improving the utilization of the system. Subsidies should ideally only be used where there is a possibility of their being phased out. In Yele a subsidy was used as catalysts for new connections. When the subsidies were phased out, an income decrease was seen. Last three years, the sales of electricity are increasing.

10. **Mini-grid regulation** is essential for the national and local embeddedness and for attracting private investors. Conflicting policies and a lack of coherence need to be prevented.

Sierra Leone developed together with some consultants and the United Nations a mini-grid policy. Nevertheless, the document is still waiting for the approval by the parliament. This document standardizes license procedures, tariff settings and agreements for grid arrival. In Segbwema, the initial tariffs determined by the project developers were rejected by the Energy and Water Regulation Committee, the national regulator in Sierra Leone. This is discouraging for developers. Clear and straightforward regulation improve the institutional sustainability.

For implementers

For implementers of mini-grids, a preliminary study to the potential location(s) is necessary. This should be done in a holistic manner, in which all relevant aspects are included. The potential clients, needs, uncertainties, resources and financial models have to be clear to design a mini-grid. The holistic approach is important, because electricity is not a service or product in itself. The mini-grid is only feasible if there is a (future) substantial demand load. Therefore, supporting entrepreneurs to buy efficient and energy productive equipment can be more efficient than only focusing on financing of capital. The developers should focus on the socio-economic needs and subsequently at the technical design that fits with the needs. It seems that the Sumbuya area can fulfil many requirements for a long-term sustainable mini-grid:

The presence of a potential large customer, the fruit company Sierra Tropical, can provide a stable base load and income flow from the start of the operation. In order to work towards sustainable electrification of the community and to enhance the satisfaction of the residential customers, it is important that the generated power is well allocated amongst the potential large agro customer, different small industrial and commercial customers and villages. There is a strong need to create community energy committee(s) that have representatives of each customer group and each village. This committee is important for receiving feedback information, ensuring awareness and solving conflicts. The committee can moderate the negotiating procedure about land acquisition for offices and generation assets. Hybridization and flexibility are required to achieve a high efficiency of the system. The electricity for irrigation is only required during the peak of the dry season. During the dry season the power generation capacity of a hydro plant (without reservoir) will be lower, PV-panels can provide the needed power. During the rainy season the output of the Photo Voltaic-system is lower, but the output of the hydro will be higher. The hydropower can supply the baseload of the system, PV systems can be integrated to cover the peak loads. With a possibility to expand the network and electrify system, the system is more adaptive to future's uncertainties and the growing demand load. The tariffs should be determined in close cooperation with the EWRC and the villages.

Conclusion

Minigrids are promising to bridge the gap between grid extension and Solar Home Systems. The design and operation of minigrids is simultaneously challenging; lessons learnt about success and failure factors have to be taken in account. The above mentioned lessons learnt are containing the most relevant aspects for developing mini-grids in Sierra Leone. In the short and medium term, mini-grid investments in developing countries cannot only rely on revenues from clients, but needs subsidies. Nevertheless, the growing portfolio of renewable projects in Sub-Sahara Africa, learning processes, better regulation and capacity building, is paving the way for new mini-grid developers and investors. A suggestion for subsequent research should be to investigate the financial structures that support the large development of mini-grids in Sierra Leone.

Acknowledgments

This report is both the product of an extensive research to mini-grids in Sierra Leone and the concluding part of the master Complex Systems Engineering at the TU Delft. I gratefully acknowledge the support and assistance of everyone that helped me to conduct this research and to provide me the opportunity for having this exciting foreign experience.

First of all, a word of gratitude to Marcel Wauben from Witteveen+Bos. Marcel, many thanks for arranging this graduation internship and your support during and after my stay in Sierra Leone. Your enthusiasm, encouragement, patience, reflections and expertise have been significant to accomplish my thesis work. Thanks for bringing me in touch with Donald Keus from PowerNed.

Donald, I would like to thank you for allowing me to use the electricity situation in Yele as case study for my research. Without your input and the possibility to cooperate with the PowerNed staff, this research was not realizable. A very special thanks to my 'brothers' in Yele, the staff of PowerNed, who explained me a lot about the electricity system, answered so many questions for my research and introduced me to so many people in the community of Yele. I admire your perseverance and passion.

My gratitude goes out to the other members of the graduation committee. Prof. Kornelis Blok, thank you for being part of the thesis committee and for your calm and reasonable comments. Dr. Bert Enserink, thank you for your supportive guidance and your constructive feedback.

I would also like to thank many other people in Sierra Leone, who helped me with data and valuable information. I thank the people from EnDev, WHH and UNOPS. Andrew Brooke-Smith and Patrick Blake, thank you for your hospitality. I hope this thesis will help in the development of a mini-grid in the Sumbuya area.

I would also like to thank my dear family and friends for their patience and permanent support. My deepest gratitude goes out to my wife Carolien; no words can describe how I appreciated your encouragement.

Sjoerd Janse

Table of contents

Abbreviations

AC	Alternative Current
AfDB	African Development Bank
ATP	Ability to Pay
CLSG Transco	Côte d'Ivoire, Liberia, Sierra Leone and Guinee transmission line
CPR	Common pool resource
DC	Direct Current
EDSA	Electricity Distribution and Supply Authority
EGTC	Electricity Generation and Transmission Company
EU	European Union
EWRC(A)	Electricity and Water Regulatory Commission (Act)
FIT	Feed-in tariff
GDP	Gross Domestic Product
GoSL	Government of Sierra Leone
HBS	Home-Based Systems
IEA	International Energy Agency
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
LCOE	Levelized Cost of Energy
Le	Leone
LHF	Lion Heart Foundation
kWp	kilowatt-peak
MFF	Microgrid Failure Factors
MoE	Ministry of Energy
MTF	Multi-Tier Framework
NEA	National Electricity Act
NGO	Non-governmental Organisation
NPA	National Power Authority
PPA	Power Purchase Agreement
PPP	Public Private Partnership
PV	Photovoltaic
RE	Renewable Energy
RREP	Rural Renewable Energy Project
SDG	Sustainable Development Goals
SHS	Solar Home Systems
SMF	Sustainable Microgrid Factors
SSA	Sub-Sahara Africa
UNOPS	United Nations Office for Project Services
WHH	Welthungerhilfe
WTP	Willingness to Pay

List of figures

List of tables

1 Introduction

1.1 Context

Most sub-Saharan countries in Africa have a low electrification ratio, especially remote rural areas with poor infrastructure have rarely access to electricity. At this moment 84% of the people living in these remote rural areas have no access to electricity. However, access to electricity is essential for sustainable growth of these areas. Electricity can support the development of small businesses and can improve the agricultural processing industry. Dependency on a diesel generator for domestic use is not possible for the majority of the sub-Saharan people, because they cannot afford this. The United Nations have aimed in one of the seventeen Sustainable Development Goals (SDG) for 2030 to “ensure access to affordable, reliable, sustainable and modern energy for all” (2,3). Some countries are on track with these goals, other countries still have a long way to go. Several causes may underlie this lagging behind. Technical causes are poor infrastructures, long distances, a low demand load and the absence of a central grid. Socio-institutional causes are a lack of knowledge, lack of education and capacity building, poverty, corruption and high start-up costs (4). Connecting rural areas to the central grid is (economically) not feasible for most rural areas. The high investment costs for electricity transmission towards remote areas is for most developing countries not affordable. Therefore, international and national NGO’s focus mainly on the expansion of off-grid electricity generation. Mini or microgrids are needed to provide 84% of these rural people in sub-Saharan Africa access to electricity. These off-grid systems in rural areas could be connected to the central grid in the future, but for the time being off-grid generation appears to be the most feasible solution to supply electricity due to the absence of a central grid and the high investment to make a connection to the central grid. Nevertheless, many challenges are incorporated with the expansion and development of sustainable off-grid systems and research is essential to figure out how to overcome these challenges (3,5).

Figure 1 Map of Sierra Leone

Sierra Leone is a Sub-Sahara African country, that deals with a very low electrification ratio. Sierra Leone is significantly short of power generation capacity, now as well as in the short- and medium-term future. The country has a population of approximately 7.5 million people and ranked 179th out of

188 on the United Nations Development Programme's 2016 Human Development Index (6). The country can be characterised by a low life expectancy of 52,9 years and a GDP per capita PPP of USD 1390,30 (6–8). The urban electricity access in 2016 was 12,5 % and in the rural areas 2,5 % (9). The main existing power production facilities have a very low installed capacity of in total 137,2 MW. 77 MW is generated by thermal sources and 60 MW comes from hydropower. The large cities of Freetown and Makeni are reliant on the 50 MW Bumbuna large hydroplant, but the plant encountered several technical faults. The second and third largest cities, Bo and Kenema, have also an isolated distribution network. Due to the fact that blackouts are common, the on-grid capacity is unreliable and inadequate. Smaller towns and villages do not have a distribution network and rely completely on privately owned generators. The Ebola crisis in 2015 also accounts for the slow development of the electricity sector. International and national funding have been used for improving the health care system. Ironically the lack of reliable power generation was also a major obstacle to the country's ability to both deal with and quickly recover from the emergency. So, improving people's energy access is a key driver to increase social welfare.

1.2 Research problem

Because of the fact that 70% of the population of Sierra Leone lives in rural areas far away from the largest grid of Sierra Leone (Bumbuna - Freetown line), small-scale off-grid solutions are preferable for electrification (10–12). Electricity transmission grid implies high investments costs and the sales from the modest electricity demand in these areas cannot counterbalance the expenditures. According to Ilskog (13), while larger projects will take a long time to develop, small-scale off-grid power plants bridge the gap in the time required for the development of the large power schemes and to provide clean, sustainable power to people and business (14). These small-scale off-grid power plants or mini-grids are stand-alone power generation systems that supply multiple customers through a distribution system. Mini-grids are efficient in the way the electricity is generated nearer to the consumption points (less transport losses) and stimulates the socio-economic development of the community (15). Moreover, the fuel costs for using domestic generators are for most people not affordable. Different studies prove that rural electrification can stimulate social and economic developments, but not always results in welfare increase (15–18). Ahlberg (3) derived from Watson (19) four ranking determinants (economic, technical, political and institutional, cultural and social) for the long-term sustainability of electrification projects. Feron (17) mentions four aspects of the long term sustainability of off-grid electrification: institutional, economic, environmental and socio-cultural (Table 1).

Institutional	**Economic**	**Environmental**	**Socio-cultural**
Stability (durability) and long-term vision	Cost-effectiveness	Environmental awareness	Accessibility (disparity, equity)
Regulation, standards and enforcement	Reliability	Environmental impact	Social acceptance
Decentralization and openness to participation	Funding (initial investment; operation and maintenance)		Accuracy
Expert know-how	Contribution to the income of users		Cultural justice
Adaptability (ability to meet future needs)			

Table 1 Long term sustainability [15]

Energy supply through mini-grids in rural communities with poverty and poorly developed economies is complex because only elaborating technical designs would be not enough for robust and sustainable energy systems. Also, donor dependency can lead to a negative output for a sustainable future (3). The system needs to be embedded in the community and multiple criteria that are linked to livelihoods have to be analysed in order to design proper electricity access [12]. The governance and institutions that structure the human behaviour of multiple stakeholders within the energy system need to be analysed (21,22). Poverty, seasonal incomes, unfamiliarity with paying monthly bills and illiteracy and a lack of education make it hard for some customers to read their contract and plan their expenditures. This makes good financial management difficult [2, pp. 27], [22]. Furthermore, in many cases there is a tension between local ownership of the mini-grid and functioning as a business company that wants to recover the costs and have some reserves for unforeseen expenses (23). The strong collectivist nature of society makes it also difficult to make the business independent [23], [26].

So, rural electrification systems or mini-grids in countries like Sierra Leone require the inclusion of the societal dynamics and should be approached from a socio-technical perspective (17,25). Akinyele (26) proposed the so-called STEEP model (Social, Technical, Economical, Environmental, Policy) to determine the most common critical factors microgrids have to deal with. The model distinguishes the Microgrid Failure Factors (MFFs) and the Sustainable Microgrid Factors (SMFs) (26).

Microgrid Failure Factors (MFF)	STEEP	Sustainable Microgrid Factors (SMF)
• Lack of community engagement • Lack of education • The question of ownership • Installation by unqualified/inexperienced practitioners • Lack of practical preliminary survey • Low-level of social awareness • Insecurity of infrastructure	**S**ocial	• Effective community participation • Educating the public • Defining the infrastructure ownership • Awarding projects to qualified contractors • Effective pre-design survey • Effective awareness programme • Security for energy infrastructure
• Poor and inappropriate design • Lack of standard maintenance procedures • Dearth of local skilled practitioners • Lack of conformity to international standard codes • Use of sub-standard materials • Inadequate knowledge of renewable energy • Lack of monitoring systems • Poor project supervision	**T**echnical	• Appropriate and realistic design • Standard maintenance procedure • Use of international standards • Use of quality and approved materials • Use of remote monitoring systems • Effective project supervision
• Lack of financial support by the government • The question of who takes the financial responsibility • Lack of financial framework • Lack of revenue generation	**E**conomic	• Financial support by government • Financial commitment by communities • Financial models to integrate RE Entrepreneurs

• High cost of component replacements		• Incentives and low import duty
• Dearth of comprehensive energy resources assessment • Lack of planned environmental assessment • Weak environmental awareness	**E**nvironmental	• Site-specific resources report • Effective EIA • Effective environmental awareness and research
• Ineffective policy initiatives • Lack of political will for widespread application • Ineffective frameworks that encourage the private sector • Ineffective quality control policies	**P**olicy	• Political support • Established and strengthened PPPs • Strengthened and stable market regulatory framework • Strengthened quality control measures

Table 2 STEEP model (Akinyele, (26))

The factors which are shown in Table 2, combined with assessment criteria of Ahlberg (3) and Feron (17), are very useful to research the situation in Sierra Leone. At this moment, there is a lack of knowledge about the energy situation and especially the future expansion of rural mini-grids in Sierra Leone. In the last IRENA report, an overview of the available mini-grids in Sierra Leone was missing. This thesis aims to increase the knowledge about rural mini-grids in Sierra Leone, more specific on defining the common factors of success in the Sierra Leonean situation. By means of case studies, more generalizable insight will be figured out in order to obtain more knowledge about the socio-technical situation and future of mini-grids in Sierra Leone.

The main knowledge gap is to detect the success and failure factors of mini-grids in Sierra Leone in order to ensure and improve reliable, long-term sustainable mini-grids. The focus is on both technical aspects (grid configuration, power scarcity) as societal aspects (billing, community participation, economic instability) and their interrelatedness. Placing the results of case study research to mini-grids in Sierra Leone in the context of world-wide research to mini-grids can increase the relevance of this thesis.

1.3 Research objectives, deliverables and relevance

As shown in the research problem description, mini-grids in developing countries have to deal with a lot of challenges to achieve long-term sustainability. In this research, the common factors of success and failure from literature research are compared with the situation in Sierra Leone. The research is based on literature research, fields visits, data research and interviews. The findings from literature and practical work help to come up with some solutions on how to achieve and support long-term sustainable and feasible mini-grids in Sierra Leone.

The following **research objectives** could be defined:

- Identify and analyse factors of success and failure of mini-grids at four sustainability aspects: social, technical, economic and institutional.
- Discuss the energy system and the role of mini-grids in Sierra Leone.
- Evaluation of mini-grids in Sierra Leone on the basis of the sustainability aspects, by means of two case studies.
- Providing design requirements for developing new mini-grids in Sierra Leone, exemplified by a case study.

The research objectives will result in the **deliverables** below:

- A theoretical background to explore the main concepts and context of mini-grids.
- An extensive desk research to find key elements, barriers and challenges in ensuring the long-term sustainability of mini-grids.
- A sociotechnical evaluation study of the energy situations in Yele and Segbwema.
- An analysis of how to improve the reliability of mini-grids in Sierra Leone based on the critical factors of the desk research and the lessons learnt of the case studies.
- Recommendations for supplying electricity to large and small consumers in Sumbuya area.

Scientific and societal relevance

The research will combine theoretical and empirical knowledge about challenges around small-scale decentralized energy generation in Sierra Leone by making use of existing literature and case studies. The research is based on a systems analysis approach, which means not only the technical aspects are explored, but also institutional and socio-economic aspects are covered. The research tries to improve the long-term sustainability of two existing mini-grids and provide some socio-technical advice for a planned mini-grid in Sierra Leone. Based on the case studies some generalizations will be made in order to enhance the proper expanding mini-grids in Sierra Leone in a sustainable way. If long-term sustainability is better guaranteed, the willingness to invest for financiers could be increased.

1.4 Research question

Based on the above-described research objectives, the following research question is formulated:

How to achieve sustainable mini-grids in Sierra Leone that can give rural communities an affordable and reliable power supply?

Dividing up the research question in various sub-questions structures the way of answering the research question. The sub-questions are:

1. *What is the current energy situation of supply and demand in Sierra Leone?*
   This sub-question will introduce and shortly review the energy situation in Sierra Leone. It will give an overview of the present state of the art and future planning of the rural electricity sector in Sierra Leone. This will be done by reviewing the literature and conducting interviews
2. *Which social, technical, economic and institutional challenges are known about rural mini-grids in developing countries in order to make them sustainable?*
   Based on an extensive literature review the main characteristics of mini-grids, as well as the success and failure commonalities, are explored. The outcome is an assessment framework that can be used to assess mini-grids in Sierra Leone. The framework is described in 1.5.2.
3. *Which are the challenges of the small-scale energy system in Sierra Leone?*
   Based on the documentation, data research and interviews, the technical and institutional aspects of small energy systems in Sierra Leone will be explored. What is well arranged and what are the challenges in order to enhance the security of supply and robustness of the energy system in Sierra Leone? How can you ensure good alignment of both the supply and the demand? Which are the critical factors of the small-scale decentralized energy system in Sierra Leone? Who are the influential stakeholders and which interest do they have? The sub question can be answered by means of case study research.
4. *Which design requirements are needed for ensuring the robustness of mini-grids to enhance reliable energy access in Sierra Leone?*

To improve the knowledge about the energy system in Sierra Leone and to give some advice, some generalizations and lessons learnt from literature research and fieldwork in Sierra Leone are formulated to advise the future energy situation in Sierra Leone. As an example, the community of Sumbuya is taken as a test case.

1.5 Research methodology

In this section the used methodology for this research is described.

1.5.1 Literature research

The research starts with exploring relevant scientific literature and reports to find out the main concepts and challenges related to rural electrification projects and mini-grids. The literature review has marked social, technical, economic or financial, environmental and institutional sustainability factors that help to evaluate off-grid electricity projects in rural areas. Secondly, by means of documentation and literature, the context is described of the energy settings in Sub-Sahara Africa and Sierra Leone. It is important to know the country-specific characteristics of the electricity sector, the process of rural electrification and the similarities with other Sub-Saharan countries.

For this research, a lot of scientific articles and reports are used. In Table 3 Literature categories the used literature articles and report are listed. As categories are used: rural electrification, mini-grid (technical), mini-grid (socio-economic), mini-grid (institutional) and the situation in Sierra Leone. Some generic articles are placed in more than one category. The scientific articles are collected from the databases Science Direct, Google Scholar, Academia.edu. Keywords that were used for searching relevant papers are:

- Rural electrification AND Sub-Sahara Africa AND sustainability AND institutional OR technical OR socio-economic
- Mini-grid OR microgrid AND challenges AND barriers AND sustainability AND institutional OR technical OR socio-economic
- Mini-grid OR off-grid systems AND feasibility AND economic viability
- Electrification AND off-grid AND framework
- Socio-economic OR Socio-institutional OR AND approach AND mini-grid

The reports were collected from personal correspondence, Google Scholar and the internet. They have lower academic standards but are based on years of experience and provide useful information.

	Scientific literature	**Reports**
Rural electrification	[9], [10], [12], [14], [16], [17], [19], [22] [24], [56], [57], [63], [81], [84]	[18], [30], [61], [93], [95], [96]
Mini-grid (technical)	[4], [11], [15], [25], [38], [54], [97]	[47], [71], [79]
Mini-grid (socio-economic)	[2], [9], [15], [21], [25], [48], [70], [75]	[51], [59], [62], [82], [83], [92]
Mini-grid (institutional)	[3], [10], [20], [52], [86]	[46], [49], [66]
Situation Sierra Leone	[39]	[13], [34]–[37], [42], [44], [50], [91]

Table 3 Literature categories

1.5.2 Framework

The outcome of this literature study is a framework and scoring methodology to evaluate mini-grids (Table 4 Assessment table). The framework looks at four dimensions: social, technological, economic and institutional. In other studies, other categorizations are used (policy or institutional and financial or economic), but in these categories are covered by the dimensons mentioned above. Only the 'environmental' aspect is neglected in this study, because of the limited time and scope of the research.

- **Social:** The social dimension involves key variables as community engagement, ownership and benefits & acceptability of the mini-grid in the community. If the mini-grid can facilitate public services, like hospitals and radio station, the mini-grid empower the social development in the area. Nevertheless, the social dimension is complicated, because it is dependent on other factors, such as other development projects (25).
- **Technical:** Many mini-grids failed, because of the poor technical performance. This poor performance was caused by low-quality products, lack of qualified technicians, poor monitoring or a design mismatch between demand and supply.
- **Economic:** Economic viability is essential for a sustainable mini-grid on the long term. It is important that the financial return from the customers should be cover the operational and maintenance costs. Electricity tariffs can create incentives to use electricity. The local socio-economic characteristics, the available subsidies and micro-credit facilities also determine the economic sustainability.
- **Institutional:** Institutional embeddedness is important for a smooth development of mini-grid. On national scale the rules, responsibilities and regulations should be clearly defined. On local scale the management should be qualified to manage the mini-grid technical and organizational properly.

Each dimension consists of a set of indicators, grouped by some key variables. The 34 indicators are mainly based on work of Akinyele (26), Ahlberg (3), Buchholz (27), Ilskog (25), Katre (28), Mainali (29) and several personal conversations [SX]. In the third column of Table 4 Assessment tablethe primary sources are reported of the indicators. The framework tries to reflect all aspects that affect the socio-technical dynamics of mini-grids. The conversations with expert people are also used to check and validate the usefulness of the indicators, based on their practical experiences and academic knowledge [S3],[S7],[S9],[S24],[S31]. This is necessary to ensure the effectiveness of the indicators, since the indicators have a direct influence on the validity of the final assessment scores of mini-grids.

The indicators are assessed at a scale of 5 steps between 0 and 1. If the indicator is met in the case study, one point is given, if the indicator is not, a zero is given. 0.25, 0.5 or 0.75 will be awarded if the indicator has a low, medium or high level of achievement. The higher the score of the sustainability aspect, the more the aspect is contributing to the long-term sustainability of the mini-grid. The lower the score, the more attention is required. The scores of all indicators are used to determine the average of the different dimensions. In appendix 10.2 more explanation is given about the awarding of the scores. Also the scores are discussed with the people mentioned above.

It is important to mention that the framework has no weighting factors. Although the indicators have different importance, the framework has more a checklist character than final score of the different mini-grids. It rather expresses the level of closeness or disparities in performance level than exact differences.

Social	*Community involvement*	Community education Support of local leaders and politicians Share of population with electricity access Training and employment of local people	[S3],[25],[64] [26,][S4] [25] [26],[64]
	Ownership	Suitability ownership model	[4],[29]
	Benefits & Acceptability	Allocation of electricity between customers Awareness about connection and consumption Availability of streetlights Ability to pay for electricity services Electricity access public facilities (schools, clinics, etc)	[27], [S34] [28],[S31] [25] [S11],[25] [25],[29]
SCORE			
Technological	*Monitoring & management*	Metering system mini-grid Managing of electricity consumption Match of technical design with demand pattern	[S35],[29] [28],[S13] [10],[S31]
	Reliability & efficiency	Availability and utilization of services System efficiency	[25],[29] [25],[29],[S13],[S24]
	Operation & maintenance	Availability equipment and spare parts in the country Dependency on foreign assistance Quality equipment and materials	[25] [28] [10],[25]
	Modularity	Compatibility with future grid integration Adaptability and expandability	[10],[25] [S10]
SCORE			
Economical	*Costs and investments*	Financial support government Operation and maintenance costs	[26] [25],[29],[S35]
	Productive use	Industrial/commercial customers with productive use Anchor client connections	[25],[29] [25],[29]
	Financial	Non-payments or outstanding payments Tariff lag Micro-credit facilities	[S10],[S12] [S6] [25],[26],[27]
SCORE			
Policy / institutional	*Regulations*	National regulation on tariff setting and licensees Tax breaks on imported (spare) parts	[10],[25],[S10] [25]
	Organization	Capability of staff Long-term vision company Defining of responsibilities between stakeholders	[24],[27] [S1] [10],[25]
	Enforcement & Security	Enforcement of local policy Security of electricity infrastructure	[S10] [S4]
SCORE			

Table 4 Assessment table

1.5.3 Interview and stakeholders

The framework with 34 indicators has been developed to describe, assess and evaluate two mini-grids in Sierra Leone. The sustainability dimensions help to describe the mini-grids in a systematic way, capture observations and provide a summary of the evaluations. Data were collected from a range of sources, using semi-structured interviews and discussions with stakeholders, recording data from energy meters, administration books and field observations. In Table 5 Data categories the different categories with collected data are showed with the related stakeholders. Especially PowerNed and WHH provide useful information about the performance and the results of their mini-grids. The researcher had the possibility to inspect and observe the local situation of the mini-grid. Technical details are gathered by system inspection, observations, report and interviews.

For interviews and discussions an interview protocol is used. This protocol provides guidelines for the conversations. The questions are dependent on the objective of the interview, the specific knowledge of the interviewee and during the interview some other interesting insights might appear. The interview and discussions were held in English or a local language and translated by local staff. In appendix 10.4 the interview protocol and a list with approached stakeholders is shown. The list consists of a broad range of stakeholders: local community people, NGO related staff, technical experts, institutional experts, practical or academic oriented people. There has been some limited contact with the government, especially with the Energy and Water Regulation Committee. Contact with the ministries was difficult, because they communicate slowly and require a fee for providing documents. A reference to an interview or meeting can be recognized by an S between the brackets (for example [S1] is referring to the conversation with Hartlieb Euler, director of GIZ in Sierra Leone.

Besides the data obtained from the literature, some other data is needed for the research. Below a table listed the categories, the means by which the information is gathered and possible sources.

Categories	Information gathering by	Stakeholders
• **Sierra Leone**	Literature review, expert interviews, documentation	NGO's, Ministry of Energy, GIZ, databases
• **Yele**	Interviews, site observations, data collection, system inspection	PowerNed, Energy for Impact, local people, Research done by Casper Swinkels
• **Segbwema**	Interviews, site observations, data collection, system inspection	EnDev, local people, WHH
• **Sumbuya**	Interviews, site survey	Witteveen+Bos, Tropical Limited, Riverblade, local people

Table 5 Data categories

1.5.4 Case studies

The interviews and observations are part of a so-called case study research. The case studies provide the possibility to collect empirical evidence from the field and the local people, help to understand problems, issues or perceptions and to make meaning of them (30). The World Bank [26, p. 3] defines a case study as

> *"Case study as an evaluation method is a means of learning about a complex instance, based on a comprehensive understanding of that instance obtained through extensive description and analysis of that instance taken as a whole and in its context".*

In Yele and Segbwema, a **descriptive and evaluative study** is conducted to provide in-depth descriptions and in-depth understandings of the specific complex situation of mini-grid. For both mini-grids the developed framework, data, existing reports and interviews have been used. For Yele, it was possible to analyse the mini-grid in an participatory and empirical way, because of a long-term stay in Yele. Underlying processes and principles can be detected by participation in the community. Based on the evaluation of the currently decentralised mini-grids by means of the assessment framework, the main critical factors of decentralized small-scale hydropower systems are identified. These findings are compared with common factors of success and failure found in the literature. The main goal is to come up with some recommendations on how to achieve a sustainable, donor independent mini-grid in the future.

These lessons learnt are compared with a situation without a mini-grid, but that has the potential to develop a mini-grid. In Sumbuya there are plans to develop a mini-grid. A design-oriented (prescriptive) case study is used to describe the future energy situation supplying both the large firm of Sierra Tropical and the community of Sumbuya. The work done in Segbwema and Yele should be the input for this design.

The cases studies help to expand knowledge about the problems decentralized energy systems are confronted with. From that point, some generalizations will be made to discuss the future energy system of Sierra Leone and how these mini-grids affect this. The case studies in Segbwema, Yele and Sumbuya are placed in the context of decentralized electricity systems in Sierra Leone.

1.5.5 Research flow diagram

Below the research flow diagram is presented. The first row represents the different parts of the research, which are discussed in the second row. The third row shows the deliverables and the fourth row mentions the method that will be used to produce them.

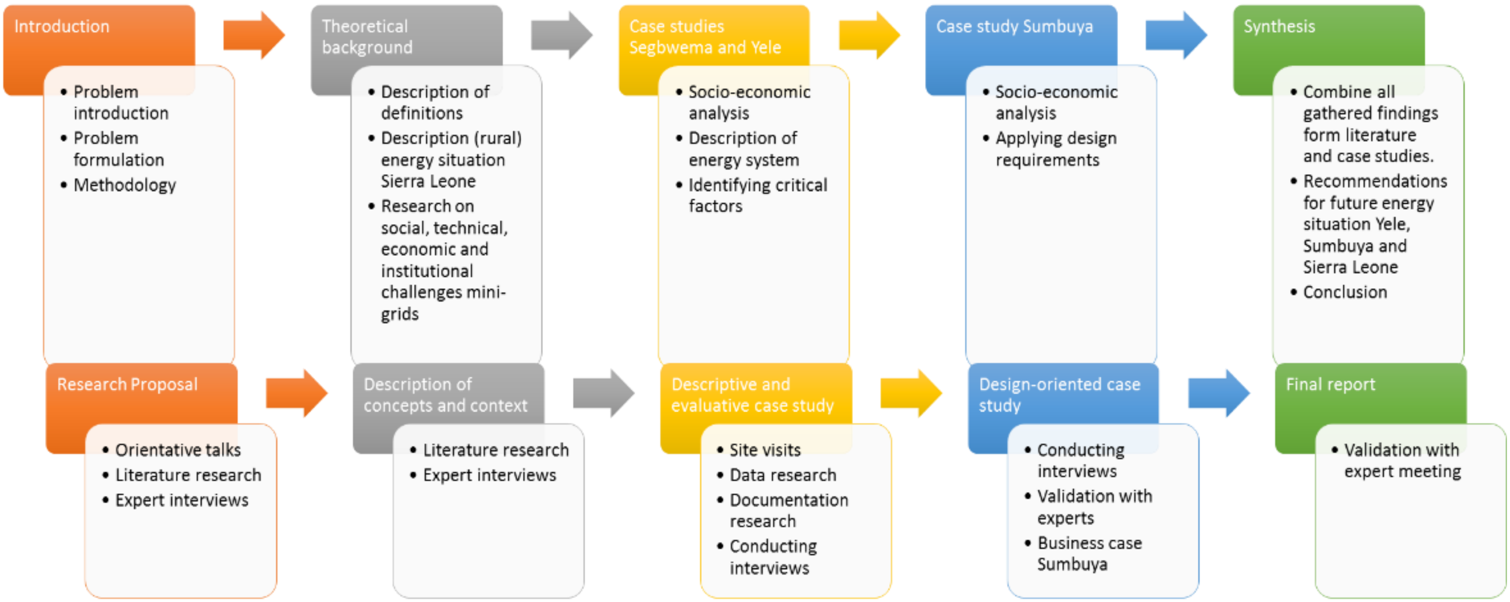


Figure 2 Research flow diagram

1.6 Reading guide

In **chapter 2** the energy situation and (rural) electrification plans of Sierra Leone are described as well as responsible institutions. The main elements of sustainable mini-grids are described in **chapter 3** by means of four sustainability aspects. **Chapter 4** introduces the current situation and related challenges of mini-grids in Sierra Leone in general, while **chapter 5** shows the results of evaluative case studies which have been done in Yele and Segbwema. **Chapter 6** lists the lessons learnt of the case studies and literature research, which are applied in **chapter 7** for recommending the future electricity situation in Sumbuya area. In **chapter 8** a discussion of the research, conclusions and recommendations for future research can be found.

2 Energy access in Sierra Leone

2.1 Electricity access in Sub Saharan Africa

Sub-Saharan Africa (SSA) accommodates about 14% of the world population and 70% of these 590 million people have no access to affordable and reliable energy services (32). Although the continent is rich in energy resources, the electrification rate is low. Due to population growth, the absolute increase in electricity access will be smoothed out and the International Energy Agency (IEA) expects the number of people without access to electricity will be in 2030 similar to the present day. In urban areas in SSA, the connection percentage (2018) is around 70% and in the rural areas nearly 20%, while approximately 80% of the population without a connection is situated in these rural areas (33). Besides a low electrification rate, also the energy consumption per household is low. Those households in urban areas that have access to electricity consume on average 200-300 kWh per year, compared to almost 1600 kWh for urban households in the European Union (34). In contrast, rural consumption rates of 50 to 100 kWh per year are even lower than in urban areas. From the total consumption rate, about 27% is used for residential consumption. The industrial sector, especially mining and refining activities, requires about 50% of the total energy consumption in SSA.

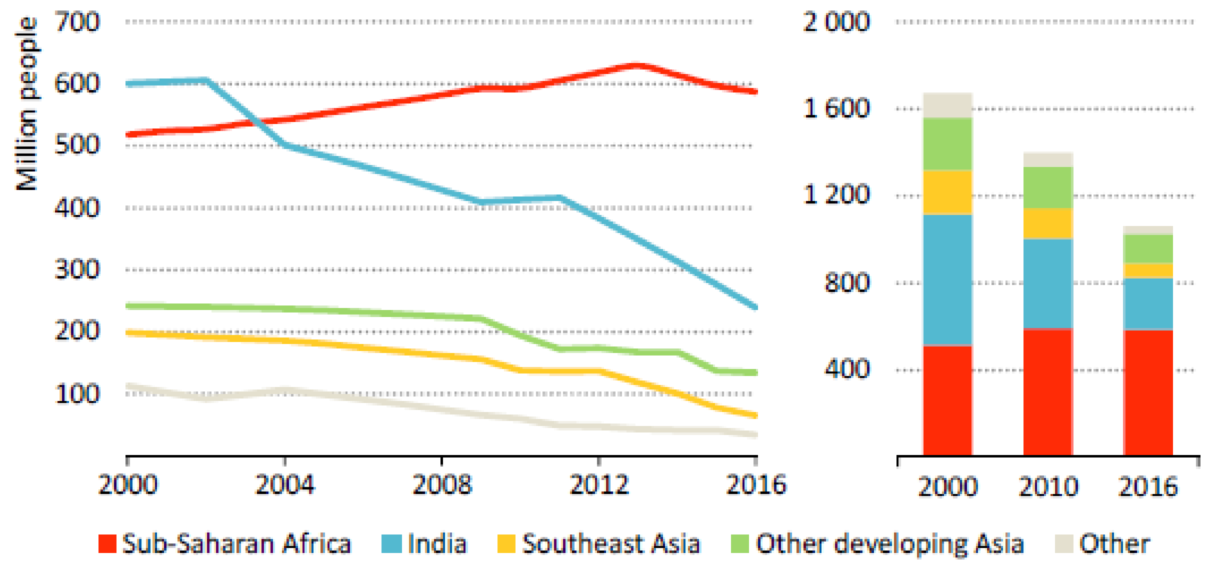


Figure 3 Population without access to electricity by region (32)

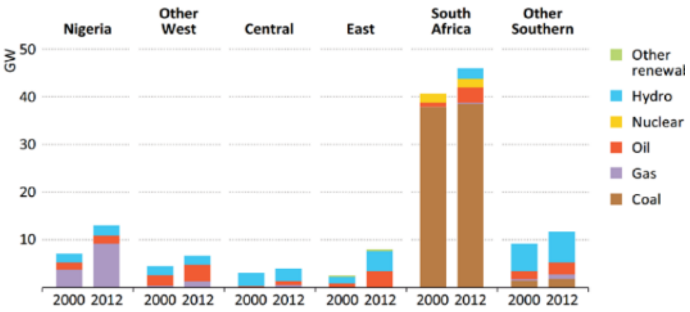


Figure 4 Generation capacity per region in SSA

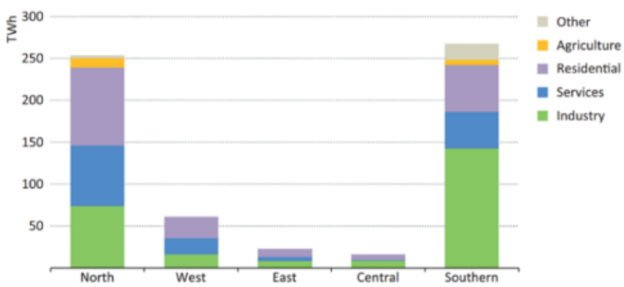


Figure 5 Electricity consumption by region (32)

The electrification rate in rural areas is lower, because utilities are focussing more on urban and sub-urban areas, which are located close to the central grid [3]. Electrification of the rural areas is required to stimulate social and economic development. Access to electricity in rural areas creates the ability to start industrial and income generating activities [66].

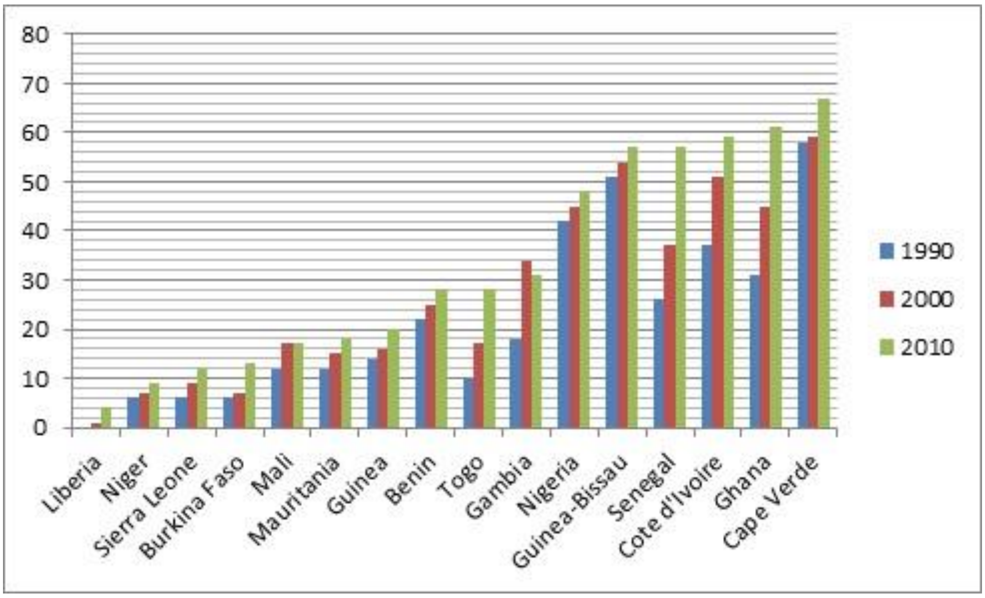


Figure 6 Electricity access in West-African countries (35)

In the last decade some countries, for example, Kenya, Ghana, Tanzania, Ethiopia and Rwanda, have made progress in expanding electricity access to the rural areas using national electrification schemes and rural energy projects. New hydropower plants and related grid expansion give people particularly in urban and semi-urban areas access to power. Also, a remarkable growth of renewable off-grid systems has been shown last years. The falling costs of solar photovoltaics (PV) panels and batteries, increasing interest of private investors for off-grid energy systems, growing familiarity and economies of scale promote the installation of more off-grid systems in SSA. Through a stable investment climate, East Africa has a higher growth rate compared to West and Central Africa (33). These off-grid systems, that will be more discussed on in chapter 3, offer a solution to increase the electrification rate in rural areas. Nevertheless, the installation and operation of these systems face a number of technical, economic and institutional.

2.2 The energy sector

2.2.1 Country description

Sierra Leone is one of the smaller countries of West-Africa with a land area of 72.000 km^2. The population is approximately 7,5 million and with a rate of natural increase of 2,13% per year, the expected population in 2030 is 9,7 million people. The country has been divided into four provinces, 14 districts and 149 chiefdoms. The capital city of Freetown is the largest city with approximately 1.25 million people. Approximately 60% of the population is still living in rural areas. Sierra Leone is a constitutional parliamentary republic, with a president as head of both the state and the government. The parliament or the House of Representatives has 124 members, 112 members can be elected every five years and 12 members are Paramount chiefs, chosen by the different rural chiefdoms.

Figure 7 Sierra Leone's state symbol

The bloody civil war (1991-2002) disrupted a lot of the country's economic and social settings. According to the United Nations Human Development Index (HDI), Sierra Leone is a Least Developed

Country (LDC)[1], with an estimated Gross National Income per capita of US$ 500 and 60% of the people are living below the national poverty line (36). The youth unemployment rate is high, and the country is suffering from corruption. The life expectancy is 52,9 years, and Sierra Leone has one of the highest infant mortality rates in the world. While it has substantial mineral (diamonds, iron ore, gold, rutile), agricultural (cocoa, palm oil, sugar), and fishery resources, poor governance and high investment risks hamper the socio-economic development. The country received support from NGOs and donor agencies to improve the deplorable situation of basic facilities like electricity, drinking water, health care and education. The United Nations Development Programme (UNDP), the World Bank, IMF and the UK Department for International Development (DFID) are main partners in the development of the country.

General information Sierra Leone

Population (2018)	7,557 mln.
Area (2018)	71.740 km^2
GDP per capita (2017)	$ 500
Capital city	Freetown
Ethnic groups	Temne 35,5%, Mende 33,2%, Limba 6,4%, Kono 4,4%, Fullah 3,4%, Loko 2,9%, Koranko 2,8 %, Krio 1,2%, Others, 10,2%
Languages	English (official), Krio, Mende, Temne

Figure 8 Map and factsheet Sierra Leone

[1] 181 out of 188 countries

Figure 9 Temperature and precipitation curve [13]

The country has a tropical climate with a dry season (December-May) and rainy season (June-November). The average annual rainfall is 2700 - 3600 mm/year. Due to the relative closeness to the equator, the daytime variations are 1 hour. The temperature ranges between 28-35°C and the humidity is during the rainy season very high, about 80%.

2.2.2 General description of the current energy situation

About 80% of the energy consumption in Sierra Leone are from biomass sources. Wood and charcoal are used as biomass generation source for cooking and craft activities. Imported kerosene forms the second largest energy source, while it is used for many purposes (lighting, cookstove, etc.). While the coverage of the national grid is low, most industrial companies use hydrocarbons for the electricity supply.

The national electrification rate of Sierra Leone was just 13% in 2016 (37); the estimates range between 11,7 and 22% (35,38,39). But the sources of electrification are different (Figure 10). The grid-access rates were 11-35% for urban areas and 2-3% for rural areas (35,39,40). The largest four cities (Freetown, Makeni, Bo, Kenema) consume near 90% of the available power production. Sierra Leone struggles with a large imbalance between the insufficient power supply and the growing demand, which results in a mismatch in the country. At this moment the total operational power production lies at around 170 MW, while the demand is estimated to be over 250 MW [S38].

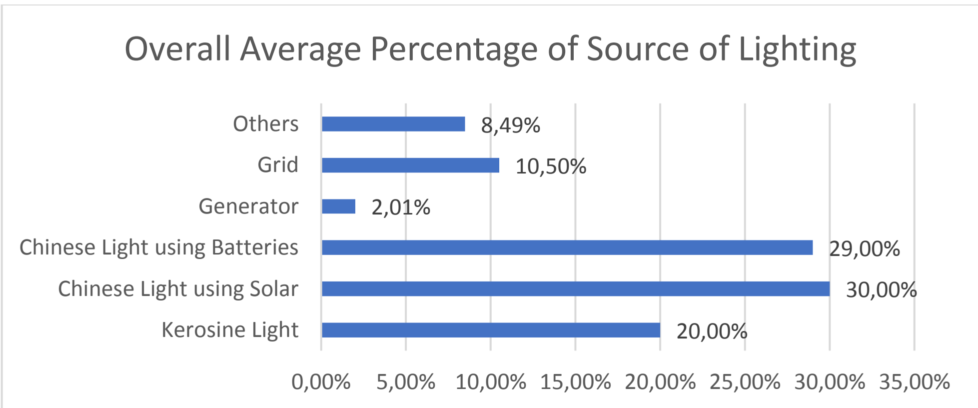


Figure 10 Lighting in Sierra Leone (41)

Moreover, a rapidly increasing demand of about 10-20% a year is expected coming decade (39). The power supply is affected by the seasonal pattern, due to the water scarcity during the dry seasons for generating hydropower. The operational capacity of the Bumbuna plant is less than 40% during the dry season, leading to frequent power blackouts (42). Due to the lack of a stable power supply, heavy fuel oil generating plants are required to manage the intermittent power supply (38). Diesel generators are required for the mining sector to meet its large power demand.

Location	Source	Capacity (MW)	Operational
Bumbuna	Hydro (reservoir)	50	Yes
Bhanka Soka/Port Loko	Hydro (run of river)	2	Yes
Charlotte Falls	Hydro (run of river)	2.2	Yes
Dodo/Goma	Hydro (run of river)	6	Yes
King Tom	Thermal (diesel)	10	Yes
Blackhall Road	Thermal (diesel)	16,5	Yes
Port Loko Thermal	Heavy oil fuel	30	Yes
Karadeniz Power Ship	Diesel	30 (total capacity 126)	Yes, at least until 2023
Lungi	Thermal	6	Yes
BKPS	Thermal	10,8	Yes
Kono	Thermal	2	Yes
Lunsar	Thermal	1	Yes
Makeni Addax	Biomass	15	Yes, low availability
Total capacity		**182,5**	

Table 6 Available power plants Sierra Leone (>1 MW) (Sources: (35,39))

Less than 14% of the population was connected to the central grid in 2017 (35). The central grid consists only of a 161kV transmission line with a length of 250 km that supplies Freetown, the Western Area, Makeni and Magburaka. The cities of Bo and Kenema are connected to a 33kV line, that is supplied by the Dodo hydropower plant. From the electricity supplied by the central grid, 60% is used for industrial and commercial purposes and 38% by households (35,43). The cost and technical losses of transmitting and distributing electricity to rural areas, the poor infrastructure and low demand rates make it more attractive for energy utilities to focus on urban areas. Urban customers are more reliable and higher electricity consuming customers. The remoteness of the rural areas makes it hard to maintain and monitor the network. Nevertheless, for urban areas, the efficiency and access rate are constrained by the low stock of energy-efficient appliances. Besides the low connectivity, the reliability of the network is very poor. Frequent brownouts, blackouts and load discharges are common in the country. Unreliable service levels lead to households that are disconnected several times.

The electricity tariffs of 18,76 USD/kWh of EDSA are relatively expensive for rural customers. People in rural communities have small financial resources and a seasonal-fluctuated income flow (40). This results quite often in a low energy consumption and a low willingness to pay of the customers. The low electricity consumption rate makes the service costs for operators higher for these customers.

Renewable energy

The country has a large potential for renewable energy, but very low levels of utilization. The potential hydropower capacity is between 1200-1600 MW, that can be produced by large hydropower plants, but also by mini-hydropower plants that are more suitable for off-grid areas (44). The solar radiation in Sierra Leone is estimated between 1460 kWh/m² and 2100 kWh/m², which made the market for small solar systems and plants attractive. (45). Last decade many solar street lights, systems and plants have been installed, but the import of spare parts seems difficult.

Figure 11 Bumbuna hydro plant and Karadeniz power ship

A large agricultural sector creates the potential for biomass generated power. Waste from palm oil, cassava, sugar cane or rice husks can be used to produce biodiesel or bioethanol. Nevertheless, Addax Bioenergy failed as the first massive bio-ethanol plant in the country. This plant, that has been constructed to generate 32 MW and 90,000 m^3 bio-ethanol, has been taken over by Sunbird after several years of underproduction and costs exceedances. At this moment the plant has a maximum generation capacity of 15 MW.

2.2.3 Organization of energy sector Sierra Leone

The Ministry of Energy (MoE) is the governmental institute that has the mandate to make policies and regulations about all type of energy issues. The National Electricity Act (NEA) and the Sierra Leone Electricity and Water Regulatory Commission Act (EWRCA) are the main formal laws that regulate and coordinate the development of the energy sector in Sierra Leone. Both acts are signed in 2011, but effective from 2015. The National Renewable Energy Policy (2015) and the National Energy Efficiency Policy (2015) support the increase of renewable energy technologies and the increase of the efficiency within the energy sector (43).

In the past, the energy sector was regulated by the monopolistic and vertically integrated state company National Power Authority (NPA). The National Electricity Act unbundled the different activities of the power supply chain in order to liberalize the generation, transmission, distribution and sale chain blocks. Now different bodies are responsible for the power supply:

- The **Electricity Generation and Transmission Company** (EGTC) is responsible for the generation and transmission of electricity to the grid. The generated power is sold to EDSA by means of power purchase agreements. EGTC is also responsible for the expansion of the country's generation and transmission capacity. Public/private partnerships with Independent Power Producers and other investors are used to decrease the power shortage and lack of transmission lines (38).
- The **Electricity Distribution and Supply Authority** (EDSA) is responsible for distributing and sales of the electricity. They are responsible for the maintenance and expansion of the distribution grid, except in areas that are issued out to licensed private companies or communities. In urban settlements, EDSA sells the electricity that is generated by EGTC or Independent Power Producers (IPPs).
- The EWRC Act constitutes the **Electricity and Water Regulatory Commission**, that monitors the energy market, licenses energy contracts, sets the tariffs, ensures the market competition and regulates the electricity sales to customers. Each utility or (private) company that own a power facility must apply for a license from the Electricity and Water Regulatory Commission.

In Figure 12 Institutions energy sector Sierra Leone the main actors are shown. Private Fuel Supply Companies supply EGTC and IPPs the fuel they need for generating power. The EGTC is also responsible for the transmission, but a System Operator controls the balance on the grid. The EDSA distributes the power to the customers and manages the sales. Only eligible customers have the possibility to be supplied directly by IPPs or the EGTC. In the figure also the CLSG Transco is shown, which is the planned 1357 km transmission line between Ivory Coast, Liberia, Sierra Leone, Guinea. It connects the national networks with each other. These countries work together to exchange the intermittent power. A regional Regulator (ERERA) will be responsible for monitoring and control (46).

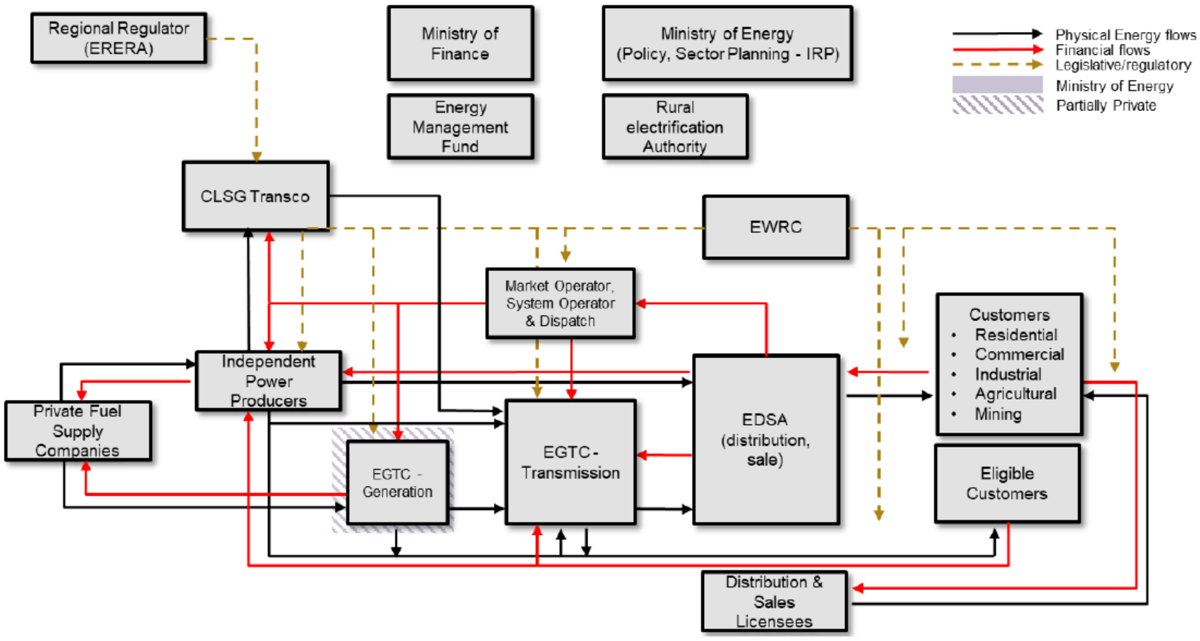


Figure 12 Institutions energy sector Sierra Leone (47)

2.2.4 Power to All

In the Electricity Sector Reform Roadmap (2017-2030) the Ministry of Energy stated that they will reform and expand their energy sector and electricity network in order to give more people access to power. The Electricity Sector Reform Roadmap is the result of the Energy Revolution initiative in 2016 that set targets for households' access to electricity. At this moment the installed generation capacity is far below the required load demand, the systems have enormous system losses and the inadequate generation mix resulted in a lack of reserve capacity. The MoE wants to connect all district headquarter towns in 2030 and increase the total installed capacity up to 1229 MW in 2030. The new NEA acknowledges electricity supply as a standalone activity. That creates an environment where utilities can supply power through off-grid systems, but also for awarding distribution licenses to private parties or concessionaires. Independent Power Producers (IPP) will be attracted to expand the power generation and to maintain the grid. These grids could be transferred in the future as assets to EGTC or EDSA [S3].

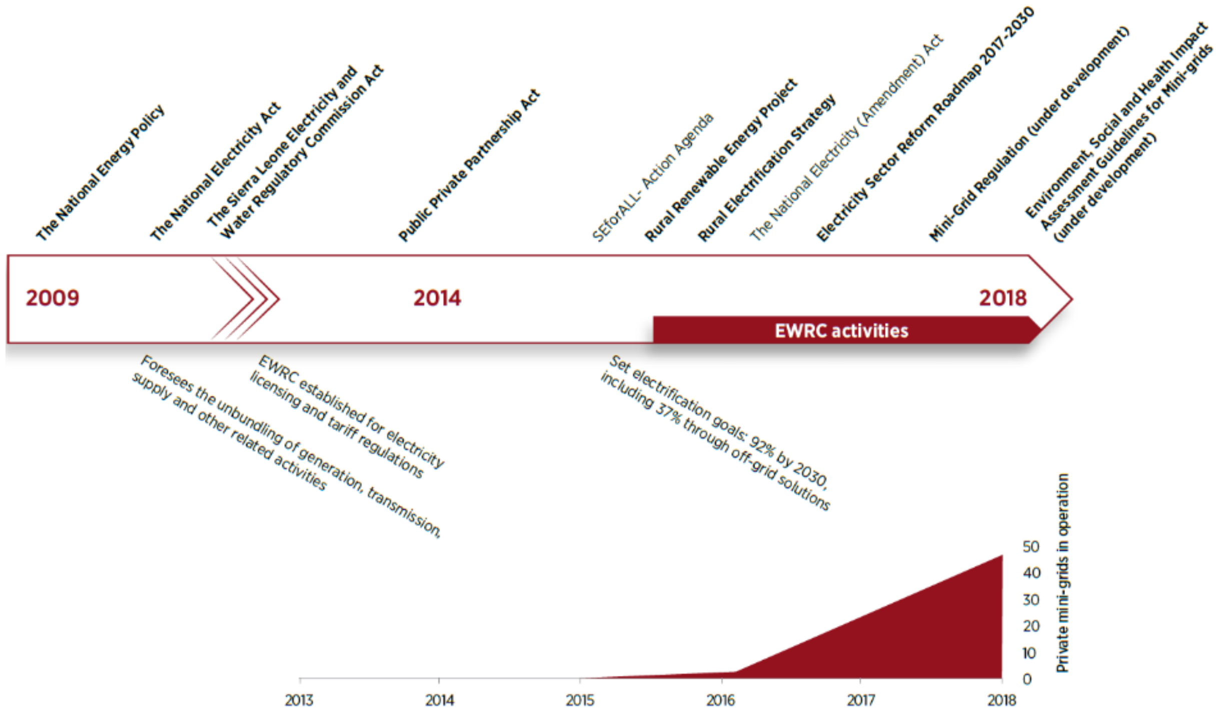


Table 7 Timeline of mini-grid regulation (48)

The MoE is also working on a feed-in tariffs policy that promotes the use of specific technologies and different capacity rates. To achieve alignment between the different technologies the EWRC set technical criteria and standards of performance for different part of the supply chain (generation, transmission, distribution, sales).

The Renewable Energy Policy that has been signed in 2016, promotes utilization of country's available renewable resources. Therefore, Sierra Leone is attracting private companies that have expertise and experience in renewable energy technology in Sierra Leone. The Renewable Energy Association of Sierra Leone (REASL), launched in 2016, serves as a knowledge platform for these business partners (43). The government promised to provide a framework for the investors and recommends action plans for implementation of feed-in tariffs, PPP mechanisms and tax benefits.

Rural electrification

To electrify the rural areas in Sierra Leone, some initiatives have been started past years. The governments of the United Kingdom and Sierra Leone signed the Energy Africa Policy Compact in 2016 to support the launching of solar-related technologies to reach 250.000 households, by means of solar home systems and solar mini-grids. The programme included also technical assistance and policy support to create demand and improve access to finance. The government has set the targets shown in Table 8 for the expansion of the electricity access, but until this moment there is no Rural Electrification Agency that has a special focus to monitor these targets.

	2010	2020	2030
Share of population served by electricity services (%)	8.6	44	92
Share of population connect to the grid (%)	8.2	30	55
Share of rural population served by renewable energy and hybrid mini-grids (%)	0.4	11	27
Share of rural population served by standalone renewable energy systems (%)	0.003	3	10
Number of RE/hybrid mini-grids	2	25	65

Table 8 Rural electrification targets [45]

The EWRC launched in 2017 a draft version of the Mini-grid Regulations. This document (that is waiting for approval by the parliament for two years now) provides regulation on licensing procedures, interconnection agreements and tariff settings. Mini-grids below a capacity of 100 kW, for instance, can sign a basic mini-grid licence. In basic licenses, the tariffs can be negotiated between the licensee and the customers. As regards to full licenses, the tariffs are set by the EWRC through a methodology in which many variables are included. An important aspect involves the arrival of the central grid. For basic licenses, mini-grid owners are required to decommission and remove their assets within two months without any compensation. In respect to full licenses, the contract can be replaced into an interconnect mini-grid contract. The company and the government need to work together to work out a new agreement (48),[S3].

Nevertheless, after changing of government in 2018 it has seemed that the new government gives less priority to the reforming of the energy sector. For example, although the former government installed already 8470 solar street lights, the new government stopped a further rollout of solar streetlights and in the past years a lot of street lights have been stolen. So, although the Ministry of Energy has the mandate to coordinate the Reform Roadmap, it is highly questionable if the goals will be achieved in 2030.

Initiative	Lead Organisation
Rural Renewable Energy Project	UNOPS, DFID, UK-Aid
Promoting Renewable Energy Services for Social Development project	WHH, EU
Renewable Energy Policy	MoE, EWRC

Table 9 Initiatives addressing mini-grids in Sierra Leone

NGO's, like UNOPS, UK Aid, WHH and GIZ work also together with the government in public-private partnerships. UNOPS and UK Aid are installing 50 smaller (6-36kW) mini-grids and 40 bigger (>36kW) mini-grids, located at health facilities (Rural Renewable Energy Project). Off-grid concessionaires will be assigned to each district to connect and take over the already developed grids by UNOPS and develop new mini-grids. Selecting only a single concessionaire at district level guarantees a uniform service level as well as electricity supply tariffs. WHH and GIZ installed 3 solar mini-grids (in Segbwema, Panguma and Gbinti), promote the sales of Solar Home Systems through local retailers, and installed about 100 Solar Home Systems for clinics, schools and charging centres (PRESSD-project). The final goal of the project is providing energy access to a minimum of 16000 households in Sierra Leone. The PRESSD-SL project has been funded by the European Union (75%) and a consortium of international NGO's [S4].

For mini-grids it is essential to work together with the Local Community Councils and their traditional leaders, the paramount chiefs. The paramount chief is head of a local chiefdom and is highly authorized by the local people. He is the final responsible for community development, resource mobilization and accountability at the community level. Land transactions and lease agreements cannot be signed without permission of the paramount chief. The Community Councils will be trained by the Ministry of Energy to adequately exercise being a contracting authority for concession the operation, maintenance and expansion of local electricity services. They are also trained to select the electricity technology that is most sustainable on long-term.

2.3 Challenges in the energy situation

At this moment the energy sector in Sierra Leone is dealing with several challenges in order to give more people access to power.

At first, there is a lack of private investors for developing the energy sector. Sierra Leone has been seen as economically and politically unstable for many years. Past years Sierra Leone has been considered more positively by international investors. Nevertheless, economic incentives and microfinance possibilities are limited.

Secondly, although the former government developed more regulation for power generation, licensing and concessions, the administrative procedures are bureaucratic and not clear. For example, qualified and certified solar products can be imported duty-free and without harbour fee, but in practice, it seems very difficult to attract this financial benefit.

Thirdly, the transmission and distribution infrastructure needs to be improved. The civil war disordered the energy infrastructure and some equipment is very outdated. Transport losses are immense, which result in low energy efficiencies. Many industrial companies use a diesel generator, also because of the poor service standards of EDSA (35).

Figure 13 Different options for rural electrification

2.4 Potential of mini-grids

To stimulate the electricity access in rural areas, there are basically three options to give access to electricity in rural areas.

- A first option is **extension of the national grid**, which can lower the electricity tariffs due to economies of scale. However, this option is for most remote, rural areas in Sierra Leone not feasible. Extending the transmission lines to these difficult accessible areas through poor infrastructures and geographic conditions, makes grid extension costly. Furthermore, these areas can usually be characterized by a small consumption and a limited ability to pay of households. Recovery of the investment costs is challenging. Next to financial reasons, a connection to the central grid in Sierra Leone does not guarantee a secure supply, while blackouts are common. Finally, the potential political support in peri-urban areas is larger, more organized and active than in rural areas. Focussing on electrification of peri-urban areas (instead of rural areas) is for politicians more attractive to gain political support (49).

- A second option are the **Homed-Based Systems** (see section 3.2). Dependent on the demand load and dispersion of the households, options that can be chosen are diesel generators, Pico Hydro Systems (PHS) or Solar Home Systems (SHS). There are no costs for the construction and maintenance of a distribution grid. However, the prices of these systems are for most people in Sierra Leone not affordable. Also if there is a possibility to hire or lease a SHS, which make the systems more affordable, there is no clear evidence how SHS or PHS address the poverty of households (50). In case these systems must generate electricity for income-generating activities, the small scale of SHS makes it less applicable and expensive.

- The third option are **mini-grids**: local generation source(s) with a small-scale distribution grid, eventually combined with a storage system. Mini-grid systems are suitable at places where the costs of grid extension or for Home-Based Systems are higher than mini-grid, as is illustrated by the area shaded in green in Figure 14 (51). These locations are quite often small villages with a high density of households per area. The mini-grid can supply enough power for domestic lighting, hospitals and productive use, such as milling and welding. To accelerate access to power in rural areas and stimulate the local socio-economic development, mini-grids are most preferable. Sierra Leone has a large potential for solar and hydro mini-grids. These renewable energy technologies have been more accessible, affordable and available in terms of price, efficiency and reliability. Nevertheless, mini-grids involve financial, technical and organizational challenges. In the next chapter, these factors will be addressed.

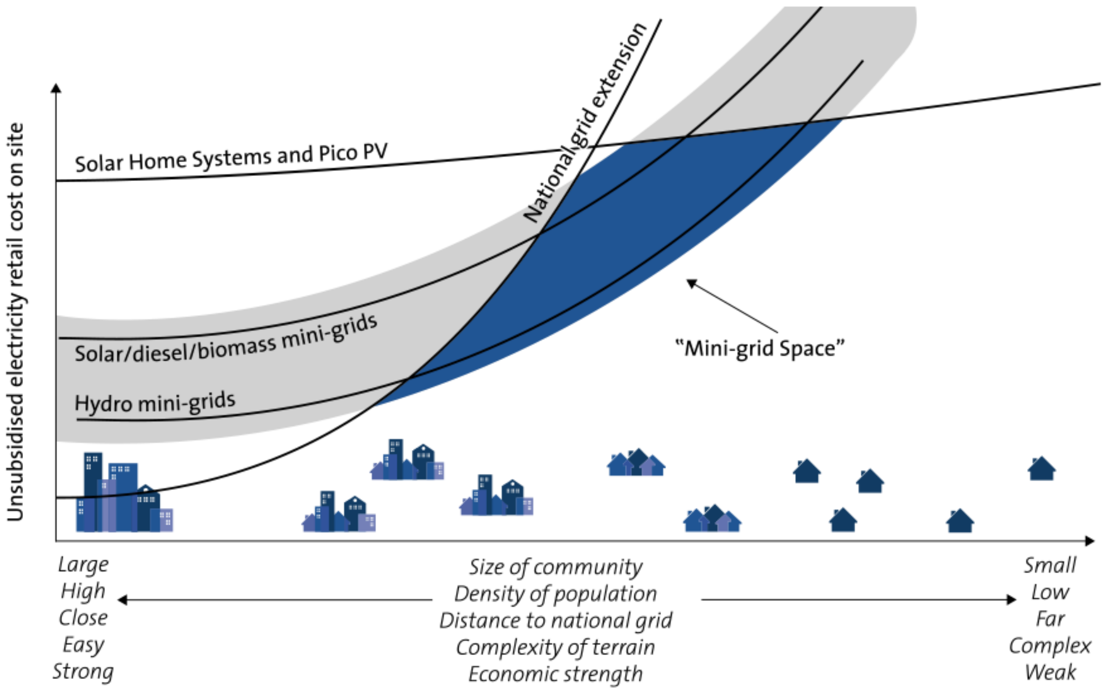


Figure 14 The mini-grid-'space' (52)

3 Mini-grids

Although decentralized power systems are used for ages, renewed interest for electricity projects in rural and remote areas in Sub-Saharan Africa, gives the sector a boost. Due to their smaller scale and decentralized approach, mini-grids can raise the reliability of power supply. In the beginning, the focus was only a purely technological approach, but nowadays an approach has been common that focusses on 'end users their needs and involvement, capacity building, markets, policies, financing and allocation of responsibilities' (49). To discuss these aspects, first, some definitions and characteristics are given.

3.1 Definition and scale of mini-grids

A mini-grid sometimes also called a micro-grid, island or isolated grid can be defined as a small electricity system with local (modular) generation source(s) with a distribution network. Mini-grids can operate autonomously without connection to the national transmission grid and supplies most often concentrated and isolated villages [9]. Energy storage systems can be integrated into mini-grids to store the generated power and to balance the system. Desmhmukh et.al. (11) define mini-grids as: 'one or more local power generation units supplying electricity to domestic, institutional, and commercial consumers over a local distribution grid'.

For Sub-Saharan Africa, the renewable generation sources of most off-grid systems are solar photovoltaics (PV), mini-hydro and biomass gasification [10]. Mini-hydro's are typically run-of-the-river plants and limited to areas with adequate river flows. In areas with a large agriculture industry, biomass-based generation could be an option. PV-systems are the most popular renewable based technology, but diesel- or kerosene-based system are most common, due to the low upfront cost and the widespread availability. Nevertheless, these grids are more pollutive and less cost-effective, due to their fuel utilization.

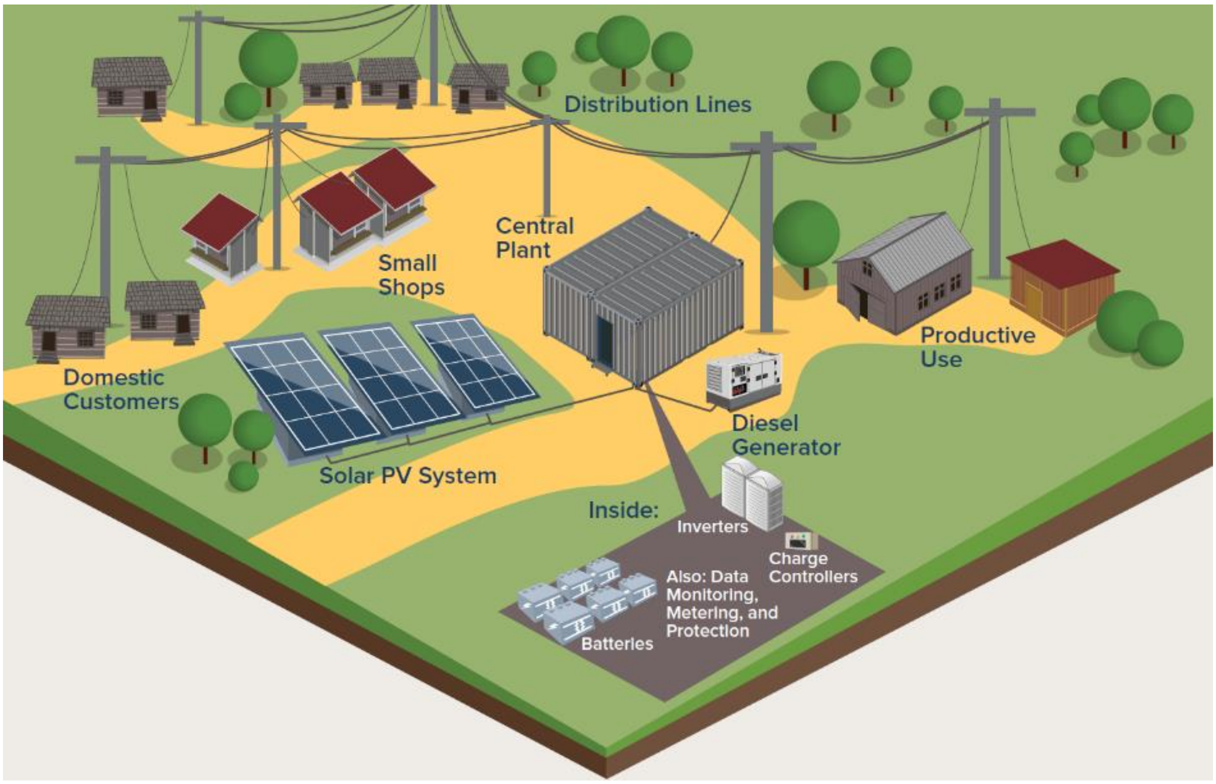


Figure 15 Example of a hybrid mini-grid (1)

In a review article Mandelli (5) classified the off-grid systems as in Table 10. Mandelli distinguishes mainly decentralised and distributed energy systems. The main difference between decentralized and distributed system is the number of energy sources. Decentralized energy has a single energy source, while the distributed system has at least two different kinds of energy sources, for example, a combination of hydro and solar. Decentralised systems can be stand-alone systems or mini-grid system, dependent on the number of consumers and the availability of a distribution system. Stand-alone systems do not have a distribution system and are mostly designed for individual customers or individual factories. There is no interconnection with other customers. These stand-alone systems are also known as Home-Based Systems or Productive-Based Systems. Home-Based systems are designed for customers with an average individual demand load of 10-100 Watt. Customers with a demand load smaller than 10 kW have only portable lights, in some literature listed as pico-solar systems. The technology of the systems varies from a basic solar battery system to a high-tech solar system for electricity and heating (5,53). A mini-grid distributes the power to households with an average energy consumption between 100 and 1000 Watt. Mini-grids require more planning and institutional context to be long-term sustainable.

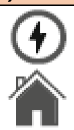
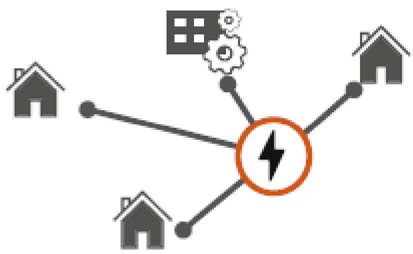
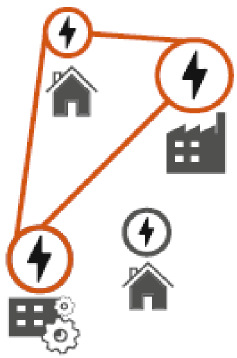
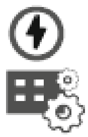
Off-grid systems Matrix	**Decentralized**		**Distributed**
Rural Energy uses	*Stand-alone Systems*	*Mini-grid Systems*	*Hybrid Mini-grid Systems*
Household basic needs	 Home-Based System	 Systems including a distribution grid	 Systems including a distribution grid
Productive uses	 Productive-Based System		
Consumer Number	Single	Multiple	Single OR Multiple
Energy Sources	Single		Multiple

Table 10 Off-grid system matrix [4]

The fact that distributed systems consist of two or more conversion unit results in a virtual power plant with two or more generation assets, for example a mini-hydropower, a PV system and a diesel generator. The generation assets are monitored with central control units that help to manage the system. They help to match demand and supply by receiving real-time data. Mandelli (5) refers to these systems as hybrid mini-grids, that like decentralized system distribute electricity to single or multiple consumers. Hybrid mini-grids have different advantages (5,54,55):

- More flexibility in planning and operation and the possibility for capacity expansion if the energy demand will grow.
- Better guaranteed security of supply.
- Better mitigation of intermittent power supply to increase reliability and load matching. They mix dispatchable power (diesel generator, biomass) with non-dispatchable power sources (solar power).
- As results of the previous point, the battery capacity can be lower, because during peak load a second generation source can deliver the required electricity.

Hybrid mini-grids generate 75-99% of their power by a renewable energy source, which lowers the energy prices. The remaining the power is mostly generated by a diesel generator. A diesel genset has also a function as a backup in times of a high demand load, a limited supply or maintenance hours of renewable energy source (49,54).

The IEA and World Bank use the scheme below, using tiers relating to the installed capacity and delivered service. Each tier has a specific demand and services, that can be supplied by a matching technology and scale.

Categories	kW	Tier	Services	Peak capacity		Duration	
				Power	Daily capacity	Hours per day	Hours per evening
Pico-grids	0-5 kW	Tier 1	Task light and phone charging	Min. 3 W	Min. 12 Wh	Min. 4 hours	Min. 1 hour
Micro-grids	5-15 kW	Tier 2	General lighting, radio and fan	Min. 50 W	Min. 200 Wh	Min. 4 hours	Min. 2 hours
Medium mini-grids	15-60 kW	Tier 3	Tier 2 and appliance like a fridge, grinder	Min. 200 W	Min. 1 kWh	Min. 8 hours	Min. 3 hours
Large mini-grids	60-350 kW	Tier 4	Tier 3 and appliances for productive use	Min. 800 W	Min. 3,4 kWh	Min. 16 hours	Min. 4 hours
PPA mini-grids	350 kW-10 MW	Tier 5	Tier 4 and high-power appliances	Min. 2 kW	Min. 8,2 kWh	Min. 23 hours	Min. 4 hours

Table 11 Multi-tier framework

3.2 Impacts of rural electrification

Rural electrification can help to increase many aspects of human and economic welfare in remote areas. Although the absence of electricity is not life-threatening, access to electricity affects individual lives, communities, and societies very strongly. Most governments are focussing on central grid extension to improve the national electricity access. In rural areas, a connection to the central grid is often not possible, because of the high investment costs due to long distances, sparse population densities and low consumption patterns (11). The long distances result in high transport losses and the high investment cost of transmission and distribution lines. Small-scale energy systems or mini-grids are a viable solution for electrifying these areas. The electricity is used nearby its generation and electricity losses are lower. Mini-grids are also able to support productive uses, such as telecommunications towers, irrigation pumping, agro-processing and refrigeration. Access to electric power by small-scale and off-grid plants can be an important driver for sustainable socio-economic development because it provides opportunities for new activities, business and services (56).

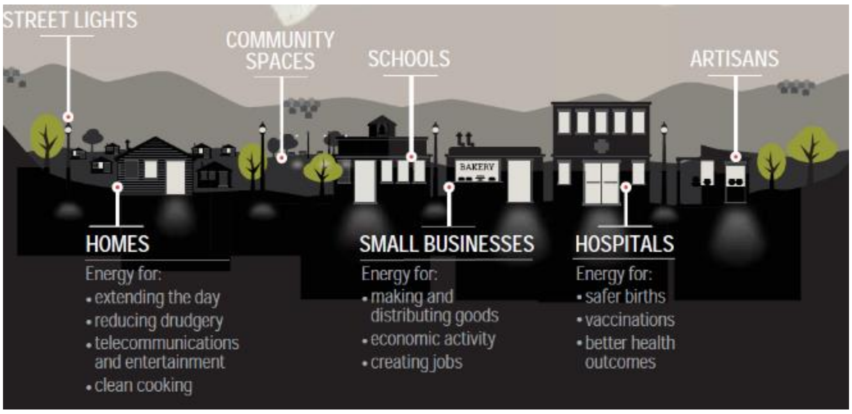


Figure 16 Energy access is the key for socio-economic development [48]

Rural areas are sparsely populated and are located in remote or isolated areas that are quite often difficult accessible due to poor road conditions (5,57). The poor infrastructure and long distances from larger towns resulted in a lower service level (health care, markets, water supply, etc.). Traders have to travel long distances to buy and sell their stuffs. The rural people are quite often underrepresented in governmental institutes and educated people (doctors, technicians, teachers, etc.) are less willing to work and live in rural areas with lower development levels and less qualified education facilities for their children (58). The people in the rural village are living mostly self-sufficient, and have small economic activities like farming, pastoralism, cattle raising, mining, fishing or forestry (59).

The social benefits of mini-grids in rural areas are significant (13,25,58,60,61). Good lighting and electricity supply can support study activities for students and business activities in the evening to decrease the high illiteracy levels. Electricity access gives the opportunity to charge and use mobile phones, radio's, televisions and in that way, it improves access to news, business information and distance education. Commercially, mini-grids support starting new businesses, like welding, charging stations, agro-processing factories, restaurants and sales of cool drinks. But also, public services for the community can be supported, like vaccine refrigeration, street lighting, water pumps and telecommunications towers. Important is that mini-grids do not initiate development, it can only stimulate development that is ongoing.

Different studies show that rural electrification can stimulate social and economic developments (15–18) but often fail. Energy supply in rural and poor communities with low load density is complex. The low load densities result in high cost for each unit of electricity, but it should be affordable for relatively poor customers. If electricity access is not affordable for most households, only households with higher incomes profit. Rural electrification seems more complex compared to urban electrification project (15). The system needs to be embedded in the community and multiple criteria that are linked to livelihoods have to be analysed in order to design proper electricity access (21,22). It has been proven that community-involvement in the decision-making process increases the positive social impact on the community. So, only elaborating technical designs would be not enough for robust and long-term sustainable energy systems (15). Rural electrification should be based on thorough socio-economic studies. For example, to optimize the connection rate, it is evidently necessary to determine the ability and the willingness to pay. The willingness to pay is 'the maximum amount that an individual indicates that he or she is willing to pay for a good or service' (62). It is important to know the willingness to pay to determine if a mini-grid is financially feasible in a community, i.e. whether the revenues can cover the costs of running of the mini-grid.

3.3 Challenges and barriers

Despite their promising social impacts, mini-grids in rural areas with low socio-economic standards pose technical, economic and institutional challenges. Underperformance and high failure rates are common. For example, the government of Malawi implemented six PV-hybrid mini-grids in 2004. However, financial and technical sustainability seemed not sufficient, participation with the community was limited, inadequate tariffs were set and low-quality materials and equipment were used (63). Various articles have been presented about critical factors for off-grid generation in rural Africa (13,23). Sometimes inappropriate installation of equipment or poor maintenance led to the failure of the mini-grid. But, more frequently failures are more a complex combination of technical, financial and governance aspects. Many off-grid-rural electrification grids in developing countries failed. The technical design was developed without interaction with the institutional and local context. For mini-grids it is essential to include the societal dynamics. Using a socio-technical approach can prevent this [S33]. In the sub-sections, the main social, technical, economic or financial and institutional or organizational aspects and challenges of mini-grids will be discussed.

3.3.1 Social challenges

3.3.1.1 Community participation

Most mini-grids that are successful, are characterized by a strong involvement of the local community (11,13,23). The community as end-users will use, pay for and assess the electricity system. Community participation from the initial phase until operation phase ensure the long-term sustainability, while the system depends on consumers' satisfaction and behaviour (18). The community must welcome the mini-grid, because imposed solutions (with good intentions) result in dissatisfaction and will lower the number of customers (49). Also, during operation monitoring customers' satisfaction is important. Unreliable power supply or unfair allocation of power capacity could result in a lower willingness to pay and lower satisfaction. Community participation creates awareness of critical operational aspects and shared responsibility of the electricity system. In other words, participatory approaches can increase the robustness and resilience of the grid. The awareness and responsibility can be facilitated by regular meeting with community and the community elders, promotional programs and clear communication and information (13,64). The sustainability will increase if local people are trained as technicians, this decreases the dependency on technicians from the capital city or foreign countries. It creates also new jobs and a sense of ownership within the community (26), [S3]. The mini-grid can promote the social sustainability by placing streetlights and prioritize electricity connection of public facilities. The people benefit from the availability of the mini-grid.

Educating people on basic elements and the usage of an electricity system is very useful. This can, for example, be done by radio shows, community meetings or school programs. IRENA mentions several reasons why community participation is essential for successful mini-grids and can mitigate the following failures (48):

- Poorly sized system: without a thorough understanding and estimation of the expected load demand and the ability to pay, there is an increased risk of under- and overdimensioned grids. If customers install new machinery, communication is important to adapt to the system design.

- Insufficient savings: if the tariffs are too low, covering the running costs and maintenance is difficult. Consumers' ability and willingness to pay are not clearly defined.
- Load curtailment conflicts: in case of supply constraints during dry seasons, load rationales without community discussions can result in local conflicts.
- Insufficient revenue: Ineffective enforcement leads to underpayment or theft. Problems are also related to funding that dries up.

Stronger reliance on community participation in planning and management can mitigate these challenges (65). Receiving information from the community leads to a better and more adequate design of the grid (66). It helps to anticipate future population growth and an increasing number of connections. Community participation also helps to reduce local conflicts. These conflicts can emerge from payment issues or fraud. Sometimes politically or economically powerful customers pressure the mini-grid staff to bend the rules for special benefits, which can result in a stalemate or conflict in the community (49,67). Or established counterproductive use of electricity behaviour, such as wrong phase-connections, can be restricted. With respect to community participation, it is important to respect the local organizational structures and traditions. As regards to structures, adopting and enforcing local norms and regulations is important. In SSA countries the traditional leaders or chiefs have a very significant role in the community, both in the decision-making process as well as the local public opinion. Working together with the local chief and community councils can increase the acceptance and helps to gain priceless information for the planning, design and operation of the mini-grid. Especially in an oral culture, communications and a good relationship with the leaders of the community support the social sustainability of a mini-grid (4).

3.3.1.2 Ownership

Investors set sometimes also community participation as a prerequisite for funding. Community participation is not only essential for community-owned mini-grids. Mini-grids owned by utilities or the private sector profit also from community participation. Ownership determines the responsibility for the implementation and the operation and management of the mini-grid. In literature the following ownership-models are most commonly used:

- Community-based model: the mini-grid is owned by the community, whose responsibility also involves the operation, monitoring, tariff collection and maintenance of the system.
- Private sector operator: Private actor run a mini-grid, while after some time the mini-grid is handed over to other actors.
- Utility-based approach: (National) utility companies are responsible for the operation of one or more mini-grids parallel to the national grid.
- Hybrid business model: a combination of the above kind of ownerships. Most of the time vertically integrated, at which each level (production, distribution and demand management system) has other entities that are responsible for owning or operation.

The sort of ownership should be determined by the actor with most interest. The electrification of larger towns should be done by utilities. The possibility to set tariffs which are cross-subsidized by the utility offers a large benefit to provide affordable electricity. Sometimes, the utilities develop, build, maintain and operates the mini-grid by themselves, sometimes they only facilitate the implementation of a mini-grid (11). Utilities have generally (more) financial resources and technical capabilities. Private owned mini-grids are financed by private equity donors, commercial loans or public support. Private owned mini-grids may be appropriate at locations with a large (agro)industrial customer with a large demand load and a stable cash flow. Excess power can be allocated amongst the residential and smaller commercial customers. A second option is clustering of village mini-grids, owned by one private actor

(11,53,68). Community-based mini-grids are ideally meant for networks with low demand loads. The owners are the consumers (sometimes represented by cooperatives) and have a strong interest in affordable prices and a reliable power supply. Disadvantages are the lack of human capital to maintain and monitor the system. Especially if the system has not a limit system to manage the consumption, it is vulnerable to the 'tragedy of the commons' in which every individual over-exploit shared resource. Hybrid ownership can take the advantages of other ownership models but is overall more complicated. In most cases PPAs, PPPs or other concession agreements have to be signed (49,55). In Table 12 the main advantages and disadvantage of the different ownership models are listed.

Model	Advantages	Disadvantages
Community	• Increase awareness • Users are owners • Create assets and local ownership	• Lack of technical and business skills • Critical governance • High grants needed • Corruption risk due to overlapping social and business relationships
Private	• Greater efficiency • Profitability allows for scaling up of operations • Better operation and monitoring capacities • Without political interference	• Difficult to find financial support • Few experienced companies • Changes in regulation and tariffs can reduce profitability • Grid-interconnection potential risk
Utility	• Technical skills • Good links to legal systems • Less regulation needed • Cross-subsidized tariff-system with national grid • Access to spare parts and maintenance	• Liberalizations make rural electrification to people with low resources less attractive. • Often inefficient and bankrupt • Driven by political agenda • Not core business
Hybrid	• Different actors contribute strenghts, technical, financial and governance know-how. • Scalable and profitable	• High transaction costs • Complex management structure

Table 12 Different mini-grid ownership model (48,68)

Next to discussing specific ownership, it is important to make some other notes. At first, sometimes the organization is split up in cooperatives and Independent Power Producers (IPP). Cooperatives are responsible for the distribution of the energy, payment collection, and maintenance of the grid. The IPPs generate the electricity and sells it to the cooperatives [S9]. Secondly, in many cases, the specific ownership is split from the responsibility to operate and maintain the mini-grid (49). Sometimes the mini-grid is leased by a system operator or a community that has been contracted to manage the system.

Lessons learnt 'Social challenges'
• **Engagement and strong relationship of the local community is essential for social sustainability and for receiving appropriate information.** • **Respect to local structures, tradition and leaderships is a key factor for social sustainability.**

- **Creating awareness and responsibility amongst the customers is needed to create shared interests.**
- **Education and promotion are important to stimulate awareness and electricity consumption.**
- **Roles and responsibility about the electricity infrastructure and operation need to be clearly defined.**

3.3.2 Technical challenges

The power generation/storage system and the distribution system are the two main elements of a mini-grid. Diesel, hydropower, biomass, wind, PV or a combination of these technologies are the main sources of power generation of a mini-grid. Below some characteristics are discussed of the different technologies.

- While the wind speed is too low in Sierra Leone, this technology is not feasible for generation purposes.
- Mini-grids that are diesel based have the highest share at this moment, being the mature technology in rural electrification. Diesel generators (parts) are easily available in SSA, have low start-up costs, but have high running costs and are pollutive. Most people cannot afford the fuel cost. In many cases, a diesel generator can serve as backup capacity for renewable energy systems.
- The share of PV-based grids is increasing due to enormous decreased manufacturing costs. PV-systems usually include a container with (lead-acid) batteries for power storage and mitigation of the intermittency. Invertors convert the power from DC to AC voltage. One big advantage of PV-systems is its modularity, a future demand growth can easily be captured. PV-systems are less adequate for systems with large differences between peak demands and baseloads. The battery storage capacity needs to be approximately four times larger than the installed capacity to meet the demand load, while the batteries are relatively the most expensive.
- Hydropower-based mini-grid have sometimes a very small reservoir for sustaining the head but are typically run-of-the-river plants in SSA-countries. Even though hydropower plants are dependent on the water flow, hydropower generation is more predictable.
- Biomass gasifier has an advantage that it can use locally available biomass, but it is important that a sufficient supply can be guaranteed. An ineffective supply chain for feedstocks results in lower power efficiencies. Additionally, batteries systems need to add to create a reliable power supply.
- Hybrid systems combine at least two of the technologies mentioned above. The generation sources complement each other to provide a reliable power supply and to reduce the OPEX.

Technology		**LCOE ($/kWh)** *2015*	**Lifespan**	**Advantage**	**Disadvantage**
Diesel		0.311-0.607	Short	Easy installation and availability	Fuel cost

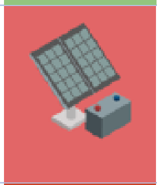
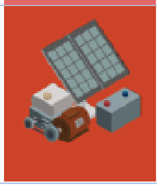
Hydro		0.13-0.27	Long	Low cost per kWh	Lack or seasonality of flow
Biomass		0.07-0.24	Short-moderate	Easy storage	Technology less mature
Solar		0.10-0.25	Moderate	Abundant resource in Africa	Access to funds for high initial investment
Hybrid			Moderate to long	Flexibility through diesel backup	Transport of diesel

Table 13 Technology comparison (based on (69–71))

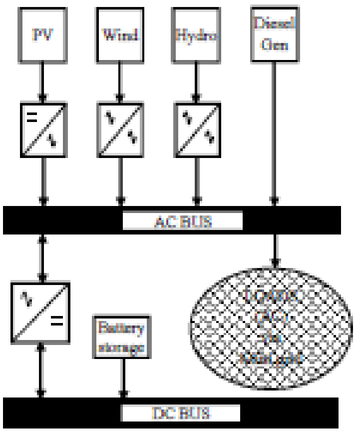


Figure 17 AC/DC configuration

Especially PV and biomass and hybrid systems have a storage or battery facility to store the generated power and make the electricity supply more reliable. The distribution system has a DC, AC, or DC/AC configuration. Solar mini-grids on a small scale can use a DC configuration, but on a larger scale they need an DC/AC configuration for the transmission and many AC-devices. Mini-grids that are based on other technologies have an AC configuration and a DC/AC configuration for a battery connection (see Figure 17). Based on the scale of the distribution grid, a decision has to be taken between one or three phases power supply. A single phase network has lower capital costs, but has higher power losses. Especially if a productive use fo energy is stimulated, a three-phase distribution system is necessary.

For future demand growth, it is important that the mini-grid can be upscaled by more generation capacity and generation sources. For PV-systems, this can be done easily. For hydropower systems and biomass systems, this is more difficult. The modularity is also a key issue during grid arrival. If the mini-grid can be connected to the central grid, the long-term sustainability is guaranteed.

3.3.2.1 Sizing of the system

The design and operation of a mini-grid resulted for different cases into a failure. Difficult accessibility and poor infrastructure hinder the installation and increase transportation costs and time. Very important is a proper sizing of the system, aligned with the demand profile. When the share of industrial or commercial electricity use in a village is low, rural electricity demand profiles are defined by household consumers. A typical electrical load profile of a rural Sub Saharan Africa mini-grid has an evening peak demand (Figure 18). This is due to increased usage of electricity for light and leisure activities, like music or television, when the sun sets (60).

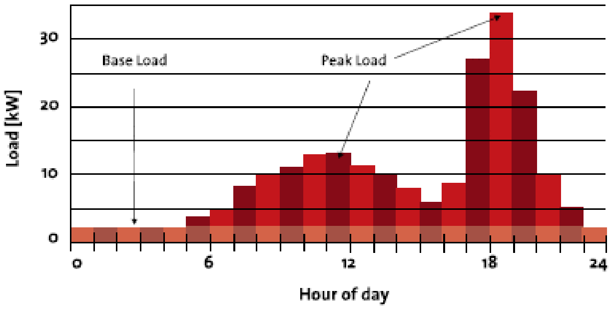


Figure 18 Typical load profile medium mini-grid [69]

Demand profiles are also determined by (seasonable) income patterns, seasonal farming related productive loads (irrigation, milling), efficiency of appliances and occasional events (68). Insufficient knowledge about the load conditions with a future load growth can result in an inappropriate system design and volatile patterns. Oversizing of the systems results in higher operational costs, lower efficiency rates and higher payback times, because of the overinvestment. A lower load factor caused higher maintenance costs and sometimes permanent damage to the equipment. Undersized systems are characterized by shortcuts, unreliable power supply and local conflicts. Load profiles are important to determine the power demand to design a system that fits this demand. Based on experiences in Kenya, GIZ developed the following flow chart (Figure 19) for demand assessment and to assign the financial viability. The financial viability of different supply options depends on the demand characteristics. Determining population density and socio-economic context, calculating load profiles and variables as the willingness and ability to pay are important input data for determining the demand characteristics. Solar irradiation, seasonal river flows, diesel prices are key variables to choose suitable source(s) for generation to match with the demand [S1].

3.3.2.2 Maintenance and equipment

Sometimes the size of the system fits with the demand load, but lack of maintenance led to a lower efficiency rate. This can be ascribed to the shortage of professional technicians, a lack of responsibility or poor quality of used materials. Finding educated technicians is difficult in several ways. At first, most educated technicians are located around the larger cities. They are not willing to leave to rural conditions with fewer education facilities and often lower salaries. It is essential to attract local people that are willing to learn the specific skills for maintenance and acquiring spare parts. Secondly, few technicians have experience with renewable technologies. Meter systems are not resistant to lightning because of low quality standards. Timely repairs and regular maintenance is important, but a lack of timely breakdown reporting and maintenance services occur in many mini-grids (72).

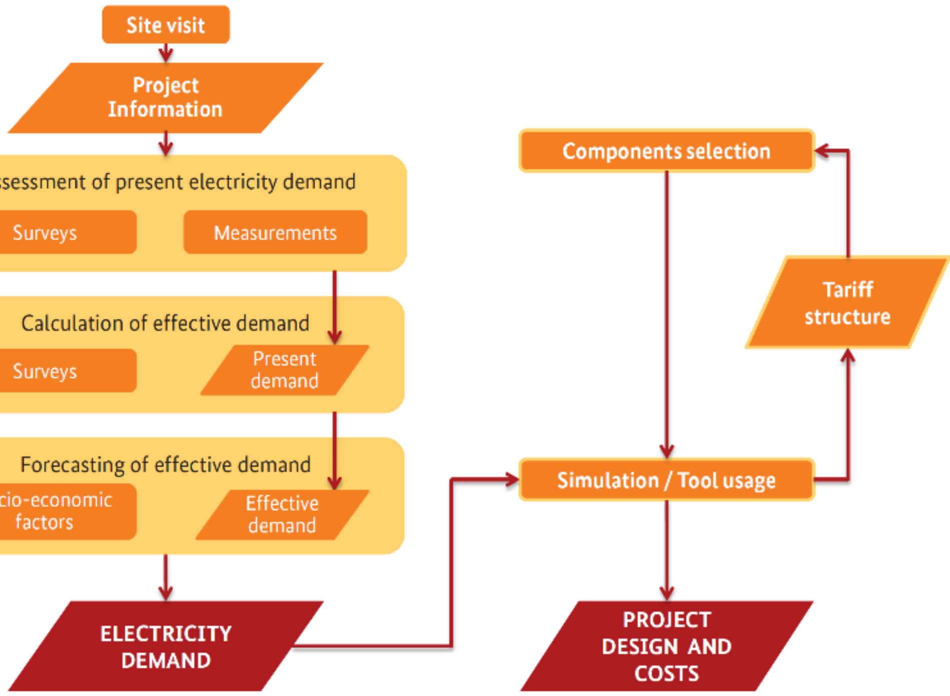


Figure 19 Flow chart of the sizing process (73)

3.3.2.3 Reliability

Besides the demand, the reliability is a key issue in the technical design. Reliability refers to electricity supply that is stable, non-interrupted, without voltage fluctuations and capable to anticipate on peak demands. Brownouts and blackouts are indicators for the reliability of the system. Blackouts refer to periods with a total lack of power, brownouts refer to a voltage drop-down. Brownouts can result in malfunction of electric appliances on the long term (74).

3.3.2.4 Efficiency

The load factor in a mini-grid is an indicator to determine the efficiency of the system. The load factor is given for a certain time period as the ratio of average load to maximum possible load in the considered time. For a mini-grid operator, high load factors are favourable. A consumer with a high load factor has moderate changes in his electricity demand pattern. Therefore, he imposes fewer control requirements to the grid. In this regard, a low load factor increases cost pressure in any mini-grid system, due to high required peak power from the generation side. For example, in a hydro mini-grid, the highest load defines the theoretical turbine size needed. But the turbine size is constrained by the available water flow, which can lead to an underpowered system. Moreover, to meet a low load factor in a diesel mini-grid a relatively high power diesel engine has to be installed. That engine is in return operated with a low capacity rate, resulting in inefficiencies causing high operation and maintenance costs. Thus, cost pressure or unsuitable system design can lead to unfitting installed capacities that constrain power availability in the mini-grid (15). In that sense, it is advantageous in an off-grid electrification project to avoid relatively high peaks on the demand side to reach a high mini-grid capacity utilisation.

3.3.2.5 Monitoring

Monitoring is essential for managing the performance of the mini-grid. Sometimes it is needed to manage the demand due to the limited amount of generated power. Spreading the load over time can help to manage the peak hours of the system or limit the consumption in order to maintain a continuous supply. Some options for demand-side management in a rural African context are:

- Demand limiters, which can cut-off the power if a maximum level of consumption of the customer is achieved. The maximum level of consumption per month determines the fixed tariff, which users need to be pay every month. It is problematic that the demand limiters cannot monitor the consumption behaviour. In India, many people with demand limiters have no switches and the moment the mini-grid turns on and off determines the availability of domestic electricity (75).
- Time schedules or rationales to divide the demand and prevent peak load. Welding activities, agro-processing activities and pumping activities can be allocated during the day.
- Prepaid or smart meters are familiar for payments of electricity and to monitor consumption. These pay-as-you-go fit well amongst people with an irregular and seasonal income flow. Customers are responsible for their own electricity consumption and credit balance.

Lessons learnt 'Technical challenges'
• **Solar PV is the most popular type of mini-grids. They are the easiest to maintain and the manufacturing costs will decrease further. Hydro power plants and diesel generators have the highest reliable power supply.** • **Proper load demand assessment by consulting the population density, consumption pattern and WTP is essential in the planning process.** • **Using sub-standard maintenance and equipment affects the system negatively.** • **A smooth supply-chain of spare parts reduces the repair time.** • **Proper demand management during the operation improves the lifetime of equipment.** • **Smart metering and remote monitoring help to detect technical risks and failures.** • **Hybrid or storage systems increase the security of supply and reliability of the mini-grid.**

3.3.3 Economic challenges

In respect to the economic viability, it is important for commercial and private-based grids that the investment funding can cover the fixed costs and the revenues cover the daily operation and maintenance through the entire lifetime. Fixed costs are typically generation equipment and distribution network costs, interests, transaction costs, management fees and daily operation costs (money collection, maintenance, security, customer relationship management, etc.). For donor-based grids, cost recovery is not a prerequisite, but covering the daily operation activities is at least required. In literature, it is mentioned as 'balanced cost recovery in the long term' [35, pp. 69]. Due to the small customers density in rural areas, the costs per customer electrified are higher than urban areas (53). Long term economic viability can be achieved by an extensive planning and design phase. Therefore, many variables are needed for input.

Revenues		**Expenditures**	
Initial	*Daily operation*	*Fixed*	*Variable*
Funding	Connection fees	Generation technology	Fuel costs
Grants	Electricity sales	Distribution grid	Maintenance costs
Subsidies	Service fees	Equipment	Taxes
		Depreciation assets	Non-payment
		Interest rates	Technical losses
		Salaries	Customer relationship

Table 14 Revenues and expenditures mini-grid

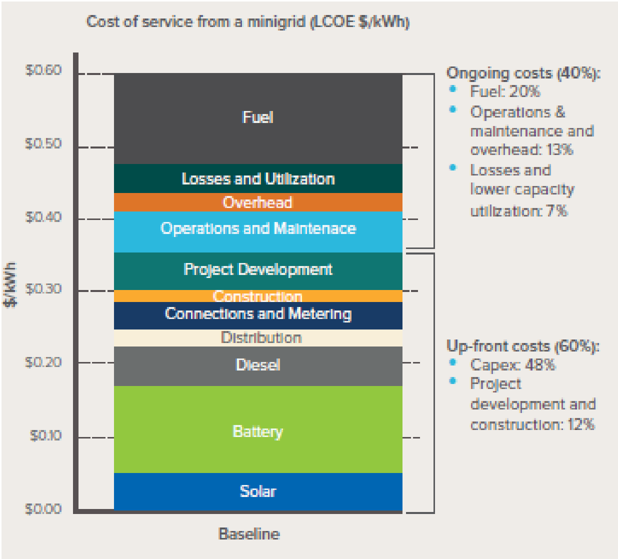


Table 15 The typical cost for a mini-grid (1)

3.3.3.1 LCOE

Mini-grids with diesel generators as generation source are the easiest way to fulfil the electricity demand, but high diesel prices, replacement cost and transportation logistics increase the costs in remote locations substantially. Despite these challenges, diesel mini-grids remain popular, because of their relatively low capital costs, ability to generate power at any time and the long-time experience with diesel gensets. Renewable based mini grid seems a competitive and reliable alternative because the running costs are much lower. The start-up costs seem the bottleneck for most mini-grids, although the costs of PV systems have been reduced enormously. In respect to the economic feasibility, the Levelized Cost of Energy (LCOE) needs to be taken into consideration to compare the different technologies. The LCOE stands for the calculated lifetime costs, divided by the total energy production. In the LCOE all kind of costs (CAPEX, OPEX) over the system's lifetime are included (77). In Table 15 an example of the typical LCOE of a hybrid mini-grid is shown. The costs were estimated in 2016, but it is expected that the costs will decrease drastically. In 2020 a LCOE of 0.30-0.45 per kWh is expected, due to costs reduction in hardware, replication benefits and better access to finance (70).

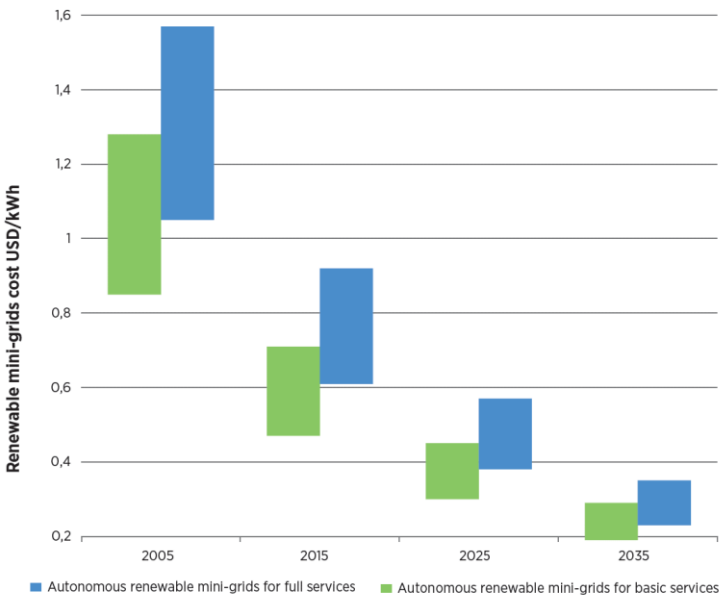


Figure 20 Cost reduction mini-grids (70)

Nerini (77) categorized six groups of consumers depending upon their consumption pattern and in relation with the multi-tier framework discussed in 3.1. Based on this categorization and the population density the LCOE of grid-connection, stand-alone systems and mini-grids can be calculated. For instance, for tier 0 stand-alone systems have the lowest LCOE and are the least cost energy solution. For other categories, the decision about the scale depends on the population density. In two case studies also the local electricity price and the distance to the nearest grid connection have been included. An increasing population density from 100 to 500 households/km^2 can result in a cost reduction of 5-65 % (77).

Level of access	Tier-0	Tier-1	Tier-2	Tier-3	Tier-4	Tier-5
Indicative appliances powered	*Torch and Radio*	*Task lighting + Phone charging or Radio*	*General lighting + Air circulation + Television; Computing; printing*	*Tier 2 + Small appliances (i.e. General food processing and Washing Machine)*	*Tier 3 + Medium or continuous appliances (i.e. Water heating; Ironing; Water Pumping; Rice cooking, Refrigeration; Microwave)*	*Tier 4 + Heavy or continuous appliances (i.e. Air Conditioning)*
Consumption (kWh) per household per year (recommended from the WB framework)	*<3*	*3–66*	*67–321*	*322–1,318*	*1,319 –2,121*	*>2,121*
Consumption (kWh) per household per year – As calculated in [18]	-	*22*	*224*	*695*	*1800*	*2195*

Table 16 Tiers of access (77)

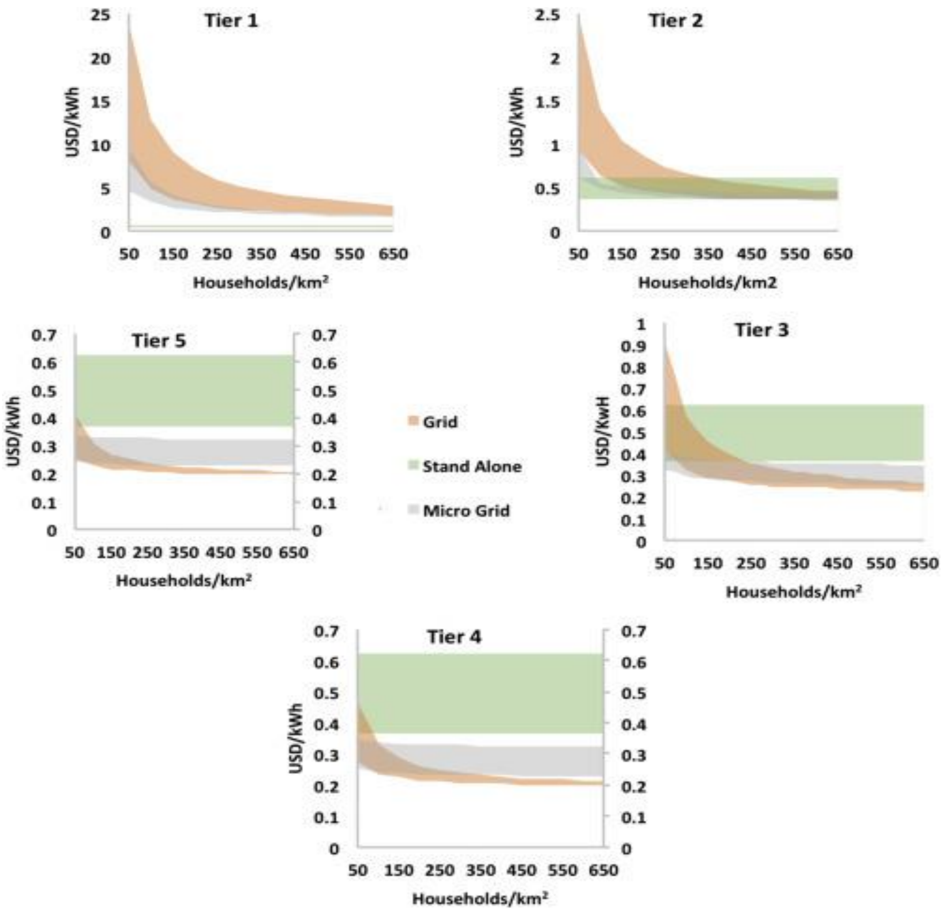


Figure 21 Graphs of electrification tiers (77)

3.3.3.2 Tariffs setting

In order to cover the system's running and replacement costs, a suitable setting of tariffs and subsidies must be designed. It depends of the local procedures and the ownership-model which actor has the responsibility to set the tariffs. A tariff that is able to cover the cost is referred to as break-even tariff (16,59). Especially for rural areas with lower demand and lower ability to pay, tariff setting is important to receive sufficient revenues. Full transparency in the tariff setting procedure allows trust and increases the acceptance by the community. The graph in Figure 22 shows how tariffs can be set. The X-axis shows the total electricity sold per year, the Y-axis the cost/price. Each curve has a fixed part and a variable part (variable costs versus energy price). At the break-even point the revenues cover the cost, upwards the mini-grid can generate profit, downwards the mini-gird need subsidies or grants to be financial viable (68).

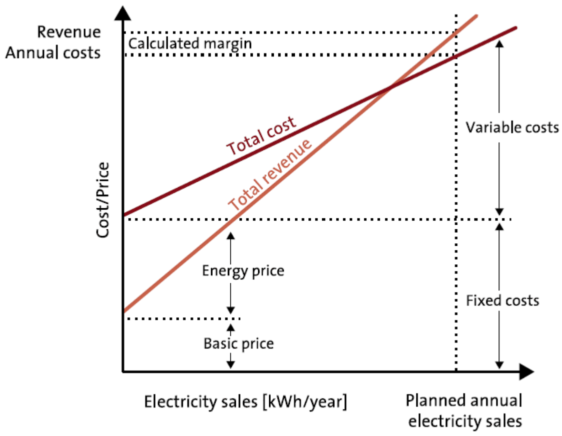


Figure 22 Price-setting [70]

Most mini-grids charge a connection fee to cover the connection costs. This fee creates also some awareness and commitment to keep the connection line operational. Subsidies can cover part of these connection fees to increase the affordability of electricity access. To charge the electricity consumption and cover the running costs, two systems (with variations) are common: a system with a fixed tariff or a consumption-based system (68). A fixed or flat rate tariff system is very easy to implement but provide less information that can be used for management of the system. The flat-rate tariff can be based on a maximum amount of power or a fixed time period. A consumption-based system has to allow meter readings or usage of pre-paid meters. Moreover, meters with a network connection can use phone networks to sell certain amounts of kWh to consumers. Still, to introduce a consumption-based tariff system more electrical equipment and organization in metering and billing is necessary, which results in higher cost. But a consumption-based tariff system has higher acceptance from costumers(49,51). Examples show that people are even willing to pay more, for a consumption-based tariff, because fixed billing creates conflict potential, no incentives for efficient usage and inequality (25). Poor people cannot afford some flat rates, while large-scale consumers do not contribute to the revenues. It is also possible to combine the flat-rate tariff and a consumption-based tariff in one village. In Ghana, they have a lifeline tariff. Consumption below 50 kWh is charged with a fixed lifeline tariff. Above the lifeline, every customer has to pay for every consumed kWh of electricity (78). The main disadvantage of prepayment metering is the cost of the meter because the worldwide production volume is relatively small.

Categories	*Description*
Capacity- or Energy based tariff	Tariffs are based on energy consumption

Customer class tariff	Tariffs based on consumer groups (households, small-business, industrial, etc.), ABC-model
Stepped tariff	Tariffs are depending on consumption level of the consumers
Progressive tariffs	Tariffs increase at higher consumption rates
Regressive tariffs	Tariffs decrease at higher consumption rates
Flat-rate or power-based tariffs	Tariffs based on a maximum amount of power or restricted time period
Time based tariffs	Tariffs fluctuate together with the time of the day (peak / off-peak)
Flexible tariffs	Tariffs dependent on available demand load, season, generation source.

Table 17 Tariff structures

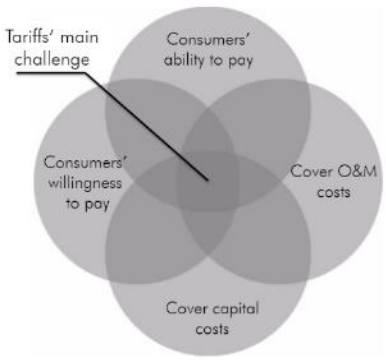


Figure 23 Tariffs setting

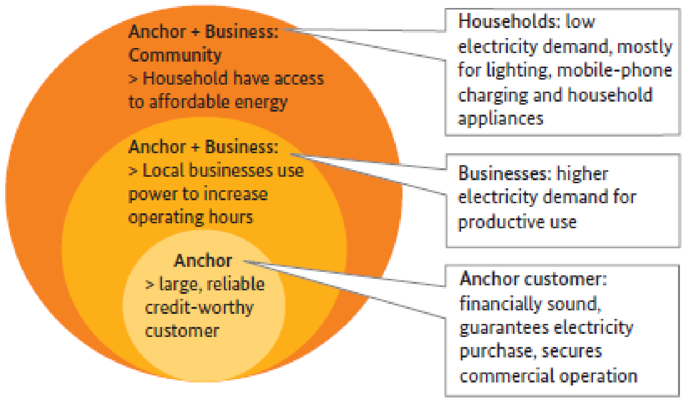


Figure 24 The A(nchor) - B(usiness) - C(ommunity) Model

The tariffs setting have to find a balance between covering both the running costs and capital costs ánd the consumers' willingness and ability to pay. Between sustainability and affordability. In order to set customer class tariffs, the so-called A-B-C model (Figure 23 Tariffs setting Figure 24 The A(nchor) - B(usiness) - C(ommunity) Model) is useful to categorize different customers:

- Anchors (A) are large, reliable public, commercial or industrial customers, like hospitals, agro-firms, telecommunication towers. They need a stable and reliable power supply.
- Businesses (B) form small enterprises, offices and primary health clinics, which require during daytime and quite often in the evening electricity to run their operations.
- Community (C) customers are households, having a small consumption and limited ability to pay.

Anchor and business customers are essential to stimulate productive use of energy. If economic activities increase, the viability of the mini-grid business case will increase. In some cases, it is useful to work together with financial institutions. Small retailers are quite often not able to finance (new) equipment to increase their productivity and applications for credit are rejected (79)

After tariff setting, it is important that the payment methodology works properly. The collection seems not always easy. People are unable to pay or want some favour. Enforcement by means of sanctions or disconnecting people can create awareness that non-payment impacts the long-term sustainability of the system. So, informing the community about the payment and enforcement procedure is essential (49). In most African countries prepaid systems are preferred. These systems allow customers to pay electricity in advance dependent on their available cash money (68,80).

In order to stimulate the electrification of rural areas and as far as possible also the renewable technologies, governments can use subsidies and taxes. In Figure 25 some measurements are shown, although some incentives are very difficult to realize in a SSA-setting. Fiscal benefits for solar systems or taxes on fuel prices, for instance, strongly affect the costs and the technologies' choice. Feed-in tariffs in some SSA countries have stimulated renewable energy sources. Kenya, Tanzania and Uganda have established feed-in tariffs, but lack of enforcement in Kenya hindered the effectiveness of the feed-in policy (81). Subsidies can reduce the high upfront costs and influence the tariffs and the scale of the mini-grid, because electricity access will be more affordable.

	Generation based (kWh)		
Supply side	Fiscal measures Feed-in tariffs Bidding systems	Quota obligations Green certificates Fiscal measures	**Demand side**
	Subsidies Grants Fiscal measures	Quota obligations	
	Capacity based (kW)		

Figure 25 Incentives for off-grid projects

Another aspect of the economic viability is the financing of the grid. Off-grid energy systems in developing countries are often initiated and established with donor-money and foreign assistance. The projects are dependent on the continued support of these outsidess, which make them vulnerable (16,50). Private investors are attracted to enter this market. For private investors, it is important that governments can assure the centralized grid will not arrive within the repayment period of the mini-grid.

Lessons learnt 'Economic challenges'
• Different tiers of financing are needed to create a profitable mini-grid. **• The only prove way to operate a mini-grid without subsidies is by stimulating productive use of energy by anchor customers.** **• Tariff setting is essential for the economic viability of the grid.** **• Flexible tariffs can guide user' consumption pattern and the efficiency of the mini-gird.** **• The ability to pay and the willingness to pay affect the viability of the mini-grid.** **• Subsidies have to be applied in order to prevent dependency on subsidies for long-term.** **• Local business hubs and agro-industrial activities increase revenues for the whole community and increase the sustainability of the grid.**

3.3.4 Environmental challenges

Environmental issues play an important role in the design and planning phase of a mini-grid. Especially for hydropower systems with a (small) reservoir, an environmental assessment is evident, due to the ecological impact and changes in the water flow. These environmental assessments take a while in SSA, which can delay the whole process. Due to the limited time of this research, this topic is not extensively discussed.

3.3.5 Institutional challenges

Low institutional quality is a barrier for investors to finance rural electrification projects or mini-grids. For successful rural electrification by mini-grids, stable and durable support from the central or national government is essential (82). The national government shapes the boundary conditions for the regulations and the investment climate. National elections are a source of uncertainty. A new government can change the policies relating to mini-grids. More or less attention can be given to rural electrification. Sometimes members of parliament want to use the installation of a mini-grid for campaigning reasons. After some time, the attention gets lost.

3.3.5.1 Regulations

Uncertainties on the long term make it less interesting for the private sector to invest in mini-grids. IRENA (48) proposed three kinds of measures to stimulate effective policy on mini-grids. Firstly, ministries of Energies and rural agencies should develop national policy, rural electrification strategies and clear regulations related to quality standards, tariffs, financial support, and position of mini-grids with respect to the central grid. Strategy plans and timelines structure and clarify the share of decentralized systems and central grid. Regulators have to assess a balance between on the one hand affordability and quality for service and on the other hand cost-recovery and sustainable operation. Local governance capacities need to be used to align the rules and contracts with the local context (66). In India, for instance, there is a possibility to set the tariffs via mutual negotiations with communities to align the tariffs with the consumers' ability and willingness to pay. In many countries, IPPs have to go through time-spending negotiations with utilities to gain Power Purchase Agreements (PPA). Tanzania improved the mini-grid policies and requirements and attracted several IPPs. Streamlining requirements for newly build mini-grid can reduce transaction costs and temporarily updating the policy is important, because of the rapidly evolving technologies (48). Secondly, non-energy ministries and public agencies should refine policies related to taxation, land rights, environmental protection and banking. Acquiring land and water usage rights is in some SSA countries very complicated. Legal restrictions on independent power production and distribution need to be lifted. Thirdly, local institutions, NGO's, should work on capacity building, data collection and knowledge sharing (11), (53). Their experiences with planning and implementation issues, different generation technologies and financing projects help to make the project successful. They are the link between the national and local levels, to match the government policies with the need of costumers and developers.

It is important to recognize the implementation or operation as a dynamic multi-level complex process, in which people, technologies, institutions and resources are interconnected. In general three levels can be distinguished (3,72):

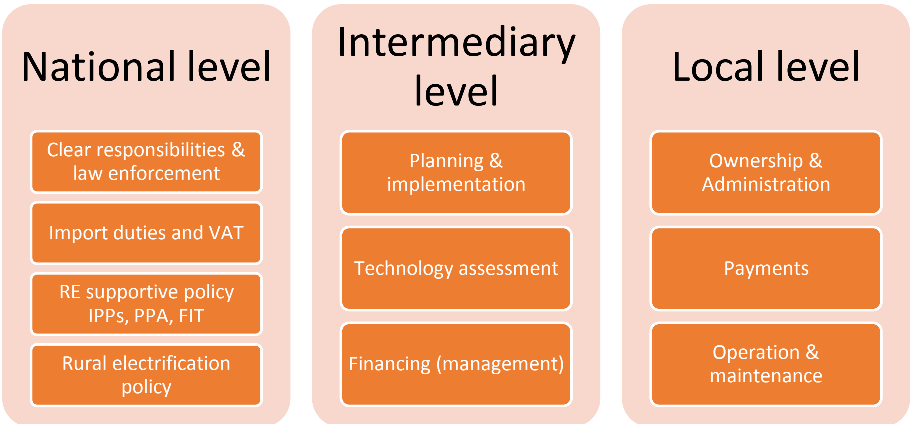


Figure 26 Three levels of governance

3.3.5.2 Organization

For the local management the work of Gollwitzer is useful. Gollwitzer (4) demonstrates how insights from the broad literature of management and characteristics of common pool resource (CPR) management can shed light on how to ensure the long-term sustainability of mini-grids. A CPR is a resource unit which is rivalrous, which means that the resource can be used only by one consumer, while exclusion from access is difficult. Multiple potential beneficiaries have to share the resource unit (4,50,82,83). Mini-grids have the same characteristics: Overconsumption can degrade the equipment, asymmetric interests and misuse can result in local conflict and a failure of the mini-grid will be the final outcome (50,84). This is also known as 'the tragedy of the commons'. The total capacity of the potential energy from the mini-grid is dependent on the generation and storage capacity. But in case one customer has powerful loads, such as mills, overload can result in brownouts or blackouts. The action of one customer affects the performance of the total system (84). The management should be capable to organize the mini-grid at a fair and effective manner. And the company should be enforcing their policy to prevent corruption, theft and free-rider behaviour. Gollwitzer mentions 6 institutional requirements for mini-grids (4,50):

1. Rules are simple and easy to understand
2. Locally devised rules
3. Ease in enforcement of rules
4. Graduated sanctions
5. Availability of low-cost adjudication
6. Accountability of officials.

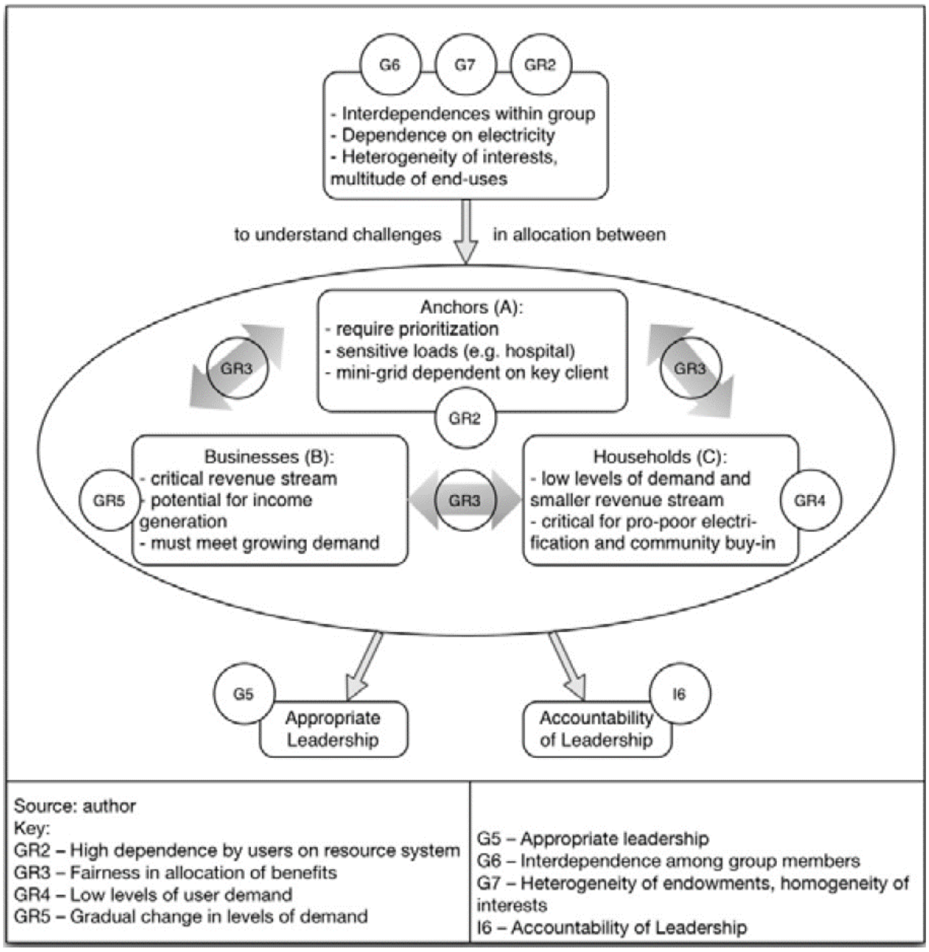


Figure 27 Second framework CPR management mini-grids [48]

Based on the framework and the ABC-model (see 3.3.3) Gollwitzer developed also a frameworks to discuss the allocation challenges between different groups of customers (50). Anchor (A) customers need a continuous power supply, while interruptions have a disruptive effect on the supply-chain or clinical care. Anchor customers are dependent on the power system for their operation, but the power system is in return also dependent on the anchor customer in terms of financial revenues and demand load management. This results quite often in prioritisation of these customers during power shortages.

Compared with the anchor customers, the demand load of businesses (B) customers is less predictable. The amount of these customers, as well as their consumption, can fluctuate or increase rapidly. Having extra revenues as a result of the use of electricity improves the economic conditions in the community and also the long-term economic sustainability of the mini-grid. If the power supply is not reliable enough, these customers can also use a diesel generator as an energy source. So, a good relationship with the business stakeholders is important for demand planning and sustainable operation. The community (C) customers ask for an affordable and reliable power supply. And although the individual demand load is low, the number of customers is the highest in these categories. Ignoring the community customers can lead to local conflicts or a loss of trust.

Important is that the allocation is perceived as fair by all the other customers. This requires appropriate and accountable leadership. Appropriate leadership can be achieved by local training and monitoring in a contextual way. Accountability can be achieved by a control mechanism from the community, such as local management platforms. Representatives from different sections of the village and each category (ABC) can promote their own interest and discuss allocation issues. Outcome will be simple and locally designed use rules, which are perceived as fair by the majority. The platforms work together with locally, specialised operators that operate, maintain and upgrade the mini-grid.

Lessons learnt 'Policy challenges'
• **Allocation of generated power needs to be done in a fair, effective and transparent way.** • **Clear mini-grid policy enhances and shorten processes such as site selection, licensing and permitting procedures.** • **Secondary issues such as subsidy schemes, land rights and environmental policies can attract or reject investors.** • **Political will from politicians and traditional leaders is essential to build a mini-grid.** • **Recruiting local technicians to operate a rural mini-grid is not easy, but important for the daily maintenance and technical sustainability.**

3.4 Assessment framework

Based on the work described in sections 3.2 and 3.3, a framework and scoring methodology to evaluate mini-grids is developed. The framework support a systematic assessment of mini-grids to detect critical factors (5,82,85–89,89,90). The framework uses the same four dimensions (social, technological, economic and institutional) as used before.

Each dimension consists of indicators, grouped by some key variables. The 34 indicators are mainly based on work of Akinyele (26), Ahlberg (3), Ilskog (25), Katre (28), Mainali (29) and several personal conversations [SX]. In the third column of the framework, the literature and data sources of the indicators are reported. After development the indicators are discussed with some expert [S4],[S7],[S31].The framework tries to reflect all aspects that affect the socio-technical dynamics of mini-grids.

The indicators are assessed at a scale of 5 steps between 0 and 1. If the indicator is met in the case study, one point is given, if the indicator is not met the in the case, a zero is given. 0.25, 0.5 or 0.75 will be awarded if the indicator has a low, medium or high level of achievement. The scores are based on quantitative data, interviews, discussions and observations. The higher the score of the sustainability aspect, the more the aspect is contributing to the long-term sustainability of the mini-grid. The lower the score, the more attention is required.

Social	*Community involvement*	Community education Support of local leaders and politicians Share of population with electricity access Training and employment of local people	[S3],[25],[64] [26,][S4] [25] [26],[64]
	Ownership	Suitability ownership model	[4],[29]
	Benefits & Acceptability	Allocation of electricity between customers Awareness about connection and consumption Availability of streetlights Ability to pay for electricity services Electricity access public facilities (schools, clinics, etc)	[27], [S34] [28],[S31] [25] [S11],[25] [25],[29]
SCORE			
Technological	*Monitoring & management*	Metering system mini-grid Managing of electricity consumption Match of technical design with demand pattern	[S35],[29] [28],[S13] [10],[S31]
	Reliability & efficiency	Availability and utilization of services System efficiency	[25],[29] [25],[29],[S13],[S24]
	Operation & maintenance	Availability equipment and spare parts in the country Dependency on foreign assistance Quality equipment and materials	[25] [28] [10],[25]
	Modularity	Compatibility with future grid integration Adaptability and expandability	[10],[25] [S10]
SCORE			
Economical	*Costs and investments*	Financial support government Operation and maintenance costs	[26] [25],[29],[S35]
	Productive use	Industrial/commercial customers with productive use Anchor client connections	[25],[29] [25],[29]
	Financial	Non-payments or outstanding payments Tariff lag Micro-credit facilities	[S10],[S12] [S6] [25],[26],[27]
SCORE			
Policy / institutional	*Regulations*	National regulation on tariff setting and licensees Tax breaks on imported (spare) parts	[10],[25],[S10] [25]
	Organization	Capability of staff Long-term vision company Defining of responsibilities between stakeholders	[24],[27] [S1] [10],[25]
	Enforcement & Security	Enforcement of local policy Security of electricity infrastructure	[S10] [S4]
SCORE			

4 Opportunities mini-grids in Sierra Leone

Before discussing two mini-grids in depth (Chapter 5), firstly an overview is given of the recently developed mini-grid policy and the existing mini-grids in Sierra Leone.

4.1 Mini-grid policy in Sierra Leone

Improving the power sector is a key element in developing the country of Sierra Leone. Mini-grids are suitable to electrify the rural areas in Sierra Leone that are located in remote areas or areas far from the central grid. Mini-grids for communities are cost-advantageous over grid extension, if the population rate amounts to a minimum of 500 households with an average consumption of 5 kWh/month and if the distance to the national grid exceeds 4 km (19). These mini-grids can stimulate the local economy, create jobs and other income generated activities.

On national scale the government has developed together with UNOPS and Inensus a policy regarding mini-grids, the SLEWRC Mini-grid regulations. The framework guides a smooth and sustainable enrolment of mini-grids in Sierra Leone (51). Based on the conceptual text (91) the policies and regulation provide formal regulation for licensing procedures, tariff determinations, bidding procedures and give clarity about interconnection and coverage issues. On community level, the policies want to provide transparency in order to prevent scepticism or mistrust amongst the customers. Mini-grids with a capacity below 100 kW have a simplified procedure, they can mutually negotiate between consumers about the tariffs without intervention of the EWRC. Above 100 kW the developer must work together with the EWRC. The mini-grid policy document aligns also with other energy programs, such as the National Energy Policy, the Renewable Energy Policy or the NEA. This document has finished the public consultation rounds and is waiting for approval by the national government. If the policy is approved, the mini-grid market is more attractive for private investors and less dependent on grants and (international) funding [S7], [S8].

Next to the mini-grid policy it is evident that banks reduce loan interest to make it easier to attract private investors. At this moment the mini-grid are mainly financed by grants and subsidies. The table below, based on (51), shows the key actors to establish a strong and long-term sustainable institutional environment that enable a smooth increase of the number of mini-grids.

Topics	Institution	Description
Policy	Ministry of Energy	Developer of national energy policy, energy planning, roadmaps, tariff structures
	Ministry of Finance	Creates financial and fiscal incentives to stimulate the development of mini-grids.
	Local councils	Involved in planning, ownership and operation issues.
Regulation	Electricity and Water Regulatory Commission	Provides rules for end-user tariffs that assure financial integrity and issues out licenses for mini-grid operations
	National Public Procurement Authority	Regulator of public tender processes
Implementation	Public-Private Partnerships	Interface between contracting authorities and private partners.
	NGO's	Support rural electrification programmes and provide knowledge and experiences.
	Private Partners	Private companies can start up and run mini-grids.

	IPPs	Independent Power Producers that generate power and sell energy to distribution companies.
Financing	NGO's, World Bank, etc.	Provider of grants and loans.
Environmental and health protection	Environment Protection Agency	Responsible for environmental, social and health impact of new developed mini-grids.

Table 18 Key stakeholders [based on (51)]

The lack of a Rural Electrification Authority is problematic. The focus of utility companies is mainly at the electrification of urban areas. Only some NGO's are working at electrifying rural areas. A Rural Electrification Authority can manage rural electrification funds, mobilizing resources and promoting the development of renewable energy. The Agency should also give technical training and support in load management, smart metering, remote metering.

4.2 Challenges mini-grids Sierra Leone

Sierra Leone tried to attract investors to build more mini-grids in Sierra Leone. The political situation is stable at this moment, but the damaged infrastructure is not repaired yet. In personal conversations, a UNOPS-RREP programme manager and a project manager mentioned the following challenges [S7], [S8]:

- Sierra Leone has little experience with mini-grids. The energy sector was confronted with delays due to unexpected situations, like the Ebola crisis.
- The remote locations and the poor accessibility infrastructure hindered an efficient installation of the mini-grids
- It is difficult to attract local qualified staff.
- Most of the material needs to be imported from foreign countries. Port authorities delay the process with strict and bureaucratic procedures.
- Although Sierra Leone finalised a regulation procedure for mini-grids, the regulation is waiting for the final approval by the parliament. Public consultations take a while.
- The elections in March 2018 changed the political agenda.
- It is difficult to get loans. The interest rates are high, because of the high risks.
- Clear communication is important. Some people think the electricity is provided for free.

Most of these issues were recognised by programme managers that work more at the national scale. Programme managers of the Energising Development (EnDev), that are based in Freetown listed the following points [S2], [S3]:

- Inexperience in accessing and attracting international funding for renewable energy projects.
- Although qualified equipment for renewable energy technologies can be imported duty-free, it is difficult for companies to receive these benefits through bureaucratic and unclear procedures.
- In some villages the power consumption is very low, due to the low financial resources of the households
- Few experiences with mini-grids in Sierra Leone.
- Weak and neglected after sales service.
- The use of poor-quality products resulted in technical and financial problems on long term.
- Few anchor clients in the country that can stimulate the productive use of a mini-grid.
- Community leaders can create an enabling environment or a disabling environment for the operation of a mini-grid.

In order to solve some of the challenges, EnDev is collecting data to increase insights in the installation and the operation of mini-grids. They also organize business days and promotion days to educate and attract young people as technicians and managers for off-grid energy systems.

4.3 Existing mini-grids in Sierra Leone

At this moment there are 63 mini-grids in Sierra Leone. Most mini-grids below 400 kW are located in agrarian communities with a population of around 500-10000 people distributed among 100-2000 households. Most mini-grid are PV-mini-grids and most of the PV-mini-grids are part of the RREP program of UNOPS. From the renewable mini-grids, 50 mini-grids have a capacity below 50 kWp, 3 have a capacity between 50-100kWp and 1 have a capacity of over the 100 kWp [S2]. In Table 19 the mini-grids are shown that are available in the country.

Location	Capacity (kW)	Ownership	Key stakeholders and funders
Diesel			
Daru	120	Private	
Kambia	1000	Private	
Kono	600	Utility	
Kabala	500	Private	
Moyamba	200	Community	ENFO, private donor
Hydro			
Goma	6000	Utility	
Port Loko	2000	Utility	Chinese government, MoE
Yele	250	Private	INGO LHF, Zebra
Makali	128	Hybrid	Chinese government, MoE
River no.2	120	Community	WHH, ECREE
PV			
Gbinty	79	Hybrid	WHH, Oxfam, ENFO, EU
Panguma	66	Hybrid	WHH, Oxfam, ENFO, EU
Segbwema	127	Hybrid	WHH, Oxfam, ENFO, EU
Mattru	10	ECREE	ENFO, ECREE, World Bank
14 mini-grids	16	Hybrid	UNOPS, DFID, MoE
22 mini-grids	26	Hybrid	UNOPS, DFID, MoE
14 mini-grids	36	Hybrid	UNOPS, DFID, MoE

Table 19 Mini-grids in Sierra Leone

Most of the mini-grids that have a capacity below 50 kW are solar-based energy systems around community health centres (CHCs) and are part of the RREP project of UNOPS and DFID. During the Ebola-crisis most of these centres were struggling with their power supply. This hindered an effective disaster management and logistics of the resources and vaccines. With funding of DFID and UKAid, UNOPS launched a plan to implement off-grid systems near CHCs. This grid supplied solar power to the clinics, but also to the community. The connection fee is subsidized by UNOPS, nut people pay prepaid cards with a cost-reflective tariffs, which to cover the running costs of the mini-grid. Annual reviews evaluate the process of implementation [S8]. Large benefit of the project is the holistic approach and the modularity. The holistic approach means that the mini-grids are incorporated into a program that stimulate productive use (tailors, welders) and socio-economic development.

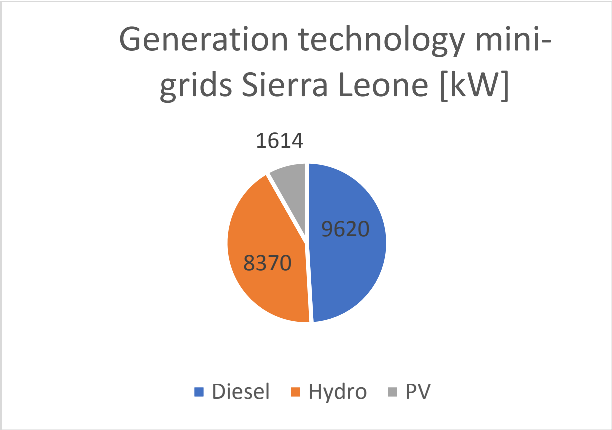


Figure 28 Minigrid technologies (based on EnDev information)

At local level this means community participation, training of local entrepreneurs and technicians ánd electricity access to education and community facilities. By means of community meetings, newspapers, radio shows and social media the communities are involved in the electrification process. Modularity means that in the second stage off-grid concessionaires will be assigned to each district to connect and take over the already developed grids from UNOPS. Selecting only a single concessionaire at district level guarantees a uniform service level as well as electricity supply tariffs. These private partners are required to expand the mini-grids and develop at least 40 new, commercial mini-grids (>36kW) in larger communities. The government will support the set up and installation of a distribution network, the private partners are responsible for the generation assets.

In total, people from 90 villages get access to electricity through the RREP project. Although the installed grids are based on solar-PV technology, private partners are free to choose for a hybrid configuration. A PPP contract with the MoE (including a timeline for operators) guarantees a smooth handover. WHH and GIZ installed the 3 bigger solar mini-grids in Segbwema, Panguma and Gbinti (PRESSD-project). These mini-grids have a capacity between 66 and 127 kW. They supply households, hospitals, clinics, local entrepreneurs and agriculture activities [S6].

From the hydropower generation grids, two have a large scale and are owned by utility EDSA (Goma and Port Loko or Banka Soka). In Yele (260 kW) and Makali (500 kW) are the only two mini-hydropower stations. Both plants are constructed before the rebel war. Nevertheless, only the plant in Yele has been repaired. The hydropower plant in Makali is waiting for assistance from Chinese investors for many years. Next to these renewable based mini-grids, there are five diesel mini-grids in the country. The diesel mini-grids consist of a distribution grid, which are fed by a diesel generator. The diesel mini-grids of mining companies are not listed, because they often deliver electricity only to their own staff. The diesel mini-grid in Daru, a small town in the East of Sierra Leone is one of them. Most of the 6000 people are connected to a distribution grid that is supplied by a diesel generator. A private company is responsible for the operation and maintenance, fuel and replacement. A customer-based tariff determines the monthly bills of each customer.

Figure 29 Diesel generator and mini-grid Daru

The total number of mini-grids in Sierra Leone, to the knowledge of the author, is 63. The number of mini-grids is still low, and the PV mini-grids have also quite often a low capacity. For example, in Tanzania, 109 renewable mini-grids are operational, from which 50 % have a capacity above 100 kW. Nevertheless, half of the 109 mini-grids were developed after 2008, the year Tanzania started with very clear regulations and rules for mini-grids.

5 Experiences with existing mini-grids

As part of the study, field visits in Yele and Segbwema were conducted. In the map below, Yele is located in the left, Segbwema in the right.

Location	Mini-grid Technology	Characteristics community	Business model
Yele	Hydro	Larger village, industry, hospitals	Private
Segbwema	PV	Larger village, hospital	Hybrid

5.1 Yele

Yele lies approximately 150 kilometres from the capital city Freetown in the centre of Sierra Leone. Yele is the headquarter of the chiefdom Gbonkolenken, which is part of the Tonkolilli district. The chiefdom is reigned by the community elders, presided by the paramount chief, the elected leader and highest ranked person of the chiefdom. The population of Yele is around 8000 inhabitants and about 850 households. Facilities in Yele are four primary schools, one secondary school, two hospitals, a radio station, a water plant, churches and mosques. People are living mostly as subsistence farmers. They farm mainly peanut, cassava, potato, farm-plant, eggplant, pepper and rice. Some households keep livestock, mostly goats, for self-consumption. Besides the surrounding mango trees, banana and pineapple plants, the area is characterized by many palm trees. Crude palm oil is extracted by local farmers or the large palm oil treatment factory and sold to small and large traders. The palm oil factory was constructed 10 years ago together with a hospital by the International Non-Governmental Organisation Lion Heart Foundation (INGO LHF), based in Sierra Leone and supported by the Dutch NGO 'Stichting support Lion Heart Foundation'. A holistic approach, named 'Best of Both Worlds' was set up to combine a business approach with a philanthropic vision. The health and education facilities were (partly) funded by the profit from the palm-oil factory and the hydropower company [S24].

Indices	Range of characteristics
Population	8000
Economic activities	Fish farming and Farming: palm oil, cassava, potatoes, plantain, bananas, pepper
Commercial activities	Welding, retail, grain milling, palm oil processing, barbing
Households energy use	Electric bulbs, fans, radio sets, cell phones, refrigerators
Local cost of diesel	7000 Le (*exchange rate: $1 = 8500 Le)*

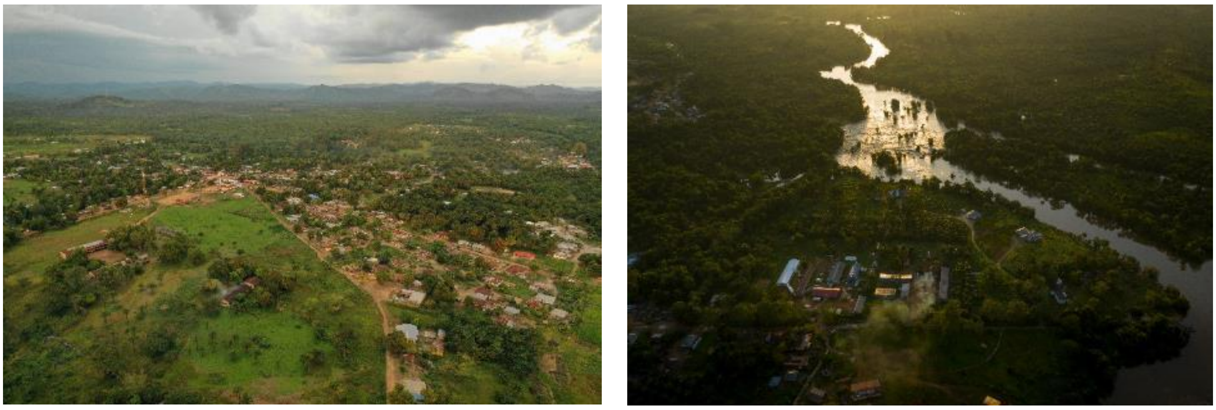


Figure 30 Yele village and 'industrial area'

5.1.1 Mini-hydro Yele

The needed power for the palm oil factory and the hospital is delivered by a mini-hydropower plant. The water of the Teye River, which runs through Yele, is converted into electric power that is distributed to the community by a medium and low voltage distribution network. The hydropower plant that has been constructed before the civil war, was destroyed during the war. With donations and technical support, the INGO Lion Heart Foundation have repaired the hydropower plant and power lines in 2012. With limited resources, the plant has been running in close cooperation between the energy supplier and the community. People who were fully dependent on diesel generators for power supply now discovered a large reduction in energy costs. The aim is to provide access to electricity in such a sustainable way that it will contribute to the long-term social and economic development of Yele (18), [S18], [S24]. Households use their electricity for lighting, for charging of their phones and radios and for appliances like a fan, refrigeration, television set and stereo installation. For cooking and heating, they still use charcoal and traditional fuelwood.

LION HEART FOUNDATION Lion Heart Medical Centre	PowerNed Electricity company	Natural Habitats organic products grown in a sustainable habitat Palm oil factory

Figure 31 Main actors Yele

INGO Lion Heart Foundation started with three entities in Yele, Lion Heart Medical Centre (LHMC), Nedoil and PowerNed. PowerNed is the company that is responsible for the operation of the electricity system in Yele. Unfortunately, in 2012 internal disagreements resulted in a splitting of the three entities. Now the palm-oil factory, the hospital and the electricity company operate financial and organizational autonomously.

Figure 32 Mini-hydro Yele

Fact sheet mini-grid Yele	
Location	Yele, Tonkolili District
Start date	June 2012
Technology	Mini-hydro, MV transmission, LV distribution
Installed capacity	2 x 125 kWp
Number of households served	340 households
Other consumers	Palm oil factory, water plant, communication tower, radio station, hospital, clinic, schools, churches, mosques, small enterprises
Ownership and management	PowerNed Ltd

5.1.2 Social aspects

The mini-hydro of Yele is owned and managed by PowerNed, a NGO based in the Netherlands. The daily operation is managed locally by a team of technicians and assistance-workers. PowerNed is a private utility, which means it is functioning as a provider of public services but is a privately-run company. It is not receiving government subsidies. PowerNed is also responsible for the daily operation of a waterplant that supplies several water taps.

Figure 33 PowerNed office

The local staff consists of 7 people: a technical team (1 technician responsible for hydro operation, 1 technician responsible for network operation, 1 operational manager responsible for overall operation), 1 liaison officer, 1 cashier, 1 accountant and 1 manager for the waterplant. The staff is managed (at this moment mostly from distance) by a managing director from the Netherlands and an operational manager in Yele and is supported by 3 security people (who are also doing monitoring activities at the hydro power house). The managing director was during the start-up phase almost continuously in Yele, but handed over management tasks to the local staff. The main activities of the staff are controlling and monitoring of the hydro, network maintenance, maintaining connections, meter readings, payment collections, prepaid cards sales and recording of systems operation. The technical team studied at the Government Technical Institute (GTI) in Freetown and were trained locally by a Dutch expert of Zebra Technologies during the installation and start-up of the system. Two staff members followed a technical course for managing hydropower plants in China. The technical team is as result of intensive training capable to solve the main issues. Good example of achieving long term sustainability is the training of four young locals in the technical operation. They are involved in the activities of the technical team to learn specific skills and knowledge of the hydro plant and the distribution network [S18], [S24].

Nevertheless, the company is dependent on foreign assistance. Especially for spare parts, financing and institutional issues. Some equipment, spare parts or specific technological knowledge are not available in Sierra Leone. They need to be imported from foreign countries. It would be more cost-effective if these parts are available in Sierra Leone, but the market is too small and the electricity sector is in its infancy. For financing issues, it is important to find a qualified accountant, that can produce systematic financial reports. There is a shortage of qualified accountants in the country and most graduated accountants prefer to stay in the capital city of Freetown. In Yele they have an accountant, but for a system of checks and auditing, reviewing of the managing director is necessary. In a culture that is susceptible for bribery and fraud, PowerNed must be cautious continuously to prevent such malfunctioning activities. The contacts with ministries, regulators, foreign investors and technical experts are done by the Dutch managing director. This dependency at one person makes the company quite vulnerable.

Even though the team is dedicated, sometimes the communication between the staff is insufficient. Some problems are reported too late, some information is contradicting and only once in the week there is an official staff briefing, in which the problems can be discussed. The culture of honour, respect and reputation results in a conformist behaviour instead of calls for action in cases of mismanagement and misfunctioning of staff members.

Figure 34 Community meeting

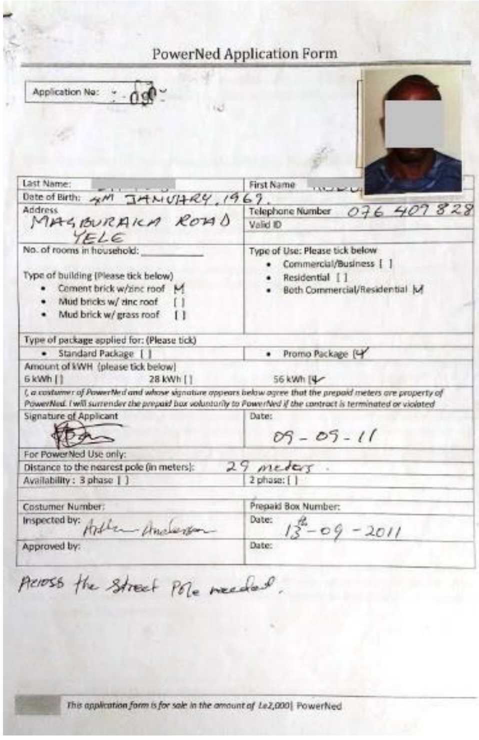
To enhance the support of the community PowerNed regularly meet the community elders, the board of the community. They have together with the Paramount Chief the most powerful position in the community. If there are important events, changes in operation or new developments, PowerNed always inform the Paramount Chief. If the paramount chief says, 'I am with you', accomplishing of procedures is going faster. The meetings also made clear the position and responsibility of PowerNed. In the past PowerNed has been considered as aid organization that delivers power for free. It is important to emphasize PowerNed is a private utility that can only operate if they are economically viable. Besides of the community elders, some landowners have powerful positions in the community. For assets, you need their support [S24], [S25].

In the past PowerNed used the radio station to communicate about their operation and to promote an efficient and productive use of customers' appliances. These radio shows have been stopped for three years now, due to payment issues of the radio station. To support the relationship between the community and PowerNed, PowerNed takes also care of a repaired government-owned water treatment plant in Yele to increase the well-being of the people of Yele. The operation of this water plant is funded by earnings of PowerNed and donor money. PowerNed installed also 100 street lights, but at this moment most street lights are out-of-operation, due to the scarcity of available power. Some community-places receive power for free, to enhance the relation with the community.

Figure 35 Radio station Yele

Education of customers was in the beginning of the hydro-project a main part of the project. Workshops were organized to educate people on the electrical consumption and the use of their appliances. At this moment these activities are stopped. Important is the alignment of the communication with the local culture and tradition. Low literacy levels require community meetings and radio shows instead of documents and brochures. A traditional conservative culture requires straight procedures (step-by-step) for the management of the system.

The people of Yele are controlling the fairness of the rationale of power supply in Yele. People are complaining to the technical team if the shift-over between the two parts of Yele is too late or too early. People do understand the system of rationales now, but in the past, it resulted in several problems. However, people do not understand why the hydropower cannot supply power to the town continuously. Especially during blackouts in the peak of the rainy season they do not understand why the power generation is hampered. In those times they have complaints about the daily operation of PowerNed. Because of some lightning problems in the rainy season and a low accuracy with the prepaid meters, PowerNed decided to implement new prepaid meters, tested through a pilot project with 10 prepaid meters. Most pilot-customers are satisfied with these new meters, but some of them are complaining about the high consumption of electricity with the new prepaid meter. This can be ascribed to the higher accuracy of the meter, but it is mainly be affected by a misunderstanding of the metering of electricity. Other complaints are about the long waiting times for a new connection or meter. Reasons for the waiting times are dependency on donor money and investment decisions. The customers are very sensitive on tariff changes. Higher tariffs, to cover the running costs, were interpreted as attempts to make more profit or to release the benefits to the community.


PowerNed Application Form

Application No: 09

Last Name:	First Name
Date of Birth: 4M JANUARY, 1969.	
Address MASBURAKA ROAD YELE	Telephone Number 076 407 828
	Valid ID
No. of rooms in household: ______	Type of Use: Please tick below
Type of building (Please tick below)	• Commercial/Business [ ]
• Cement brick w/zinc roof [✓]	• Residential [ ]
• Mud bricks w/ zinc roof [ ]	• Both Commercial/Residential [✓]
• Mud brick w/ grass roof [ ]	
Type of package applied for: (Please tick)	
• Standard Package [ ]	• Promo Package [✓]
Amount of kWH (please tick below) 6 kWh [ ] 28 kWh [ ]	56 kWh [✓]
I, a costumer of PowerNed and whose signature appears below agree that the prepaid meters are property of PowerNed. I will surrender the prepaid box voluntarily to PowerNed if the contract is terminated or violated	
Signature of Applicant	Date: 09-09-11
For PowerNed Use only:	
Distance to the nearest pole (in meters): 29 meters.	
Availability : 3 phase [ ]	2 phase: [ ]
Costumer Number:	Prepaid Box Number:
Inspected by:	Date: 13th-09-2011
Approved by:	Date:

Across the Street Pole needed.

This application form is for sale in the amount of Le2,000| PowerNed

Figure 36 Application form

The responsibility of PowerNed reaches up to the electricity meter. The households are responsible for the connections, appliances and sockets. To formalize this responsibility and to create awareness amongst the customers, PowerNed has written agreements that need to be signed by the customers to stipulate the terms and conditions of the relationship. PowerNed has the responsibility to solve issues regarding faulty meters and connection cables. The customers have the responsibility to keep clean the meter box, to pay their bills and to use the connection properly. If customers violate one of the conditions, PowerNed has the right to disconnect the customers or remove the connection. In cases of fraud, there are procedures available to enforce the policy and to solve the issue. Despite the available and explicit regulations and policies, the reality often ends up more informal [S18], [S19]. Business and private life are interwoven, resulting in mutuality and pressure of local actors. The technical team tried to mitigate claims and complaints in a 'friendly' manner.

The people in Yele have a quite ambivalent position to PowerNed. On one hand, they are proud because of the lights in Yele. For example, people in larger cities have later or still no access to electricity. On the other hand, the people have not a large willingness to help or support the company. Every year it is difficult to find enough people that are willing to help with banking the river. The community considers the activities of PowerNed more as business activity than as a community responsible project.

Lessons learnt 'Social challenges'
• **Participation of the community was in the beginning a key factor but must be continued during the operation of the hydro-network.** • **The mini-grid in Yele is dependent of foreign assistance, which makes the company vulnerable.** • **Educating and training of local people is important for the long-term sustainability of the mini-grid. In Yele capacity building of local people is a key element.**

- **Effective and cultural-sensitive communication is important. Use methods that are familiar in the community.**
- **Make use of procedures in the daily operation to ensure a stable frequency of activities.**
- **Make clear the position and responsibility of both the company and the customers.**

5.1.3 Technical aspects

The hydropower plant was constructed with a generator and two turbines with a total installed capacity of 250 kW. After 1 year a shaft of one turbine broke and is until this moment not replaced, although an upcoming renovation plan includes also a new shaft. The actual generation capacity is much lower than the installed capacity. Due to the differences in water flow between the rainy season and dry season, the capacity that can be generated, differs throughout the year. Especially during the peaks of the dry and rainy seasons, there is not enough power to supply the whole town. Figure 37 shows a seasonal pattern in which the peaks of the rainy seasons have the lowest generation and consumption rates. By means of a hydraulic pump, the speed and active power of the generator can be managed manually.

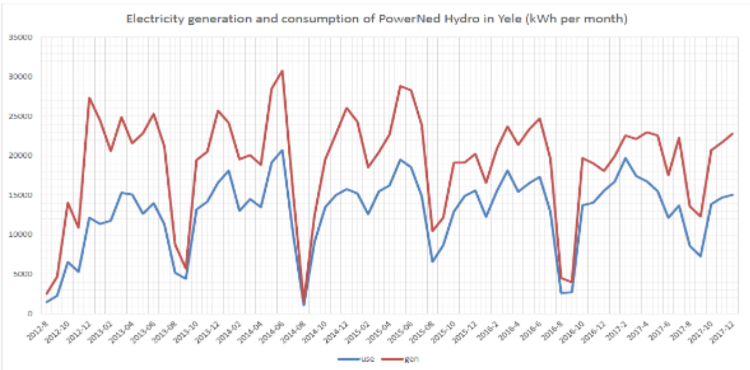


Figure 37 kWh generation and consumption 2012-2017

The hydropower plant is located next to a natural rapid in the Teye river. The river is diverted through an intake channel, through which the water flows before being dropped in the turbines. In the peak of the rainy season, there is a backwater flow from the river at the outflow channel of the hydro. The water level backstream of the hydro is too high, resulting in a too small head to generate enough power. At the end of the dry season, the flow discharge is too low, although banking of the river with sand bags at the natural falls mitigates this problem partly. The banking process is increasing the head in order to generate more power. It is a waste of effort that the dam is flushed away during the rainy season. A concrete dam in the Teye river is one of the company's long-term goals. A rationing schedule during the peaks periods manages which parts of Yele are supplied. At the start, the rationale was misunderstood by some people, but now most people understand and accept the situation.

Figure 38 Banking of the river

PowerNed is not using a diesel generator as back-up. Only the hydropower plant supplies electrical power to the distribution grid. From the generator of the hydropower plant, the power is transformed by a step-up transformer to a 2km 11,5 kV transmission line. This transmission line transports the power to three transformers that lower the voltage level down to 400 V for distribution lines (7,5 km) to the customers [S24]. The map in

Figure 39 shows the three specific areas which are supplied. The 'industrial area' contains the palm oil factory, the regional hospital, a waterplant, four guesthouses and a few households. The 'junction area' contains a lot of newly built houses over the last 10 years and comprises a lot of small-business activities including some welding shops. The 'oldtown area' is the original centre of the town and consists of a lot of customers with small energy consumption, a radio station and a small governmental hospital. A gas station is connected to both 'junction' and 'oldtown' lines. For the industrial area it is important to notice that the hospital has a 3 phase, 30 kW solar 'container' (18,7 kWp). The container contains 48 OPzS batteries that can store the generated power of 72 solar panels during off-peak periods. Although the system can deliver the generated power back to the 'hydro' distribution network, at this moment the electricity is used only for the hospital [S35]. Secondly, the mills of the palm oil factory have a substantial power demand.

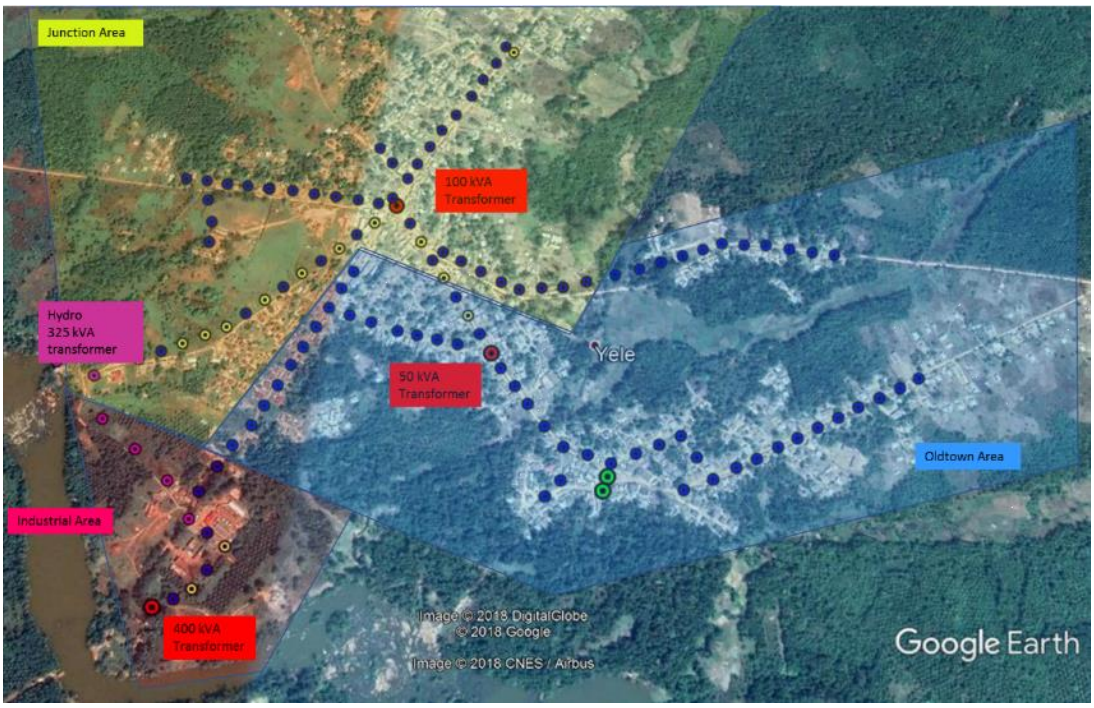


Figure 39 Map of Yele with different areas

If all mills are in operation, they use at least 16 kW, while the 'industrial' line required a capacity of 15 kW without the activities of the mills. During low generation capacity periods, this leads to frequent brown-outs and black-outs. The staff of Nedoil and PowerNed discuss in times of lower generation whether Nedoil can use the power from their own diesel generator [S19].

Figure 40 Solar container hospital

The hydro in Yele is lacking a central control and monitoring unit. At this moment the mode of operation is dependent of technicians that visit the control panels in the power station to see the frequency, generation and consumption. The frequency is regularly instable, and the voltage is fluctuating a lot, which makes appliances vulnerable. For maintaining the power quality, active and reactive power balance, an automatic system that can change the mode of operation can improve the efficiency of the system.

Figure 41 Control unit hydro plant

Looking at the demand side, the network has a total of 340 connections. Figure 43 shows a detailed overview of the different customers [S18]. These are mainly households (300), but also a palm oil factory, a water treatment plant, two hospitals, a telecom communication tower, and several small business enterprises are connected with the distribution grid. Based on the demand load in Table 20, three categories can be distinguished with related monthly consumption: domestic/households' consumption, commercial/industrial consumption and public consumption (hospitals, radio station, schools, etc.). The values are determined during the field observation and PowerNed reports. The commercial/industrial consumption has the highest individual consumption, but also the highest total consumption per month. The households have a low consumption rate per households, but due to the high number of connections, the total consumption per month is high. The number of households' connections (340) is higher than the number of actual residential customers (300). Some households have a prepaid postpaid meter, while they are not using electricity, because of a faulty meter or non-payments. The public facilities have a moderate demand load and a limited number of customers, which results in the lowest total consumption per month.

Type of customer	# of connection	Average consumption [kWh/year/household]	Subtotal [kWh]
Households (prepaid)	280	180	50400
Households (post-paid)	20	288	5760
Small business	15	540	8100
Hostels	2	480	960
Welding workshop	5	1080	5400
Dispensaries	3	180	540
Churches / mosques	5	180	900
Primary schools	2	60	120
Business / expat housing	4	5760	23040
Communication tower	1	11400	11400
Radio Station	1	960	960
Water plant	1	1560	1560
Hospital (LHMC)	1	6600	6600
Hospital (governmental)	1	1200	1200
Mills (Nedoil)	1	15300	15300
TOTAL	340	45768	132240

Table 20 Demand load customers Yele

Type of consumption	#	Monthly consumption [capita in kWh]	Total monthly consumption (kWh)
Domestic	340	15,6	4680
Commercial/Industrial	31	174	5395
Public	11	85	945

Table 21 Customer categories

During 2018 the hydropower was 85% of the time operational. 15% of the time the hydro was not operational due to maintenance and water level issues. Figure 42 shows two 24-hours demand profiles, which are determined by the consumption patterns. The blue line shows the average pattern of two days monitoring without running of the mills of Nedoil, the orange line shows the average pattern of three days monitoring with running of the mills. At night there is a steady consumption due to fridges, security lights, etc. In the morning a typical pattern shows the wake-up activities of the Yele people, like listening to the radio and lighting. Commercial and industrial activities shape the consumption curve during the day. In the evening a second peak shows the evening activities, like studying, charging phones, watching TV's and small business activities. The graph is based on some meter recording.

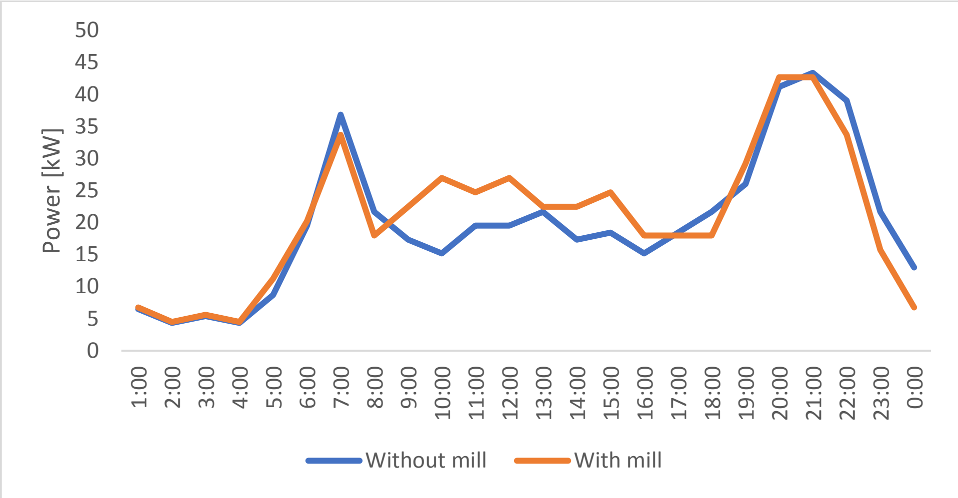


Figure 42 Demand profile 24-hour Yele

Most of the maintenance work can be done by the local technical team. Cables are cleared, households are connected, repairs are done at the hydro plant. Spare parts and cables can be bought in Makeni, about a 1,5 hours' drive along dirt roads from Yele. Panels, meters, equipment and specific spare parts for the hydro station need to be imported from foreign countries, because of their unavailability in Sierra Leone. The absence of a local suppliers makes the supply chain of spare parts quite vulnerable and expensive.

Because of the AC-configuration of the grid, it is possible to expand the network and add more generation technologies on the grid. The availability of more generation sources will provide a more stable power supply with a higher reliability rate. PowerNed wants to expand its network in the future at least to 1000 customers, which is possible with the current capacity.

Lessons learnt 'Technical challenges'
• **Focus on load demand management is essential for the reliability and stability of the mini-grid.** • **Monitoring and metering of the technical system generate data to moderate the system.** • **A hybrid configuration decreases the dependency on a single generation source, increase the reliability and income flow.** • **Incentives to stimulate productive use during off-peak hours increase the efficiency of the system.**

5.1.4 Economic aspects

The reparation and renovation of the hydro mini-grid has been financed mainly by funds and donor money collected by the Stichting Support Lion Heart Foundation. The Schokland Fund, the Dutch Daey Ouwens Fund and the German DeveloPPP program funded the hydro project over 1.7 million euro in grants. The manufacturer of the turbines, Newmills, also co-founded the turbines [S24]. At this moment the revenues can cover the running costs. For investments and large expenditures, PowerNed is dependent on donations. These donations are done sometimes in kind, like the transformers that have been donated by a Dutch system operator.

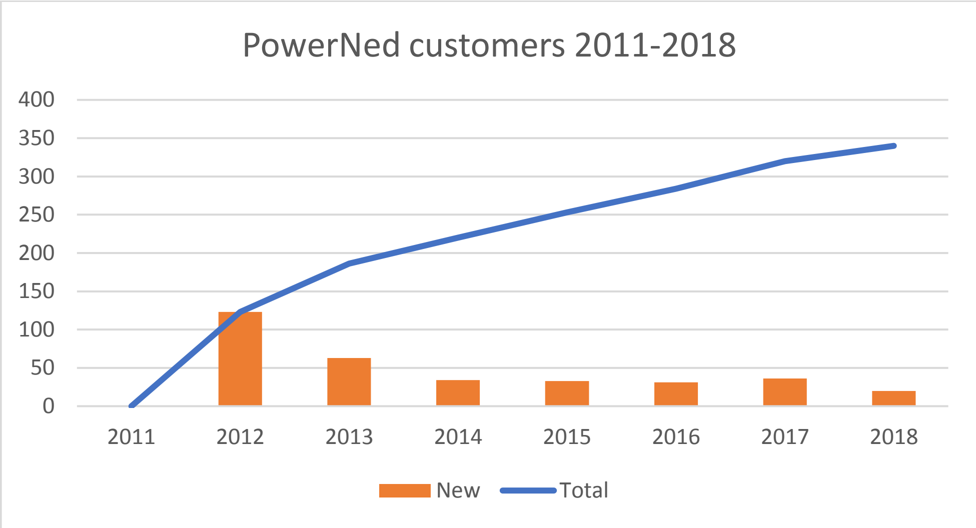
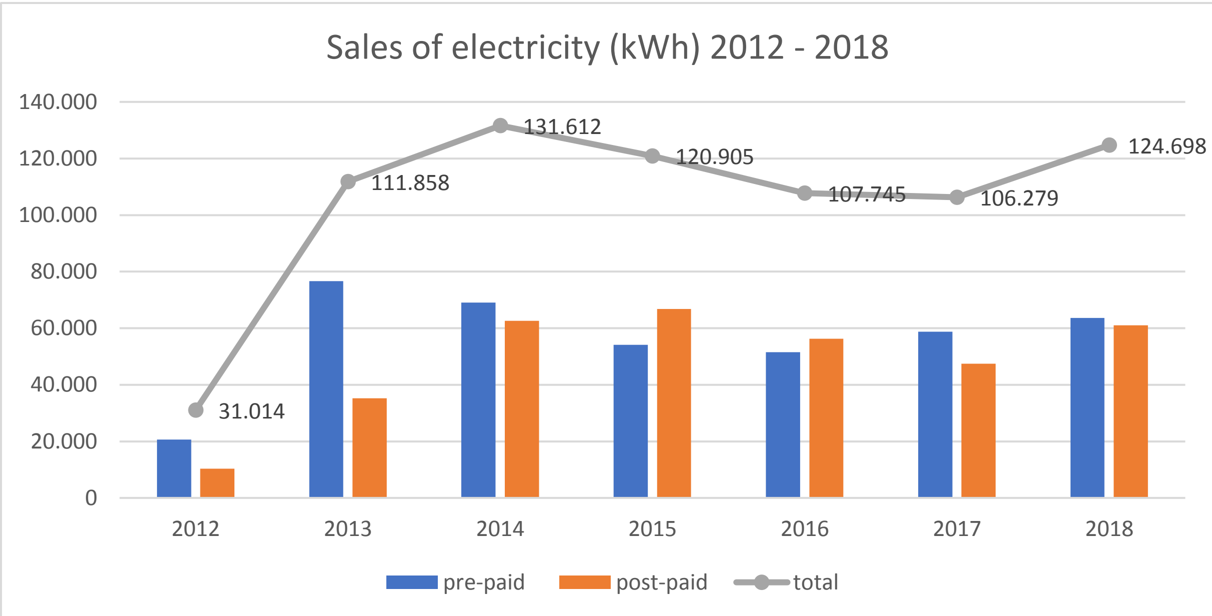


Figure 43 PowerNed customers

The first years after launching the highest number of customers were connected. People wanted to be proud owners of having electricity access and a promotional package was stimulating to become a new customer of PowerNed. In the next years the number of yearly new connected people has decreased, because of the turning over from the promotional period to a more market-based regime. Despite of the number of connections, the consumption of connected customers is affecting the economic viability much more. In the previous section about the technical sustainability the consumption pattern has been discussed, but these patterns correlate with the income flow [S25]. PowerNed benefits from a high number of commercial and industrial customers. These customers have a higher consumption, usually more financial resources and the connection costs per used electricity (wiring, meters) are lower. The palm-oil factory, the hospitals and the communication tower of Orange are important customers. The establishment of a large agro-industrial company, which is now starting their activities in Yele, will increase the total demand, but also results in higher revenues for PowerNed.



Prepaid-meters and post-paid meters are installed at each customer for payment and to manage and monitor the customer load. The pre-paid meter operates as a pay-as-you-go system. Three retailers in Yele buy the prepaid cards in bulk and sell them to the customers. The retailer receives a fixed percentage on each card sold and profit from the electricity trade. The cards have certain amounts of kWh credit (5, 28 or 56 kWh) which can be used by households to charge their meter. If the credits run out, it is not possible to use electricity anymore. The 5 kWh cards appeared the most popular. The people have normally a minimum cash balance, they prefer the cheapest kWh-cards.

Figure 44 Prepaid meter Yele

Most industrial and commercial customers have a post-paid meter, which gives continuously electricity access. This meter is read by the PowerNed team every first day of the month, followed by receiving a monthly bill. Most large industrial customers are reliable customers and pay their bills within the payment period. Some residential customers have also a post-paid meter, but in many cases, there is a (temporarily) lack of payments. After some time, these customers are disconnected from the grid. It seemed that this kind of meter only works for people that are reliable and able to pay the bills. A lot of domestic post-paid customers have a lot of outstanding bills and have several excuses for their non-payment. They continuously requested for extensions of their payments or made only small part-payments. It was hard to argue with their reasons for not paying delayed salary, failed harvest, death of a family member, or other incidents that affected their financial situation. PowerNed has become stricter in their enforcement policy, some customers have built up debts of bills for several months. Sometimes a case of fraud or abuse has been discovered, the suspected customers received a penalty dependent on the seriousness. Overall it is evident that there is a difference between the formal rules and actual practice. Clear and strict procedures in policies in contracts actually are more flexible and lenient [S19], [S20].

In Table 22 the tariffs are shown. The most expensive part is the smart meter. These meters are expensive to fabricate and must be imported to Sierra Leone. Otherwise, these tariffs create an awareness amongst customers to maintain and clean the meter. Dependent on the distance between the pool and the meter, some meter of cables is needed to connect the meter to the distribution network. After commissioning of the meter, the people need to buy kWh credits to charge their meter. There are two different tariffs. Residential customers pay less for their kWh consumption and service fee than commercial or industrial customers.

In Table 23 the average income and expenditures of customers in Yele is listed. It is obvious that the electricity tariffs align with the WTP of customers, but that the high connection costs make it less affordable for every customer to get access to electricity. In practice some households share their connection, to provide phone charging for their neighbours.

Specification	Tariff (Le)
Application form	5000
Connection fee + meter	1.175.000 (595.000)

Cable	27.000 per m
kWh-price households	1600
kWh-price industrial consumers	1800
Service fee domestic	15.000 per month
Service fee commercial/industrial	18.000

Table 22 Tariff table Yele [S19]

Affordability of electricity access	All	Rich	Poor	Units
Monthly income	600.000	900.000	300.000	Le/month
Monthly expenditures	550.000	700.00	300.000	Le/month
Average consumption	15,5	50	5	kWh/month
WTP	1800	2000	1600	Le/kWh

Table 23 Economic characteristics Yele (data based on field surveys)

Lessons learnt 'Economical challenges'
• **Only current limiters and prepaid meters are effective as metering systems in a low-resource and seasonal-influenced setting.** • **Make use of flexible tariffs to increase the affordability and the increase use factor.** • **Strict enforcement policy of payments is necessary.** • **Commercial and industrial customers are a pillar for the economic viability.**

5.1.5 Policy aspects

In comparison with other villages in the chiefdom, Yele has made a lot of developments. Swinckels (92) has done research on the impact of the hydropower plant on the development of Yele. Access to electricity created new business activities and stimulated the local economy. Houses in surrounding villages have been fabricated from mud and thatched roof, in Yele, a lot of houses are plastered, having zinc roofs. People can sell and drink cold drinks, to use computers, to charge their phone locally and have business and relaxation activities in the evening. The services and facilities attract people from outside to settle in and around Yele.

Figure 45 Economic activities in Yele

It was important to make clear the position of PowerNed within the community of Yele. Contrary to the development trajectory the company envisioned, some expect the aid role of PowerNed in Yele to grow. Swinckels (93) mentioned that several stakeholders argue that the company should provide electricity for free for several institutions in the town. Some see it as a Corporate Social Responsibility of PowerNed. PowerNed is balancing between a non-profit NGO and a for-profit business. Electricity that is used for street lights and pumping water to the town is provided for free. But household connection cables and meters are charged. And the responsibility of PowerNed is limited up to the meter system. Some customers consider PowerNed as problem solver of all electricity problems, neglecting their own responsibility for their appliances. By educating people PowerNed tries to make people aware of the role and responsibility of PowerNed [S25]. Balancing the grid is not easy, due to the volatile energy pattern, low resources and high investments costs. PowerNed explained several times that electricity management is not just a 'switch-on-switch-off' activity, but rather complex and not-predictive.

PowerNed and the Government of Sierra Leone (GoSL) have signed a Memorandum of Understanding (MoU) during projects kick-off. Since the Ministry did not possess enough funds itself to repair the plant, it was very keen on foreign investment in this regard. PowerNed has been authorized to set up a mini-grid and to sell electricity to the community people of Yele. The MoU formalised the position of PowerNed and made clear the relation with the government [S24]. Nevertheless, PowerNed tried to make the operation of PowerNed independent of political interference. Politicians can use electrification projects for election purposes while these projects need more sustainable support. Otherwise, for regulations, information and institutional issues PowerNed has a lot of informal and formal contacts with governmental bodies and ministers. In a formal culture in which informal relationships are very important for doing business, PowerNed visited regularly ministers and cultural leaders, like the paramount chief. The managing director is responsible for the contacts with these institutions.

Despite many efforts, PowerNed is not receiving support from the government in form of subsidies to expand the network or to maintain the waterplant. At this moment the connection fees are relatively high to the level of income, because of the high costs of the prepaid meters. If the government subsidies this prepaid meter, more people can be connected to the grid. It is difficult to transform ministerial attention in sustainable support of the utility. Although PowerNed is a private company, the social-economic impact is evident. PowerNed is not expecting the arrival of a new grid within 15 years, while Yele is located remotely. Since 2018, a new government is focussing also more on education than grid extension. Nearby towns, such as Matotoka and Mile 91 have been waiting for grid connection for many years [S18], [S24].

The past years PowerNed professionalised their reporting activities. A five-years report gives insight in the generated power and electricity sales of PowerNed. Reports of the operation is essential to justify funding and attract new funding. Last two years PowerNed is working on a plan to expand the network, to improve the intake and outlet canal, to replace the turbine that was broken, to add generation capacity by solar panels and to redesign the network configuration. However, long-term goals are not formalized in any document.

Last point for the policy aspects of mini-grids are the procedures for cases of non-payment, theft and fraud. For example, the technical team discovered some cases of meter bypasses. Cables and connection are altered to obtain free electricity supply. The prepaid or post-paid meter are either completely out of the electrical circuit or are not running due to the creation of a parallel circuit. For PowerNed it is on one hand important to follow a strict enforcement procedure to discourage malpractices. On the other hand, it is important to retain its community involvement and image. For non-payment issues, PowerNed has become more strict. People that refuse to pay, are pressed to pay or they are disconnected from electricity [S19].

Lessons learnt 'Policy challenges'
• **PowerNed is balancing to be independent of political interference and to receive governmental support.** • **For enforcement policy, loosing community support, need to be prevented.** • **Clear long-term objectives can make monitoring and focus points easier.** • **In Yele evidences of the social-economic impact of the mini-grid are quite visible.**

5.2 Segbwema

In 2017 a solar park in Segbwema (Kailahun District) started its operation. Segbema is located in the far east of the country and has about 10,000-12,000 inhabitants. The Segbema solar park is part of the PRESSD-SL project, a cooperative project between the Ministry of Energy and Welthungerhilfe. In Segbwema they have installed 405 PV panels with a total installed capacity of 127 kW for the community and another 20kW for the Segbwema Nixon hospital. 144 Lead-Acid batteries with a capacity of 488 kWh secure the electricity supply. At this moment the grid has been connected to 87 households, but 254 customers are waiting for a new connection. According to the inhabitants of Segbwema, the solar energy reduced the expenditures on kerosene enormously. People started with new businesses, like selling drinks, cold water and charging stations [S6].

Indices	Range of characteristics
Population	10000-12000
Economic activities	Fishing and Farming: palm oil, cassava, potatoes, plantain, bananas, pepper
Commercial activities	Welding, retail, grain milling, palm oil processing
Households energy use	Electric bulbs, fans, radio sets, cell phones, refrigerators
Local cost of diesel	8000 Le (*exchange rate: $1 = 8500 Le)*

Fact sheet mini-grid Segbwema	
Location	Segbwema, Kailahun District
Start date	2016
Technology	Solar-PV (405 panels), AC-bus system, 5,5 km LV distribution
Storage	144 Lead Acid Batteries (Capacity 488 kWh)
Installed capacity	127 kWp
Number of households served	204 households (130 waiting customers)
Other consumers	Water plant, communication tower, hospital, clinic, schools, churches, mosques, small enterprises
Ownership and management	Private utility

Figure 46 Segbwema map

5.2.1 Social aspects

The mini-grid in Segbwema is part of the PRESSD project, which also contains mini-grids in Panguma and Gbinty. The three mini-grids are managed by a general manager and accountant, who are involved in the accounting, administration and general operation of the mini-grids. One electrical engineer visits the mini-grids two times a year for supervision and technical advice about maintenance, repair and replacement. The daily operation of the local grids is managed by a local staff, consisting of 1 local administrator, 1 administrator assistant/ customer relationship, 2 local technicians and 3 guards that are responsible for surveillance and cleaning of the system. The local technicians connect and disconnect customers, ensure a stable operation and supervise the performance of energy meters and the overall system. In case of a failure, they report to the local administrator, who is responsible for the daily operation. He is also responsible for the cashbooks, deposits and registration of the users. The administrator assistant is supporting the local administrator in these tasks [S4].

Figure 47 PV-grid Segbwema

Segbwema is one of the larger villages of Sierra Leone. Until 2017 the small business retailers were totally dependent for their electricity generation on diesel generators. A substantial part of the business revenues was secluded for the fuel costs. The arrival of a mini-grid altered this situation, by connecting this business to the mini-grid. Although not every retailer has been connected yet, more and more enterprises will profit from the power of the local mini-grid [S8]. A hospital, a telecommunication tower and a radio station has already been connected. Besides of these larger consuming customers, up to 87 residential customers or households have been connected to the distribution grid, and 254 customers are waiting for a new connection. At this moment 70% of the customers are residential customers and 30% are industrial customers. Besides these connections the company is also maintaining and supplying 20-40 streetlights, from which the whole community is benefits [S3], [S8].

In general, most people of the communities are positive about the mini-grid. They are development minded and consider the mini-grid as essential for the socio-economic progress of the area. A small people have complaints about the mini-grid, they are looking only on getting money and want to receive the service for free. Sometimes they are thinking they have some priorities, because of their position within the community. For the company it is important to mediate between all the stakeholders.

If customers want an electricity connection, they can show their interest by visiting the local office and filling in a form. In the form also the rules and responsibilities of both parties are clarified. Subsequently, a local technician will visit the house of company to check the wiring of the house and the performance of the appliances. They test the connection and recommend using qualified materials. After payment of the connection fee, the house will be connected, and a prepaid dispenser will be placed [S6].

The company has three ways for community education and engagement. At first, they have every month a radio talk-show, the 'mini-grid-hour'. In the radio show the main issues and development are discussed, but also interaction with the community is important. People can call the radio show to ask questions. The radio show is very effective in a culture with illiterate people. Secondly, they ask frequently what appliances people use and advice how to connect them. Thirdly, technicians are going every day around to monitor the efficiency of the system and check the appliances in case of malfunctioning or underperformance. Education and communication are very important. Most people have no experiences with an electricity infrastructure and company. The community sees cash transactions happening in the office. They question what it all entails to run a mini-grid and they need to understand that an electricity company is not an aid organization, but a business enterprise [S4]. Of course, they want to improve the socio-economic situation of the village, but the company needs to be economically viable. Sensitization of the community leaders is required, because they can support or block the activities, and they are responsible for the long-term plans of the community.

5.2.2 Technical aspects

In the map in Figure 48 the actual configuration is shown. The control room is located in a container next to the main base station at the terrain of the Nixon hospital. At the main base station, the power is generated and distributed to the town. At the hospital compound also a sub-base station with other solar panels has been placed. The generated power of the sub-base station is mainly secluded for the power demand of the Nixon hospital. From the solar parks, the power is distributed by MV-lines, and transformed to LV-lines that are connected to the customers [S4].

All customers have a prepaid meter that monitor their consumption and provide the customers the possibility to charge their credit by prepaid-cards. The technical team is reading the meter every month to monitor the total demand load of all customers. At the start a trial has been executed with three larger customers to give them a post-paid meter, but they altered this in 3-phase prepaid meters after the experience. Current breakers have been considered in the feasibility phase, but they are less accurate for metering of the system and are vulnerable for lightning. The monitoring is important for checking the connections in the houses. If the appliances have a negative power factor, it affects and disturb the generation assets in a negative way [S2], [S3], [S4].

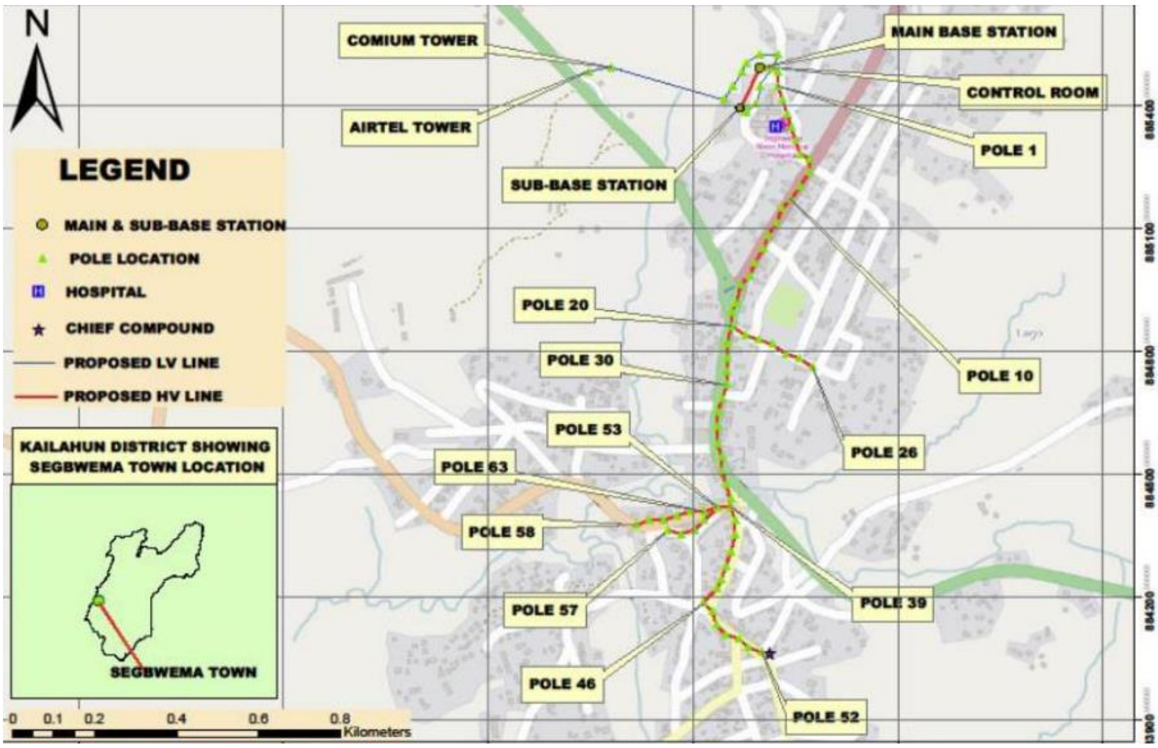


Figure 48 Map of Segbwema

From the start of the project, the system has been running under the wrong configurations. Originally the system was designed to have a diesel generator that can accommodate if the irradiation factor is too small. Due to the lack of extra generation by a diesel generator, the system has no chance to charge the batteries up to 100%. This causes a successive depreciation of the potential battery capacity and sulfation. Furthermore, due to the not fully charged batteries, they are discharged up to a level of 20%, while for the lifetime of the batteries it should be better to discharge them never below 40%. At this moment the system lost already 20% of their state of health. The system cannot supply the whole day continuously power, because of the battery lifetime. To save the batteries, a daily break has been set between 1 and 5am and if the batteries goes below 50%, the system will shut down at 10pm. Also, they met a lot of problems with the invertors and cluster controllers, quite often resulted by weather conditions. Thunder and lightning are critical moments for the system, so the system need to be resilient against these weather conditions [S4].

For the technical sustainability a smooth supply chain of spare parts is essential. Especially when meters are faulty or critical parts are broken, they need to be replaced soon. Some spare parts are available in the country, but more specific equipment and qualified material is only available abroad. It takes a while from the moment the local team orders a spare part until the items arrive. The bureaucratic processes of the supply chain frustrate the staff members and only the MoE can regulate this process better.

On the demand side several meters are monitoring the output of the system. Cluster controllers and Hobo-meters can also check the system losses within the system. The development partners can oversee remotely the performance of the system. Figure 49 shows the average consumption over one day based on the data from month January. The peak is measured at 9 pm. Figure 50 shows the average daily consumption in the second half of January. The graph shows that the daily generated power has not high differences.

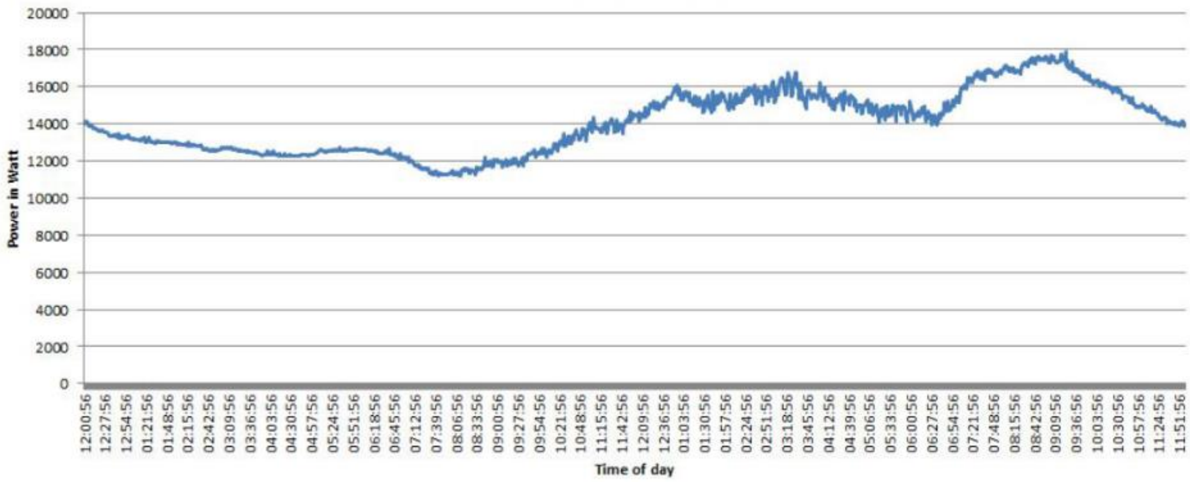


Figure 49 Daily consumption pattern (based on confidential reports WHH)

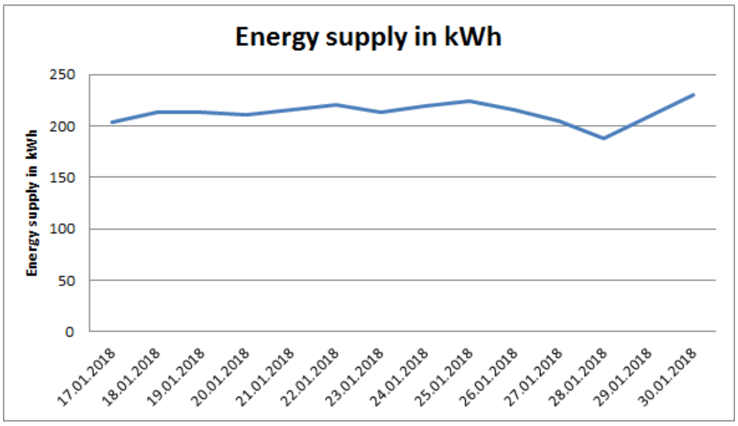


Figure 50 Average daily consumption second half of January

The inverters of the solar system can regulate the generation down if the batteries are fully charged. In the dry season this is achieved around 12 o'clock. In the graph below it can be seen that at that time a lot of potential energy is lost. If the productive use will be stimulated more during daytime, part of the available power can be used in order to obtain a higher efficiency of the system and higher revenues.

Figure 51 Battery charging

5.2.3 Economic aspects

According to the inhabitants for Segbwema, the access to the electricity grid reduced the expenditures on kerosene enormously. It is important to stress that the mini-grid reduced the overall costs of energy demand. The fuel costs, costs for batteries and charging phones in rural communities are high, and people are paying less money to the same services after the mini-grid arrival. People started with new businesses, like selling drinks, cold water and charging stations. The is also focussing on this type of customers to increase the economic viability of the mini-grid. For a sustainable operation the productive use of energy is essential. For larger consuming customers a reliable power supply is required, otherwise they will continue to use diesel generators and their own solar systems. These generation sources are more expensive but are high reliable. At this moment, the larger companies are supplied by a special line, which are giving priority if there is a shortage of available power. The PRESSD mini-grids want to secure a reliable power supply as much as possible.

But also, for the residential customers a reliable power supply is important. If the reliability of the service is higher, the willingness to pay for the service increases. The ability to pay is determined during consultation by independent experts in the feasibility phase. Based on the consultations of the socio-economic situation, the EWRC set the tariffs. These tariffs are different per area. For example, the tariffs of Segbwema are different from the tariff that are set in the other PRESSD projects in Panguma and Gbinty. There were some struggles with the tariff approval in the initial phase of the project. The Energy and Water Regulation Commission (EWRC) did not agree with the initial tariff, which was too high. Later a new tariff was set on 1800 Le/kWh. Besides of the consumption tariffs, the company started with charging a service fee of 5000 Le per month. In case customers are not in town for a period, the service fee needs to be paid. If people are not paying the service fees, the people will be disconnected from the distribution grid [S4], [S6].

Tariff	User	Power limit (W)	Energy limit (kWh/day)	Energy price (SLL/kWh)	Minimum Monthly charge (SLL)	Connection Fee (SLL)
1.0	Residential basic	440	1	2500	20,000	350,000
1.1	Residential advanced	2,200	4	2900	35,000	700,000
2.0	Commercial	3,500	7	3200	55,000	
3.0	Industrial single phase	10,000	15	3500	70,000	
3.1	Industrial three phase	11,000	unlimited	3500	70,000	1,744,000

Table 24 Tariffs in Segbwema [S8]

The mini-grid is transforming from a 'project', towards a social enterprise, that needs revenue to cover the costs. In the initial phase, the project was highly sponsored by four international NGO's, because of the high start-up costs of mini-grids. The long-term goal is to achieve an economic sustainable situation in which the company can cover the running costs. It is important to make clear to the community this position and responsibility. Because NGO's are affiliated with aid, it is sometimes difficult to emphasize that mini-grids are more business entities.

Affordability is one of the challenges of the system. Not all people alongside a distribution line are connected because not everyone can afford the costs. Especially the connection fee is for some people not affordable. Table 24 shows the tariffs in Segbwema. There are different categories of customers to make the tariff setting more aligned with the financial capacity of the customers and to increase the revenues of the company.

5.2.4 Institutional aspects

The Segbema solar park is part of the PRESSD-SL project, a cooperative project between the Ministry of Energy and international NGO's. Four international NGO's sponsored and developed the mini-grid, of which WHH and COOPI have the leading positions. The NGO's work together with the MoE and EWRC for institutional aspects, but WHH and COOPI are the owners of the mini-grid. During the feasibility phase, different community consultations have been taken place to research the socio-economic and institutional situation. The ATP and WTP of the people have been researched by the EWRC to determine the tariffs.

Figure 52 Distribution grid

From the start of the project a 'community advice committee' has been established. In the committee representatives of the local council and the paramount chief, members of parliaments, youth leaders and customer are involved. Engagement of community people and private operators is essential. The committee has a meeting once per month. At the meetings the main developments, problems and questions are discussed. The committee is very important for both support from and effective communication with the community. The close relationship with the paramount chief and the political leaders and counsellors provides also clear institutional embeddedness [S6].

The rules and regulation are formulated in the form that people must fill if they want a connection. In cases of fraud, a strict procedure is followed to enhance the regulation. At first, evidence need to be secured. If the evidence of fraud has been proved, the matter is transferred to the paramount chief. He takes the right measures, which means quite often removal of the prepaid meter. If the evidence is less clear or the mistake is small, a warning letter is given [S4]. At this moment only half of the town is covered by the grid. In the future, the network will be expanded to the other parts of the town to give all people access to electricity.

5.3 Assessment minigrids

Based on the information described in sections 5.1 and 5.2 we can compare the mini-grids. The score of the indicators can be used to compare the grid and its performance. Especially differences at indicator scores are interesting to learn from each other. framework is a tool to discuss and rank the mini-grid relatively, not to determine exact scores. The scores are validated by expert interviews [S4],[S7],[S31]. Each sustainability dimension will be discussed below.

			Yele	Segbwema
Social	*Community involvement*	Community education	0,50	0,75
		Support of local leaders and politicians	0,75	0,50
		Share of population with electricity access	0,50	0,25
		Training and employment of local people	1,00	0,50
	Ownership	Suitability ownership model	1,00	0,50
	Benefits & Acceptability	Allocation of electricity between customers	1,00	1,00
		Awareness about connection and consumption	0,50	0,75
		Availability of streetlights	0,50	0,75
		Ability to pay for electricity services	1,00	0,50
		Electricity access public facilities (schools, clinics, etc)	1,00	0,50
SCORE			**7,75**	**6,00**

The scores are relatively higher for the mini-grid in Yele than Segbwema. This can be explained by the fact that the mini-grid in Segbwema is implemented by a large, international NGO, while the grid in Yele is implemented together with the hospital and the palm-oil plant by a small NGO. Local people were attracted to join one of the companies. In Segbwema the mini-grid has more a stand-alone position, strengthened by the ownership structure of a management layer that is also responsible for the mini-grids in Gbinti and Panguma. The mini-grid in Yele is operating longer, which results in more embeddedness in the community and more connections to public services. In Segbwema, they are still busy with the expansion of the grid, which explains the lower connection rate. In Yele the awareness has been grown that PowerNed is a business stakeholder, while in Segbwema the company is still considered as an aid-partner. It is pitiful that PowerNed decreased their focus on organizing community meetings and radio shows. Participation of the community was in the beginning a key factor but get less attention during the operation of the hydro-network, especially in Yele. During the start of the mini-grid, workshops have been organised for educating and training local people. Now there are no more specific activities to engage the local community. In Segbwema the management has more attention on engaging and educating people to increase customers awareness of their electricity connection and consumption.

			Yele	Segbwema
Technological	*Monitoring & management*	Metering system mini-grid	0,00	1,00
		Managing of electricity consumption	0,25	1,00
		Match of technical design with demand pattern	0,50	0,75
	Reliability & efficiency	Availability and utilization of services	0,75	0,50
		System efficiency	0,25	0,50
	Operation & maintenance	Availability equipment and spare parts in the country	0,50	0,75
		Dependency on foreign assistance	0,75	0,50
		Quality equipment and materials	0,50	0,75
	Modularity	Compatibility with future grid integration	1,00	0,75
		Adaptability and expandability	0,50	1,00
SCORE			5,00	7,50

The technical sustainability of the mini-grid in Segbwema is relatively better than the mini-grid in Yele. The used technology in Segbwema is more up to date and the monitoring facilities are much better. In Yele, it is difficult to match the demand load and generation load continuously. This can be done only manually by the oil pump. The monitoring and metering possibilities of the technical system are limited and should be improved. The hydro in Yele is lacking a central control and monitoring unit. At this moment the mode of operation is dependent of technicians that visit the control panels in the power station to see the frequency, generation and consumption. The frequency is regularly instable, and the voltage is fluctuating a lot, which makes appliances vulnerable.

For Segbwema, the technician can monitor the load profiles remotely and can manage the system easy. Also, the used equipment (invertors, transformers) in Segbwema complies more with the latest technology standards. Nevertheless, both mini-grids cannot meet the demand continuously. In

Segbwema this is caused by an inadequate level of battery capacity, in Yele the water level hinders the generation capacity. Spare parts for PV-system are increasingly available in the country, due to the development of solar mini-grids in West-Africa. The spare parts for the hydro-mini-grid are often not available in the country and need to be imported. The mechanical character of the hydro make maintenance for the local staff less complicated. The PV-system in Segbwema can be upscaled easily, while the system is modular. Nevertheless, the lack of a diesel generator in Segbwema decreases the efficiency in Segbwema. In Yele, a second turbine can be installed to double the generation capacity, but it should be recommended to make the mini-grid hybrid to satisfy the future demand.

			Yele	Segbwema
Economical	*Costs and investments*	Financial support government Operation and maintenance costs	0,00 0,75	0,00 0,50
	Productive use	Industrial/commercial customers with productive use Anchor client connections	1,00 1,00	0,75 0,50
	Financial	Non-payments or outstanding payments Tariff lag Micro-credit facilities	0,50 1,00 0,50	1,00 0,75 0,50
SCORE			**6,79**	**5,71**

Both mini-grids are dependent on grants and subsidies to cover their investments costs. The spare parts and operational costs are lower for the mini-grid in Yele. The recovery of the operational costs is higher in Yele. More important, the mini-grid in Yele is connected to more industrial and commercial customers, resulting in a higher rate of productive use of energy. For Segbwema it is important to attract more businesses customers to the community and connect them to the grid. The post-paid systems in Yele resulted in more non-payments and outstanding payments. Although PowerNed will banish the post-paid meters for residential customers, at this moment the non-technical losses in Segbwema are lower. In both communities a bank is housed. Nevertheless, for most people acquiring credit and loans is difficult.

			Yele	Segbwema
Policy / institutional	*Regulations*	National regulation on tariff setting and licensees Tax breaks on imported (spare) parts	0,00 0,75	0,00 0,75
	Organization	Capability of staff Long-term vision company Defining of responsibilities between stakeholders	1,00 0,00 0,75	1,00 0,50 0,75
	Enforcement & Security	Enforcement of local policy Security of electricity infrastructure	0,75 1,00	0,75 0,75
SCORE			6,07	6,43

The scores for the national regulations are the same. If the developed and already described mini-grid policy will be approved by the parliament, the scores will increase. Both mini-grids benefit from qualified technicians and a capable manager. Nevertheless, in Segbwema the policy, standards and briefings are more professional. But, the mini-grid is also more interfered with by local and national politicians. In Yele the company has more independence than Segbwema, resulting in a better enforcement policy. To enhance the support of the community, both companies update regularly the community elders, the board of the community. They have together with the Paramount Chief the most powerful position in the community.

	Yele	Segbwema
Social indicators	7,75	6,00
Technological indicators	5,00	7,50
Economical indicators	6,79	5,71
Policy / institutional indicators	6,07	6,43

Table 25 Assessment sustainability indicators

Table 25 presents the final results of the sustainability assessment of the 34 indicators in Yele and Segbwema. The main differences are the scores of the social and technological dimensions. The Segbwema grid has better equipment and more monitoring tools that support the technological management of the system. The mini-grid in Yele has a higher embeddedness in the local community. In the next chapter, the lessons learnt that are derived from the assessment are described.

6 Lessons learnt

The mini-grids that are described in the previous sections are operational, but they are faced with many challenges. Based on the success and failures of the described mini-grids and the rural electrification strategy of Sierra Leone, some lessons can be learned to enhance the long-term sustainability of mini-grids.

6.1 Case-studies

On top-level, it is important that the government provides a clear set of regulations concerning mini-grids. During the development of the mini-grid in Yele, the responsible governmental agency NPA permitted private companies to enter the market. PowerNed was the first private company that operated as a utility in Sierra Leone. There were no regulations for mini-grid operators and the government has no experience with this kind of business. As a result of this lack of experiences, PowerNed was totally dependent on foreign knowledge and assistance. In Segbwema, the government has been involved more in mini-grid projects, but the development partners encounter unclear regulation and policy regarding mini-grids. Although the government presented mini-grid regulations at the end of 2017, the parliament has not approved the regulations yet. These regulations that are developed closely with UNOPS contain important procedures for the standardized tariffs, license arrangements, national grid arrival and import duties. It is important that these regulations are timely implemented, enforced and promoted, to secure both the position of communities and operators and to attract international investors. Existing mini-grids have been financed through grants and are catalysts for development, but private investors and commercially viable mini-grids are needed to make the sector more sustainable.

On the medium level, support from NGO's and knowledge institutions can help to gather data and knowledge. The mini-grid sector in Sierra Leone is quite new. Data and knowledge help to compare and benchmark the results of the mini-grids. The Energising Development Programme (EnDev) is gathering data from over the whole country to decrease the knowledge gap. Education institutes can also help to educate local people in the field of renewable energy. At this moment, several education institutes in Freetown are working to train local technicians. In the visited mini-grids there are enough qualified technicians to solve small problems. It is, however, difficult to attract qualified staff, who are willing to work in remote areas. Especially if the sector will grow, sustainable growth will be limited by a scarcity of qualified workers. Also, historical data and experiences of the mini-grids are required to compare the best practices of mini-grids in Sierra Leone. EnDev is also working on structuring information to support private and public actors to continue and start doing business with mini-grids.

On the bottom or local level, most lessons learnt can be determined. Below the lessons learnt are discussed.

Site selection

- Before starting to develop a mini-grid, preparation research on the technical feasibility, financial viability, community willingness to pay and possible technologies is important. Site selection is important, not all places in Sierra Leone are financially viable. Without knowledge about the socio-economic situation, the willingness-to-pay, potential customers and consumption, distance to the grid and accessibility of the area, it is difficult to take a decision between central grid connection, mini-grids or Solar-Home-Based Systems for the long-term. Locations with a high number of commercial and industrial activities and high levels of customer willingness to pay increase the viability of the mini-grids. Clustering several mini-grids can decrease the investment and operational costs, because of the economies of scale.

Community involvement

- Community participation from the inception of a mini-grid until operation is essential. Meetings with the community, community elders, youth leaders and government officials are important to increase the acceptance, a well fitted design and satisfaction within the community. Continuous interaction is essential for receiving feedback and detecting operational problems.
  In Yele, the developers of the mini-grid started with a palm-oil plant and a hospital. This increased the know-how of the community before starting the operation of the mini-grid. But they worked also close together with the paramount chief and community leaders. The mini-grid operation in Yele is highly adapted to the local conditions and leadership structures.
- Radio-shows and community meetings are organised in both mini-grids. The radio shows help to make people aware of the efficiency of their appliances and the limitations of the electricity supply. Comprehensive education regarding energy usage, connection and responsibilities is given. The community energy committee in Segbwema is representing all kind of customers. Such committee is very useful, for solving conflicts, gathering information from the community, spreading information, and support form the whole community.

Load demand management

- Load demand management is essential for a sustainable operation of a mini-grid. By managing the demand load properly though accurate monitoring and economic incentives to structure customers behaviour, the system will achieve higher efficiencies and is economically more favourable. The cumulative loads need to be large enough to profit from economies of scale for low-voltage lines, wires, metering systems.
- Installation of the grid. Therefore, modularity of mini-grid improve overspending on capital. The size and amount of generation assets can be increased (or decreased) during operation. The flexibility increases also the reliability and viability of the system. In case of undersupply, the reliability is low, and it is hard to retain customers, which require a stable power supply. Overcapacity results in unnecessary expenditures and a lower efficiency of the system. Modularity can improve the flexibility to scale up. For example, a company can start with an initial phase, in which a diesel generator replenishes the other generation sources and build the distribution grid and connect meter systems. After some months, they can expand the renewable generation assets, based on actual consumption and assessed potential.

Stimulating productive use

- The electricity revenues of household customers are often too small due to the low levels of electricity consumption. Connecting commercial and industrial customers is essential for achieving economic viability of the grid. But productive use is also balancing the load profile of the mini-grid through a higher utilization factor. Targeted financing of new and energy efficient equipment can be helpful. It can finally improve the capacity utilization. Stimulating productive use are done in Yele and Sumbuya, but in Yele there is not a certain approach how to increase the productive use.
- An anchor client with a high and stable load consumption, can increase the cost-effectiveness of mini grids substantially. The presence of locations in Sierra Leone that have a significant daytime productive load and a potential household consumption are rare. Most people are living from small agriculture activities. In small villages SHS remain more economic competitive than mini-grids.

Hybridization

- Hybridisation has positive impact on the reliability and cost-effectiveness of the grid. It is difficult to make purely solar-battery mini-grids reliable during peak loads. Using a diesel generator as backup can mitigate the power shortages, shutdown's and save battery capacity. The rainy seasons make generation sizing for PV-systems challenging, while the generated potential is much lower than in the dry season. Diesel generators can increase the reliability of the system and secure the customer loyalty, especially if substitutes (kerosene, diesel) are available.

Economic viability

- It is important to consider the ATP and WTP of households and business. To make the business case attractive with cost-reflective tariffs and to oversee the margins of the tariff settings. It is important to monitor the WTP during the operation of the grid to align the tariffs with the economic situation. Also, the connection charges and the process of getting connected are critical issues. The costs that customers need to be pay are too frequently too high. The costs need to be spread out over a longer period.

Monitoring and retail service

- Pre-paid meters or current limiters can be used for metering, because of the dependency of seasonal flows and volatile income patterns. Prepaid meters are preferred above current limiters, because of the fact they can provide more knowledge about the consumption pattern by remote monitoring. Although these meters are expensive, the monitoring can have a positive impact on the performance.
- In Yele local retailer agents are responsible for the sales of the prepaid cars. Although this system improves the inclusion of the community, it is generally problematic for the management of the system. In Yele, PowerNed has few information about the demand pattern of the customers. In Segbwema, the monitoring of the system is better organised and as a result they have more knowledge and data. It increases the ability of PowerNed to understand customer behaviour and provides the possibility to experiment if they are responsible for the prepaid card sales.

Organisation of the mini-grid

- The mini-grid requires capable companies or (private) utilities that have a high level of technical knowledge and is able to allocate the available power and to set tariffs economically strategic and fair. In Segbwema and Yele, qualified technicians are working in the company, but for maintenance on a system level, foreign professionals are needed. The staff turnover is in both mini-grids low.
- Bill collection is at times a difficult task. Some customers want special favour or have no financial resources to pay. It is important to emphasize the behaviour of one customer affect the sustainability of the whole system. The company must be reticent to make exemptions.
- Fraud and free-rider behaviour through bypassing the prepaid meter adds to the non-sustainability of the system. By signing a contract between customers and the company, the company can use an enforcement policy in cases of misuse. In the contract the responsibilities of each customers are clearly defined. Strict enforcement policy is essential to prevent obviation of the rules and responsibilities. This enforcement needs to be done in close cooperation with the community council. Working together make the company less vulnerable for blaming and shaming.

- The PRESSD project are working together to reduce the costs. They have one accountant, one general manager and one technician that work at the three places. In Yele the dependency on foreign assistance is high and the cooperation with other mini-grids is negligible.

Complexity and interrelatedness

- A dynamic behaviour was shown in the mini-grid system. Income levels determine household's electricity demand, households and industrial demand loads determine peak demand, but also the load factor. And the efficiency of the system determines the availability of electricity for income generating activities.
- Mini-grids should therefore be developed as incremental systems. Incremental means a step-by step approach that can mitigate with future uncertainties.

6.2 Requirements for mini-grids in Sierra Leone

The literature review and the evaluation of the case-studies in Yele and Segbwema underline the importance to use a holistic approach. The social, technical, economic and institutional aspects interrelate with each other during and should be considered during the all stages of the project. Within this complex environment, proper demand management, scaling of the system, community involvement, financing and clear regulations are key variables.

At the dimension level, the figure below listed the key parameters to achieve long-term sustainability. The list is based on the assessment framework presented in section 3.4:

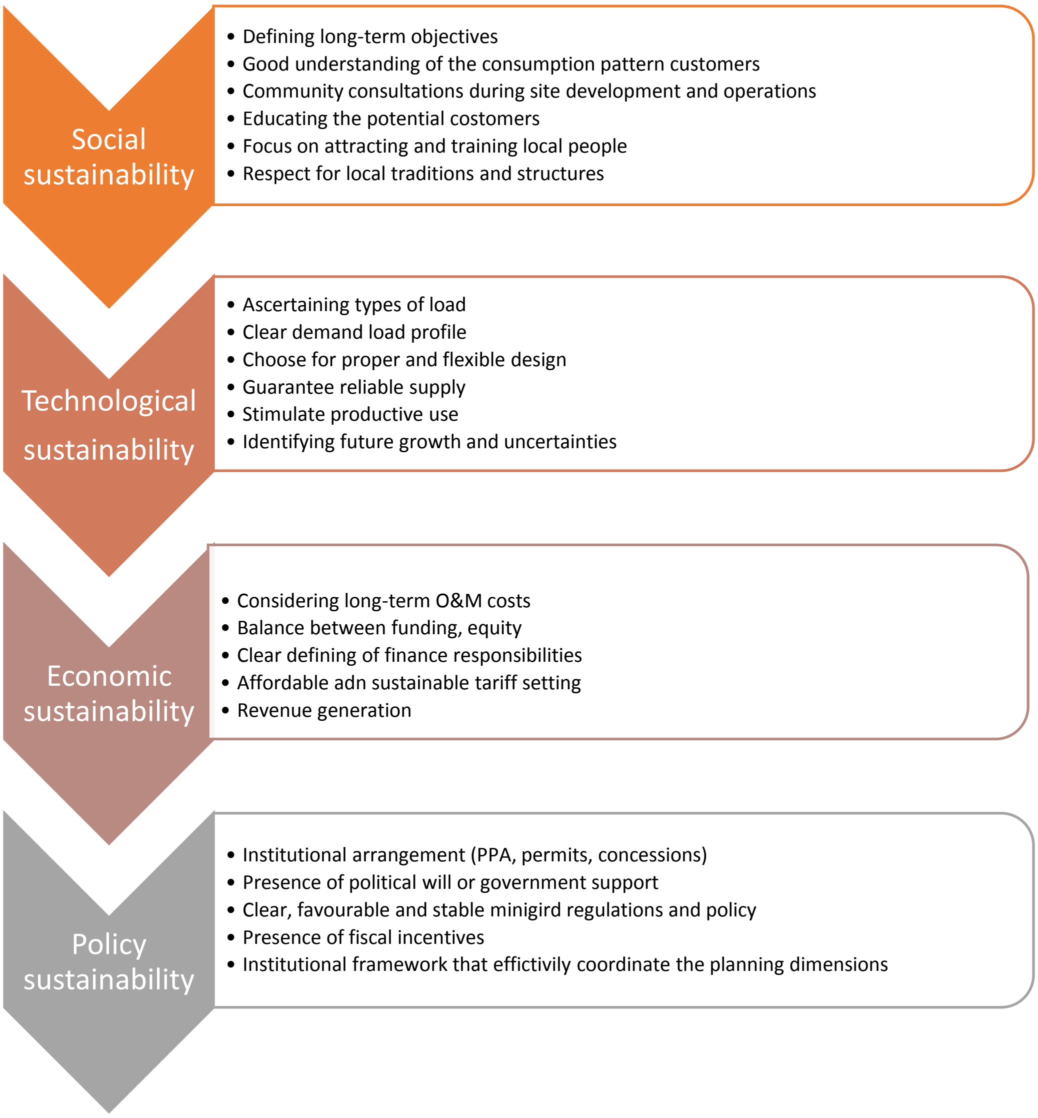


Figure 53 Sustainability parameters

To choose a certain location, the socio-economic environment and the distance to the grid are important. If there are more economic activities in the intended location, the probability of success is higher. The project design must be socio-economically driven, and in the second phase adapted technically. In a lot of cases, the future demand seemed under- or overestimated. Modularity and adaptiveness can mitigate this problem. If more generation sources are used, the generation capacity can be downscaled or upscaled during the operation time. The availability of anchor or business customers can stimulate a stable baseload of the mini-grid. If there are no anchor business customers, mini-grids are only viable in cases a productive use of energy will be created. Helping local entrepreneurs by education and funding of new equipment is required for the business case. Also, energy-efficient appliances need to be available in the service area.

Community participation is a distinct factor for the success in all stages of a mini-grid. Community involvement enables to determine the ability and willingness to pay and estimate the future demand in development stage. Future business activities can help to increase the productive use of energy and improve the load factor during daytime hours. Community participation helps to find local workers and local materials (for example pools). During operation, people can be educated about their use of appliances, company policy and development.

Attracting of qualified staff is important to maintain and operate the mini-grid. It would be preferred if the technician is involved during the building and construction of the mini-grid to give insights in the detail and to create responsibility.

6.3 Recommendations for Yele

The mini-grid in Yele is operating for seven years now. Based on the evaluation of the case study in Yele, some recommendations can be done to improve the performance and sustainability of the mini-grid in Yele. The recommendations are grouped per sustainability aspect.

- **Social aspects**

Radio shows are effective to communicate with the community and to stimulate a participatory approach. People can ask urgent questions and the staff can give instructions of PowerNed operation or advices for proper electricity connections. Regular updates and communication can increase the satisfaction and understanding of some interventions of PowerNed. PowerNed should restart the radio talk shows.

For maintenance activities and large projects, like banking of the river, it is difficult to find workers in the community. The financial resources of PowerNed are limited, so rewarding with high salaries is impossible. To increase the participation of the community, it would be better to rewarding the workers in an amount of kWh that they can use for electricity consumption.

- **Technological aspects**

At this moment monitoring of the system at the demand side is limited. To manage the system more efficiently, more metering points in the system are needed. At this moment the knowledge about the consumption pattern can only be obtained at the hydro station and manually at the meters. Implementing meters in the network can help to manage the system and detect possible failures. Remote data can help to manage the system better and improve the adequacy of the system. However, at this moment the meters are only inspected to see suspicious practices, such as meter bypasses. This meter inspection round is more effective if the consumption is listed. Data collection is essential for demand management.

The need for hybridization of the mini-grid in Yele is urgent. If the generator become defective or the shaft break, the power supply stops. Also, during peak loads, the system is dealing with brown-outs and voltage fluctuations. Increasing the power or storage capacity can mitigate these problems.

The power factor of the system is low. The transformers need to be replaced in transformers with a lower capacity to reduce transformation losses.

- **Economic aspects**

At this moment there are three different tariffs. One tariff structure for prepaid based customers, one tariffs structure for large industrial post-paid based customers and one tariff structure for residential post-paid customers. Introducing more flexible tariffs can help to guide customers electricity behaviour. Economic incentives stimulate a higher utilization and higher revenues. During times of scarcity of electricity, higher tariffs help to reduce the consumption while the revenues are the same. For the telecommunication sector in Sierra Leone, customers are rewarded with credit for free if they use more electricity. Rewarding customers can stimulate the consumption pattern of customers. The efficiency can be increased if the rewarding credits can be used during off-peak times.

Productive use of energy is essential for economic viability. It increases the electricity sales and the demand load during daytime. In Yele, many people have no possibility to buy productive use energy assets. Implementing an energy fund to provide productive use assets for commercial customers can help to support productive use of energy.

At this moment prepaid cards are sold by three retailers. Advantage is the profit of electricity sales for three retailers. Disadvantage is that this approach results in a missing link in the market chain. If the sales are done by PowerNed, the company has more accurate data about the sales, the frequency customers buy prepaid cards and the demand pattern in some areas.

- **Policy aspects**

In Sierra Leone there is a lack of qualified technicians. Using Yele as training centre can reduce the work load of the staff. And students are trained to work in other parts of the country. Long term goals and planning can be useful to measure in what case some goals are achieved.

At this moment the post-paid bill collection is frustrating the PowerNed staff. Although these meters will be replaced in pre-paid meters, the enforcement policy needs to be handled more strictly. Underpayments are resulting in lower cash flows

The mini-grid in Yele has the potential to expand to nearby villages. Especially if the road between Bo and Makeni will be paved, the economic activities will increase due to the centrality of Yele. Because of lack of mini-grids with a capacity higher than 100kW, the situation in Yele can be a starting point for other mini-grids in the country. The potential of Yele and the experiences of the mini-grid in Yele can be used to attract investors to expand and improve the mini-grid in Yele.

Although the staff of PowerNed is writing different reports (financial, technical), the quality and accuracy of the report should be reconsidered. The number if the reports should be limited and the reports should be more aligned between each other.

7 Future electricity system Sumbuya

A feasibility study of Riverblade (14) showed that Sumbuya, another area in Sierra Leone has a very good opportunity to develop a new small hydropower plant, which should have a capacity between 3.5 and 5 MW. A large benefit of this location is the presence of Sierra Tropical, a large fruit company. This large consumer can provide a stable load demand. In order to work towards sustainable electrification of the community, the generated power should be divided between the large fruit factory and the local community. The evaluative results of the case studies and the results collected by the literature desk research are now use to recommend about the electricity system in Sumbuya (93).

7.1.1 Socio-economic description

Sumbuya lies along the Sewa River, situated in the Lugbu chiefdom, Bo District, in the south of Sierra Leone. There are no bridges in the area, people are using wooden canoes to cross the river. The area is isolated from urban areas and during the civil war a lot of houses and villages were completely destroyed. The Sumbuya area has about 8000 inhabitants divided amongst 13 villages. The largest village is Sumbuya town with approximately 500 households and an average of 8 people living in the houses. The socio-economic situation is the best in this village. Most houses in Sumbuya town are built with concrete and have a zinc rooftop. The town has several public facilities, such as a meeting hall, schools, churches, mosques, a small health clinic and a communication tower. The other villages are much smaller; the socio-economic condition of almost all villages is poor. Most people are farmers, but their production yield is low. Other economic activities are fishing, gold and diamond mining. Most commercial and industrial jobs are located in Sumbuya town. Some people are doing mining activities in the Sewa River. In Figure 54 the villages are listed with the number of people, income level, level of industrial activities and public facilities (schools, community hall, etc.).

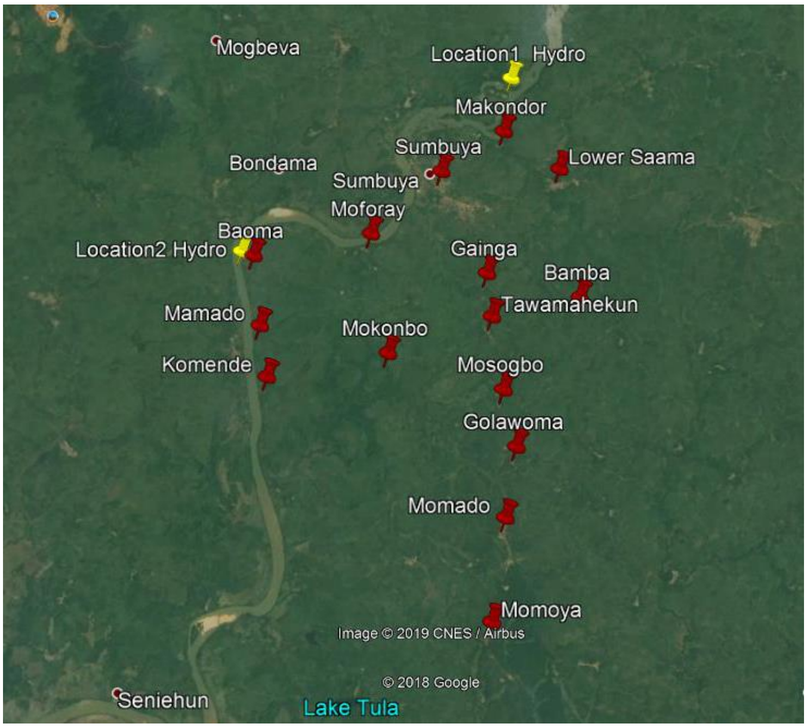


Figure 54 map of Sumbuya area

Villages	Inhabitants	Income level ($)	Industrial activities	Public facilities
Bamba	400	1200	+	+
Baoma	327	400	-	-
Gainga	231	450	-	-
Gola	139	600	+	-
Komende	210	400	--	+
Lower Saama	895	200	+	+
Moforay	379	600	-	+
Makondor	93	400	-	+
Makombo	77	450	+	-
Momado	55	600	-	+
Mosorgbo	315	550	-	+
Sumbuya	3896	10000	+++	+++
Tawamahehun	362	850	+	++

Table 26 Villages characteristics

The past years a large agro-industrial company, Sierra Tropical Limited has been established with a large area for farming activities of mainly pineapples. They lease an area of around 6000 ha for their farming activities and want to develop the area with health centres and education facilities. The establishment of this company created many new jobs, attracting new businesses and improving many households' conditions. In future, it is expected the job opportunities will increase. New farms need to be constructed and cultivating, harvesting and processing activities require human capital. At this moment more than 600 people are employed and more people will be attracted in the future. New houses will be built, and the growing population requires a higher service level (gas station, hospitals, welders, dispensaries, bars, shops). The company of Tropical Limited improved also the road infrastructure. The main road between Sumbuya and Kiribondo has been renovated last two years, resulting in a better accessibility of the Sumbuya area. While the improved accessibility was required for the construction and operation of the company, the people are benefitting largely from this investment.

7.1.2 Potential for a mini-grid

The improved accessibility, the improving socio-economic conditions of the area, the growing population and the availability of a large customer provide a fertile ground for building a mini-grid in the Sumbuya area and boost the local economy. Electricity access reduces the dependency on diesel generators and stimulate the local economy, resulting in a better socio-economic environment.

The company's main activity is farming and processing pineapples. For farming they are dependent on irrigation of their fields during the dry season. For the processing activities the company have plans to build a cannery to make bottled juice and to keep fruit in cans. Both activities require a stable and high demand load. The large scale of this company will attract new inhabitants and business activities in the area.

Sumbuya is also located far from the central grid (130 km). If the central grid is close to Sumbuya, the high demand load makes a central grid connection more preferable. But in case of Sumbuya, a mini-grid is competitive with other energy options. Nevertheless, the villages around Sumbuya town differ from each other in terms of financial resources, accessibility and available services. For some villages, the costs for expanding the distribution lines to these villages are less cost-effective than providing solar home systems to facilitate small household electricity consumption.

7.2 Sustainability aspects

By means of the lessons learnt and the sustainability indicators some considerations and recommendations are given. A **bolt font** implies a reference to a sustainability indicator of the assessment framework (3.4, Appendix 10.2). These indicators are required to achieve a long-term sustainability of the mini-grid.

7.2.1 Social aspects

Engagement with the community is important to achieve social embeddedness of the mini-grid in the communities around Sumbuya. Project developers have to receive support from the community and information about community characteristics. The people demonstrated their happiness when the project of Tropical Limited was coming and the development of a mini-grid could be a next step to improve the socio-economic situation of the area. But the concept of a mini-grid is new to communities around Sumbuya. **Communication, education and consultation** are three pillars for a successful start and successful operation of the mini-grid. Communication is important to make clear that providing electricity is a business activity, people need to pay for it. Also, responsibilities must be clear for all participants. Education is important to **train local technicians** and to **educate customers** about their future connection and consumption. This increase the awareness amongst the customers and can create responsibility. Consultations are important to gather data consumption characteristics, customers' ability and willingness to pay and to create a strong commitment of all customers.

There are several stakeholders that are important to involve during the project development phase. In the Lugbu chiefdom the paramount chief and his speakers are the highest ranked people of the chiefdom. They are ruling the chiefdom, solving conflicts and are the representatives of the chiefdom. It is essential to involve them in the project, because of their influential positions. Early adoption by community leaders will stimulate community people to take up the service. Land owners have also powerful positions, are the second highest in the hierarchy and are important for leasing or buying land. Tropical Limited is the most important business partner, because of their expected high demand load. Other entrepreneurs and business partners are important, because they are essential for creating a productive use of electricity and to stimulate the local economy. And the different villages should be represented during the preparation phase, they have different preferences. Community engagement can also be stimulated by **facilitating public facilities** (schools, religious centres, streetlights) with electricity.

There are different manners to inform and consult the stakeholders. Community meetings are open for everybody and are meant for creating support and providing information about the project. It is also recommended to set up a **community energy committee**, as has been done in Segbwema, in which all kind of customers are represented. The committee is the environment for negotiation and decision-making and also important for receiving feedback information, ensuring awareness and solving conflicts. But for larger or powerful actors it is also necessary to have separate meetings to discuss the preferences of each stakeholder. For the **satisfaction of the customer** it is important that the generated power is **well allocated** amongst the different customers and villages. The area of 6000 ha is also covering 13 villages and local conflicts between villages must be prevented.

At this moment the people of Sumbuya have expressed their willingness to pay for electricity. Fuel costs per kWh for using diesel generators are higher than the costs per kWh generated power from a mini-grid. In the first community meeting, the project team clarified the project was set up by a private utility and is not initialised by the government of Sierra Leone. It is important to emphasize the **roles and the responsibilities** of both the customers and the electricity provider. A **private-utility based**

ownership fits the best in the environment of a large customers, different small villages and several small industrial and commercial customers

General information	
Location	Sumbuya
Chiefdom	Lugbu Chiefdom
District	Bo
Region	South
Public facilities	Primary schools, secondary school, health clinic, churches, mosques, water pumps
Economic activities	Farming, gold and diamond mining, fishing
Demand estimation	**Community**
Households (+- 1500 households)	300 kW
Commercial activities	400 kW
Public facilities (street lights, water pumps)	50 kW
Demand anchor client	**Tropical Limited**
Pumps + workshops plantation	600 kW (6 months)
Cannery	1000 kW
Office and camp	250 kW
Medical clinic	60 kW
Offices	100 kW
Total demand	2760 kW

Table 27 Characteristics Sumbuya area [S24,S29]

7.2.2 Technology aspects

At this moment only a small amount of diesel generators and few solar panels generate electricity for some customers in Sumbuya. A mini-grid increases the access to energy and the socio-economic situation of the area. The large energy demand of the pineapple company creates a stable baseload for a mini-grid. The demand load of small industrial and commercial business activities is also contributing to the cost-effectiveness and the economical sustainability of the mini-grid.

Figure 55 Sewa river

Different technologies can be chosen. In Sumbuya the possibilities for a hydropower plant are researched by Witteveen+Bos (14). The Sewa River have a proper discharge and a minimum head during the year. For the generation, also PV-panels and biodigesters can be used. The solar irradiation factor is high, and the waste of the agro-processing activities can be used as biomass. A hybrid mini-grid with different generation sources is recommended to enhance the reliability of the power supply. The baseload can be covered by a hydro-plant. Hydropower plants have a high average **operating time** and lifetime. The peak loads can be managed by PV-panels and storage facilities.

Critical factor is the adequateness of the power delivery. It is important that the generation will match the demand. In Table 27 Characteristics Sumbuya area [S24,S29] an estimation is made of the future demand load. But, the uncertainty of the demand load is high. In that case, hybridization and expandability or modularity are required for the design.

- Hybridization is important to achieve a **high efficiency** of the system. The electricity for irrigation is only required during the peak of the dry season. During the dry season the power generation capacity of a hydro plant (without reservoir) will be lower, PV-panels can provide the needed power. During the rainy season the output of the PV-system is lower, but the output of the hydro will be higher.
- At this moment the development of the company is in initial stage and people of the communities are not familiar with electricity. With a possibility to expand the network and electrify system, the system is more **adaptive to future's uncertainties** and the growing demand load. The number of turbines and solar panels can be expanded over time. During the development phase there is no need to design the system with a peak capacity. In future the energy system can be expanded with a bio digester, but a sufficient and continuous flow of biomass is required. Also, the grid needs to be designed compatible with the national standards to make an **integration** possible with the main grid in the future.

Some villages have higher population and income levels than other villages. Sumbuya town and Low Saama have the highest population density, income levels and the highest share of industrial and commercial activities. It is important to connect first the villages with the highest financial resources and commercial activities to ensure sufficient demand and revenues. If a hydro will be constructed, the village alongside the voltage lines between the hydro-plant and the main villages have second priority. It is important that villages will profit from the electricity if there are assets in the villages, like poles or transformers.

Figure 56 Construction compound Sierra Tropical Limited

A cluster-based approach can be carried out to connect the hamlet villages with smaller PV-plants and a small distribution grid. In a next stage, transmission lines grid can be constructed to connect the different villages and to manage the intermittent power. At that moment there is a better overview in the specific demand in all villages. For villages with few households and a low expected demand load, there can also be decided for not connecting the village. An option could be to offer SHS's to the households in these villages.

For the technical sustainability is important to work with **standardized and qualified material**. For the supply chain the company needs to work together with other mini-grid service providers in West Africa which have a smooth supply chain, technological experience and are able to train local staff. Training local staff is important to increase the awareness of the local people and decrease the dependency on foreign experts. The improvement of the main road enables transport of (heavy) materials and equipment.

In Segbwema and Yele it seemed that stimulation of productive use of energy is important. During the evening the residential consumption resulted in a peak load. People use the electricity for lighting and to extend their working activities in the evenings. For the **utilization and the efficiency** of the system it is important to increase the daytime demand through commercial and industrial activities. More electricity consumption during daytime hours increases the utilization of the system. Small entrepreneurs need to be supported to use electricity during off-peak hours. This can be managed by time-based and flexible tariffs. But, in many cases, entrepreneurs have few equipment and machinery that are using a high amount of electricity. To stimulate productive use of electricity, the company can support the purchase of new equipment and machinery. This can be done by micro-finance facilities (loans) or by bringing the equipment for sales to the area. If more generated capacity can be used during the daytime hours, the electricity system is used more efficient.

In cases the Sumbuya region attracts new inhabitants and the maximum capacity is achieved, load management will become important. Generation supply and demand must be balanced and managed by tariffs or allocation of the capacity between all customers. **Metering systems** can help to monitor the current flows and match the supply and demand.

7.2.3 Economic aspects

It has been clear that energy use, economic growth and level of development stimulate each other. Energy access is a catalyst for business activities and indirectly for socio-economic development. These business activities are important to increase the **load factor** of the grid. The baseload of Tropical Limited provides a sustainable revenue flow, but for the villages around the farm, stimulating business activities and **productive use of electricity** is essential. The LCOE can be decreased with higher load factor. Options to support productive use are funding of entrepreneurs to buy new equipment, promotion of efficient appliances and flexible tariffs to manage customer' demand behaviour.

Lessons learnt from other locations in Sierra Leone proved the income flow have quite often seasonal patterns. **Prepaid meters** need to be used to mitigate a lack of cash to buy the electricity. Prepaid meters monitor also customers consumption pattern. Collecting these data support the management of matching the supply and demand. For some prepaid meters it is possible to set **different tariffs** (section 3.3.3) to manage the consumption pattern of the customers (time-based or stepped tariffs).

Funding for the project implementation and execution need to be attracted by grants and loans. Partial grants and subsidies allow the mini-grid developer to invest debt and equity while creating bankable projects with affordable tariff structures. Funding of the government is not expected. There are many funds worldwide available for rural electrification projects (World Bank, African Development Bank, etc). Moreover, the risk of failure of the energy system in Sumbuya is reduced through the presence of a large agro-industrial customer. Nevertheless, it is recommended for funding to distinguish the energy supply for social uses and productive uses. Funding for social use is needed to fund the high costs for prepaid meters and the connection costs. Due to the initial low levels of consumption, the costs per kWh to cover the connection costs are high. Funding for productive use can be used to set up a micro-finance institute. A **micro-finance institution** can support entrepreneurs in purchasing equipment for productive use and start-up of new business. The local entrepreneurs have limited financial resources and micro-financing can help to overcome this barrier and stimulate local economic activities and the capacity of villages to pay.

The customer tariffs should be determined in close cooperation with the EWRC and the villages. The revenues have to cover the operational costs and different tariff categories are recommended. Up-front costs, like connection fees, should be included as part of the electricity tariffs if subsidies and grant cannot cover all costs. Nevertheless, the connection fee should not be minimized to zero, while the payment of a connection fee increases also the awareness of customers to be responsible for their pre-paid meter, connections and consumption. The tariff should be approximately the same as the average **willingness to pay** of the customers.

7.2.4 Policy aspects

The establishment of Tropical Limited is a catalyst for the rural electrification of this area. It is important that the energy provider is independent of Tropical Limited to **prevent conflicting interests**. They must be two separate business entities and the energy provider is responsible for a fair allocation of the available power. It is recommended that the local energy provider have experiences with the chosen technology and the country-specific conditions.

The scale of the mini-grid requires also involvement of the EWRC. They have to hand-out licenses and are involved in the tariff setting. A generation license and a distribution licence have to be issued out. To strengthen the institutional and legal basis, guidelines and responsibilities have to be clearly defined. It can be happened that the priorities and preferences of the stakeholder are not aligned. The developers prefer for example maximum profit and high consumption, while governmental stakeholders want a broad energy access. In that case it is important to have a clear overview of the interest and power of all stakeholders and their responsibilities. Based on the objectives and constraints, a clear strategy for connection and installation can be chosen.

The ownership-model that would recommend is a **private-based ownership**. A community-based ownership is no option, because of the large scale and the large role of a large agro-customer. A utility-based ownership implies long preparation time, little experience and political dependency. **Political interference** needs to be prevented. A private-based ownership fits the best for the situation in Sumbuya, because of the flexibility and independence. The early recruitment of **qualified technician** and training of local people should be priority to create a staff with skilled employees. Proper maintenance of the grid is important for the reliable mini-grid.

The company have to develop also **enforcement policy** in cases of theft and fraud in order to prevent abuse of the system. Many minigrids suffered cases of theft, from illegal connections to the distribution system to fraud with electricity bills.

7.2.5 Process of implementation mini-grid Sumbuya

In the process flow diagram below the different stages of designing and implementing a new mini-grid are shown. The diagram indicates the steps that the investors and operating contractors must execute to achieve a well-prepared mini-grid, ensuring the long-term sustainability of the electrification project. Each step has his own specific activities and attention points. In order to develop sustainable mini-grids, it is important to pay attention to all these points. Each activity in the chain contributes to the final level of quality and cost of service.

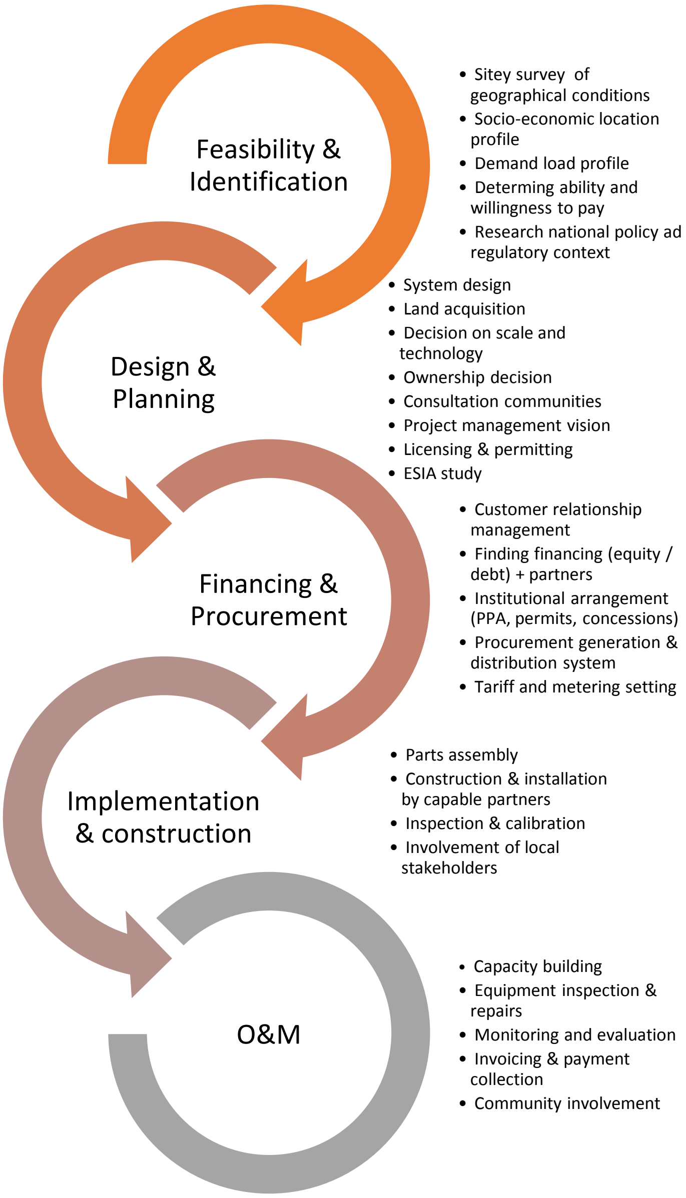


Figure 57 The mini-grid value chain (94)

8 Conclusion

8.1 Conclusion

This chapter is a synthesis of the described research, resulting in conclusions and recommendations. In chapter 1 the research objectives and research questions are described. Through answering the research questions, the main findings of the research are presented.

What is the current energy situation of supply and demand in Sierra Leone?

Sierra Leone is an African country with a low electrification rate. Especially people in rural areas have no access to electricity. Only the few wealthy people have a diesel generator, the others are dependent on solar torches. Options to connect these people are Solar Home Systems, central grid extension and mini-grids. Solar Home Systems are for most people not affordable and are not able for a productive use of energy. Grid extension to remote and isolated areas have quite often not the priority of utilities. In Sierra Leone the central grid has a low capacity with low reliability rates. The utility companies, EGTC and EDSA, prioritize the connection of (sub)urban areas and the improvement of the generation capacity and reliability.

Nevertheless, some initiatives have been initialised to electrify the rural areas in Sierra Leone past years. Especially NGO's are working by means of public-private partnerships with governmental agencies to develop mini-grids in the country. Mini-grid regulation have been developed to attract private investors. At this moment there about renewable 65 mini-grids in Sierra Leone with a capacity higher than 15 kW.

Which social, technical, economic and institutional challenges are known about rural mini-grids in developing countries in order to make them sustainable?

Mini-grid are in rural areas the most promising way to give people access to electricity, but a holistic approach is essential for designing mini-grid systems. The failure rate of mini-grids is high, because developers have focussed only on one or two aspects. In the literature, researcher use sustainability dimensions to discuss mini-grid from a system perspective. The sustainability dimensions are listed below and shortly discussed. In this research, the environmental dimension has been dropped, because of the limited time of this research.

Social sustainability

Participation of the local community support the awareness of the customers and provide priceless information about the customer needs. Community involvement is not only important during the development phase, but also during the operation of the mini-grid. From the company perspective, respecting local structures and leaders are required for doing business. From the customer perspective, awareness and responsibility are required for timely payments and maintaining proper connections and meter systems. The community can use radio shows and workshops to educate people on electricity consumption and explain the limitations of the electricity system.

Technical sustainability

The design and technology must be a result of the customer's needs. Population density, consumption pattern and willingness to pay are key parameters for the scale and generation source(s). For regular maintenance a supply chain of spare parts is essential as well as qualified technicians. Load demand management is often underestimated in mini-grids. The small scale of the system makes the system vulnerable for voltage drops, brownouts and black-outs. Storage capacity and demand management can insure a reliable power supply.

Economic sustainability

The only proven way to operate a mini-grid without subsidies is by stimulating productive use of energy by commercial and anchor customers. Productive use can be stimulating by supporting local entrepreneurs, flexible tariffs and load scheduling. The tariffs should be able to cover the running cost and affordable for most customers.

Policy or institutional sustainability

Low institutional quality is barrier for investors to finance rural electrification projects or mini-grids. For successful rural electrification by mini-grids, stable and durable support from the central or national government is essential. Besides the national regulations, the company have the responsibility to allocate the generated power fair and cost-effectiveness.

Which are the challenges of small-scale energy system in Sierra Leone?

The evaluative case study research in Yele and Segbwema revealed the complexity of mini-grids. The systems are analysed at hands of 34 indicators, grouped by 4 sustainability indicators.

Social aspects

			Yele	Segbwema
Social	*Community involvement*	Community education	0,50	0,75
		Support of local leaders and politicians	0,75	0,50
		Share of population with electricity access	0,50	0,25
		Training and employment of local people	1,00	0,50
	Ownership	Suitability ownership model	1,00	0,50
	Benefits & Acceptability	Allocation of electricity between customers	1,00	1,00
		Awareness about connection and consumption	0,50	0,75
		Availability of streetlights	0,50	0,75
		Ability to pay for electricity services	1,00	0,50
		Electricity access public facilities (schools, clinics, etc)	1,00	0,50
SCORE			**7,75**	**6,00**

Participation of the community was in the beginning a key factor but has get less attention during the operation of the hydro-network, especially in Yele. Educating and training of local people is important for the long-term sustainability of the mini-grid. In Segbwema these activities are organized more frequently, however the system in Yele have more benefits for the community (water plant, community hall). It is important that the available power is well allocated. Neglecting communication and considering the public opinion about rationales and plans results in local conflicts. Communication of the operator need to be transparent.

Technological aspects

			Yele	Segbwema
Technological	*Monitoring & management*	Metering system mini-grid	0,00	1,00
		Managing of electricity consumption	0,25	1,00
		Match of technical design with demand pattern	0,50	0,75
	Reliability & efficiency	Availability and utilization of services	0,75	0,50
		System efficiency	0,25	0,50

	Operation & maintenance	Availability equipment and spare parts in the country Dependency on foreign assistance Quality equipment and materials	0,50 0,75 0,50	0,75 0,50 0,75
	Modularity	Compatibility with future grid integration Adaptability and expandability	1,00 0,50	0,75 1,00
SCORE			5,00	7,50

Focus on load demand management is essential for the reliability and stability of the mini-grid. In Yele the monitoring and metering possibilities of the technical system are limited and should be improved. In Segbwema they can remotely manage the system, which is also expensive. In both systems they have only one generation source, and in Segbwema storage capacity. A hybrid configuration decreases the dependency on a single generation source and increase the reliability and income flow. Incentives to stimulate productive use during off-peak hours is important increase the efficiency of the system.

Economic aspects

			Yele	Segbwema
Economical	*Costs and investments*	Financial support government Operation and maintenance costs	0,00 0,75	0,00 0,50
	Productive use	Industrial/commercial customers with productive use Anchor client connections	1,00 1,00	0,75 0,50
	Financial	Non-payments or outstanding payments Tariff lag Micro-credit facilities	0,50 1,00 0,50	1,00 0,75 0,50
SCORE			**6,79**	**5,71**

Mini-grids are structurally equivalent to "macro-grids" but individually expensive without economies of scale. To attract investors, it is important to use the system view to stress the economic sense of mini-grid in isolated rural areas. Attracting funding seems difficult for mini-grids. There is inexperience in accessing and attracting international funding for renewable energy projects for billing of consumed electricity, only current limiters and prepaid meters are effective as metering systems in a low-resource and seasonal-influenced setting. In the case studies, there are no flexible tariffs, while using flexible tariffs can increase the affordability and the increase load factor. Commercial and industrial customers are a pillar for the economic viability. Stimulating productive use are done in Yele and Sumbuya, but in Yele there is not a certain approach how to increase the productive use.

Institutional aspects

			Yele	Segbwema
Policy / institutional	*Regulations*	National regulation on tariff setting and licensees Tax breaks on imported (spare) parts	0,00 0,75	0,00 0,75
	Organization	Capability of staff Long-term vision company Defining of responsibilities between stakeholders	1,00 0,00 0,75	1,00 0,50 0,75
	Enforcement & Security	Enforcement of local policy Security of electricity infrastructure	0,75 1,00	0,75 0,75
SCORE			6,07	6,43

The mini-grid in Yele is dependent of foreign assistance, which makes the company vulnerable and not-sustainable. In Sumbuya the mini-grid work together with large international NGO with mini-grid experience. If the national regulations for mini-grid will be approved by the parliament many procedures are legally bounded.

Which design requirements are needed for ensuring the robustness of mini-grids to enhance reliable energy access in Sierra Leone*?*

- Before starting to develop mini-grid an extensive research on the technical feasibility, financial viability, community willingness and the chosen technology is important.
- Community participation from the inception of a mini-grid till operation is essential. Communication with communities by radio-shows and community help to make people aware of the efficiency of their appliances and the limitations of the electricity supply.
- A community energy committee is very useful, for solving conflicts, gathering information from the community, spreading information, and support form the whole community.
- Load demand management is essential for a sustainable operation of a mini-grid. The system will achieve higher efficiencies and is economically more favourable.
- The electricity revenues of household customers are often too small due to the low levels of electricity consumption. Connecting commercial and industrial customers is essential for achieving economic viability of the grid.
- Hybridisation have positive impact on the reliability and cost-effectiveness of the grid.
- Modularity and flexibility of mini-grid improve overspending on capital. The size and amount of generation assets can be increased (or decreased) during operation. The flexibility increases also the reliability and viability of the system.
- An anchor client with a high and stable load consumption, can increase the cost-effectiveness of mini grids substantially. The presence of locations in Sierra Leone that have a significant daytime productive load and a potential household consumption are rare. Most people are living from small agriculture activities. In small villages SHS remain more economic competitive than mini-grids.
- It is important to consider the ATP and WTP of households and business. To make the business case attractive with cost-reflective tariffs and to oversee the margins of the tariff settings
- Pre-paid meters or current limiters can be used for metering, because of the dependency of seasonal flows and volatile income patterns. Prepaid meters are preferred above current limiters, because of the fact they can provide more knowledge about the consumption pattern by remote monitoring.
- The mini-grid require capable companies or (private) utilities that have a high level of technical knowledge and is able to allocate the available power and to set tariffs economically strategic and fair.
- Bill collection is at times a difficult task. Some customers want special favour or have no financial resources to pay. It is important to emphasize the behaviour of one customer affect the sustainability of the whole system.
- By signing a contract between customers and the company, the company can use an enforcement policy in cases of misuse.

8.2 Discussion & Reflection

In this thesis findings from literature are combined with evaluations from mini-grids in Sierra Leone to assist and support the mini-grid business in Sierra Leone. Although, the literature about mini-grids in Sub-Sahara Africa is expanding rapidly, there is almost no literature available of the energy situation in Sierra Leone. This thesis collected different aspects that are essential for the long-term sustainability of mini-grid and applied these aspects to mini-grids in Sierra Leone. The literature study helps to research the complex situation of mini-grids in an analytic and systematic way. Case study research give insights in the local and country specific characteristics, in which the socio-economic and institutional context is included. The holistic and systematic review includes the social and technical interactions to stress the socio-technical dynamics within the system. It seemed that the situation Sierra Leone is not very different from other SSA-countries. The used approach of the evaluative case studies is rather analytical and descriptive than statistical. This makes that the lessons learnt can be used to make some generalisations instead of one specific quantitative solution.

Sierra Leone is a developing country with a limited physical and institutional infrastructure. Corresponding with governmental agencies goes slowly, because of the bureaucratic process. Projects plan that have been written are many times partly or not carried out. Verifying received documents, reports and data seemed necessary.

For the local research, especially in Yele, the researcher was highly involved in the community. The community of Yele, however, considered the researcher as being part of the staff of PowerNed. Although the researcher stressed his role as researcher and relating interdependence, the close contacts with the PowerNed staff, could affect the objectivity of people's answers. On the other hand, without cooperation with the PowerNed staff, it would be difficult to use an ethnographic research method, due to cultural and language barriers.

Nevertheless, the lessons learnt are useful as principle for the development of mini-grids in Sierra Leone. This is exemplified by the design-oriented case study of Sumbuya. Because of the lack of recent literature of the energy situation in Sierra Leone, project developers are wondering which solution fits the best for the context of Sumbuya and Sierra Leone. Together with the feasibility report of Witteveen+Bos (14), this thesis can be used to make the final design of the energy delivery system in Sumbuya.

Large projects like rural electrification take a long time to develop. This makes the project susceptible for changing circumstances. Especially in developing countries like Sierra Leone, the political situation or disasters (for example Ebola) can slow down or change the process. Political instability can keep off foreign investors. Secondly, worldwide factors can influence the situation, such as the diesel price or evolving technology. If the diesel price decreases, the LCOE of the generation technologies will change. Thirdly, financing of such projects is dependent of foreign investors, which can change their strategies. At this moment large energy corporates entered the sector in some countries by investing in mini-grids. If the profit margin seems too low, they can stop their investments in this sector. Thus, the project is dependent on political, resource price variability and payment risk. Although some risks can be mitigated by hybridization (resource price variability) or ownership model (political risks), an uncertainty analysis or risk strategy in not included in this thesis. The research can be strengthened by adding of uncertainty analysis and a description of the different pathways to achieve feasible mini-grids in the country.

The time was limited to include financial aspects, like interest rates and financing instruments, in this thesis. While financing is an essential part of the developments of mini-grids, further research to this topic is suggested. Also the requirements for Sumbuya are preliminary. Further research can continue to work out a detailed design of the energy situation in Sumbuya.

9 Bibliography

1. Agenbroad J, Carlin K, Ernst K, Doig S. Six ways to reduce minigrid costs by 60% for rural electrification. Rocky Mountain Institute, Washington D.C.:57.

2. Goal 7: Affordable and clean energy [Internet]. UNDP. [cited 2018 Aug 9]. Available from: http://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-7-affordable-and-clean-energy.html

3. Ahlborg H, Sjöstedt M. Small-scale hydropower in Africa: Socio-technical designs for renewable energy in Tanzanian villages. Energy Res Soc Sci. 2015 Jan 1;5:20–33.

4. Gollwitzer L, Ockwell D, Muok B, Ely A, Ahlborg H. Rethinking the sustainability and institutional governance of electricity access and mini-grids: Electricity as a common pool resource. Energy Res Soc Sci. 2018 May;39:152–61.

5. Mandelli, S., Barbieri, J. Mereu, R. Colombo, E. Off-grid systems for rural electrification in developing countries: Definitions, classification and a comprehensive literature review. Renewable and Sustainable Energy Reviews, Vol. 58, pp. 1621-1646 [Internet]. 2016 [cited 2018 Jun 5]. Available from: https://ideas.repec.org/a/eee/rensus/v58y2016icp1621-1646.html

6. United Nations Development Programme. Human Development Report 2016: Human Development for Everyone [Internet]. UN; 2017 [cited 2018 Aug 9]. Available from: https://www.un-ilibrary.org/economic-and-social-development/human-development-report-2016_b6186701-en

7. Sierra Leone GDP | 1960-2018 | Data | Chart | Calendar | Forecast | News [Internet]. [cited 2018 Aug 9]. Available from: https://tradingeconomics.com/sierra-leone/gdp

8. Population of Sierra Leone. 2019 demographics: density, ratios, growth rate, clock, rate of men to women. [Internet]. [cited 2019 Feb 11]. Available from: https://www.populationof.net/sierra-leone/

9. Access to electricity (% of population) | Data [Internet]. [cited 2018 Aug 10]. Available from: https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?view=chart

10. Alstone P, Gershenson D, Kammen DM. Decentralized energy systems for clean electricity access. Nat Clim Change. 2015 Apr 1;5:305–14.

11. Deskmukh, R., Carvallo, J. P., & Gambhir, A. (2013). *Sustainable development of renewable energy mini-grids for energy access: A framework for policy design.* Berkeley, CA: Lawrence Berkeley National Laboratory and University of California–Berkeley.

12. Hirsch A, Parag Y, Guerrero J. Microgrids: A review of technologies, key drivers, and outstanding issues. Renew Sustain Energy Rev. 2018 Jul 1;90:402–11.

13. lskog, E. And then they lived sustainably ever after?: part I, experiences from rural electrification in Tanzania, Zambia and Kenya, 2014; 98.

14. Wauben MFE, van Druten E. Feasibility study small hydro power in Sierra Leone. Rotterdam: Witteveen en Bos; 2017 Sep.

15. Rahman MM, Paatero JV, Lahdelma R. Evaluation of choices for sustainable rural electrification in developing countries: A multicriteria approach. Energy Policy. 2013 Aug 1;59:589–99.

16. Bhattacharyya SC. Mini-grid based electrification in Bangladesh: Technical configuration and business analysis. Renew Energy. 2015;75:745–61.

17. Feron S, Cordero RR, Labbe F. Rural electrification efforts based on off-grid photovoltaic systems in the Andean Region: Comparative assessment of their sustainability. Sustainability [Internet]. 2017 [cited 2018 Jun 5];9(10). Available from: https://udesantiago.pure.elsevier.com/en/publications/rural-electrification-efforts-based-on-off-grid-photovoltaic-syst

18. Holland R, Perera L, Sanchez T, Wilkinson R. Decentralised rural electrification: Critical success factors and experiences of an NGO. Refocus. 2001 Jul 1;2(6):28–31.

19. Watson, J., Byrne, R., Opazo, J. What are the major barriers to increased use of modern energy services among the world's poorest people and are interventions to overcome these effective?", Collaboration for Environmental Evidence, Bangor, UK (2012) 91 pp.

20. Cherni JA, Dyner I. e.a. Energy supply for sustainable rural livelihoods. A multi-criteria decision-support system. Energy policy 2017 vol. 35 p. 1493-1504.

21. Wirth S. Communities matter: Institutional preconditions for community renewable energy. Energy Policy. 2014 Jul 1;70:236–46.

22. Terrapon-Pfaff J, Dienst C, König J, Ortiz W. A cross-sectional review: Impacts and sustainability of small-scale renewable energy projects in developing countries. Renew Sustain Energy Rev. 2014 Dec 1;40:1–10.

23. Guta DD, Jara J, Adhikari NP. e.a. Assessment of the Successes and Failures of Decentralized Energy Solutions and Implications for the Water–Energy–Food Security Nexus: Case Studies from Developing Countries. Resources no. 6, 2017

24. Moncada JA, Lee EHP, Guerrero GDCN, Okur O, Chakraborty ST, Lukszo Z. Complex Systems Engineering: designing in sociotechnical systems for the energy transition. EAI Endorsed Trans Energy Web [Internet]. 2017 Jul 11 [cited 2018 Aug 9];3(11). Available from: http://eudl.eu/doi/10.4108/eai.11-7-2017.152762

25. Ilskog E. Indicators for assessment of rural electrification : an approach for the comparison of apples and pears. Energy Policy. 2008;36(7):2665–73.

26. Akinyele D, Belikov J, Levron Y, Akinyele D, Belikov J, Levron Y. Challenges of Microgrids in Remote Communities: A STEEP Model Application. Energies. 2018 Feb 14;11(2):432.

27. Buchholz T, Luzadis VA, Volk TA. Sustainability criteria for bioenergy systems : results from an expert survey. In 2009.

28. Katre A, Tozzi A. Assessing the Sustainability of Decentralized Renewable Energy Systems: A Comprehensive Framework with Analytical Methods. Sustainability. 2018 Apr;10(4):1058.

29. Mainali B. Sustainability of rural energy access in developing countries. [Stockholm, Sweden]: KTH Royal Institute of Technology; 2014.

30. Silverman-2011-Ch-3.pdf [Internet]. [cited 2019 Feb 5]. Available from: http://blogs.ubc.ca/outofplace/files/2013/09/Silverman-2011-Ch-3.pdf

31. Morra, G.,, Friedland, A.C.. Case study evaluations, 2004 World Bank Group Washington D.C.

32. IEA. Energy Access Outlook 2014: From Poverty to Prosperity. International Energy Agency, Paris, "weo2014specialreport_energyaccessoutlook.pdf".

33. Moner-Girona, M, Solano-Peralta, S. e.a.. Electrification of Sub-Saharan Africa through PV/hybrid mini-grids: Reducing the gap between current business models and on-site experience, Renewable and Sustainable Energy Reviews 2017 1148-1161

34. IEA. Energy Access Outlook 2017: From Poverty to Prosperity. International Energy Agency, Paris, "weo2017specialreport_energyaccessoutlook.pdf".

35. Sierra Leone Energy Situation - energypedia.info [Internet]. [cited 2018 Aug 31]. Available from: https://energypedia.info/wiki/Sierra_Leone_Energy_Situation

36. About Sierra Leone [Internet]. UNDP in Sierra Leone. [cited 2019 Mar 29]. Available from: http://www.sl.undp.org/content/sierraleone/en/home/countryinfo.html

37. Ochs, A., & Gioutsos, D. Rural Electrification in Sierra Leone: The Role of Mini Grids vis-à-vis Stand-alone Home Systems and Grid Extension, 2019

38. Trace, T. EEG Energy Insight Sierra Leone.pdf, developing a programme of research on the electricity sector in Sierra Leone, 2018

39. Mestre J. National Renewable Energy Action Plan (NREAP) of the Republic of Sierra Leone. :91.

40. Konneh DA, Howlader HOR, Shigenobu R, Senjyu T, Chakraborty S, Krishna N. A Multi-Criteria Decision Maker for Grid-Connected Hybrid Renewable Energy Systems Selection Using Multi-Objective Particle Swarm Optimization. Sustainability. 2019 Jan;11(4):1188.

41. Jalloh A. Socio economic assessment of solar photovoltaic projects in Sierra Leone. Fourah Bay College, Freetown;

42. Sierra Leone [Internet]. Climatescope 2017. [cited 2018 Aug 10]. Available from: http://global-climatescope.org/en/country/sierra-leone/

43. Sierra_Leone_RAGA_EN_Released.pdf [Internet]. [cited 2019 Feb 11]. Available from: https://www.se4all-africa.org/fileadmin/uploads/se4all/Documents/Country_RAGAs/Sierra_Leone_RAGA_EN_Released.pdf

44. ECREEE. "Regional Progress Report on Renewable Energy, Energy Efficiency and Energy Access in the ECOWAS Region, 2016

45. Ministry of Energy (2013). Sector scan the energy sector in Sierra Leone. [Internet]. [cited 2019 Jan 15]. Available from: https://www.rvo.nl/sites/default/files/2018/07/sector-scan-the-energy-sector-in-sierra-leone.pdf

46. Ministry of Energy, Progress Report MoE.pdf [Internet]. [cited 2019 Jan 5]. Available from: http://www.energy.gov.sl/wp-content/uploads/2018/04/ProgressReportMoE.pdf

47. UK Aid. Rural electrification in Sierra Leone. DFID;

48. IRENA_mini-grid_policies_2018.pdf [Internet]. [cited 2018 Dec 6]. Available from: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Oct/IRENA_mini-grid_policies_2018.pdf

49. Wiemann, M. Rolland, S. Hybrid mini-grids for rural electrification: lessons learned. Alliance for Rural electrification, USAID., 2014

50. Gollwitzer L. Community-based Micro Grids: A Common Property Resource Problem. :29.

51. IRENA. Policies and Regulations for Private Sector Renewable Energy Mini-grids. 2018;112.

52. UNOPS. UNOPS Market and Technical Research Data Collection, Renewable Energy Pre-Feasibility Study – Sierra Leone. FLS Group Ltd.; 2016.

53. Bhattacharyya SC, Palit D. Mini-grid based off-grid electrification to enhance electricity access in developing countries: What policies may be required? Energy Policy. 2016 Jul 1;94:166–78.

54. Setiawan AA, Yu Z, Nayar CV. Design, economic analysis and environmental considerations of mini-grid hybrid power system with reverse osmosis desalination plant for remote areas. Renew Energy. 2009;34(2):374–83.

55. Mohammed YS, Mustafa MW, Bashir N. Hybrid renewable energy systems for off-grid electric power: Review of substantial issues. Renew Sustain Energy Rev. 2014 Jul 1;35:527–39.

56. Mandelli, S., Barbieri, J. Mereu, R. Colombo, E. (2016). Off-grid systems for rural electrification in developing countries: Definitions, classification and a comprehensive literature review. Renewable and Sustainable Energy Reviews, Vol. 58, pp. 1621-1646

57. Mainali B, Silveira S. Alternative pathways for providing access to electricity in developing countries. Renew Energy. 2013;57:299–310.

58. Schäfer M, Kebir N, Neumann K. Research needs for meeting the challenge of decentralized energy supply in developing countries. Energy Sustain Dev. 2011 Sep 1;15(3):324–9.

59. Lahimer AA, Alghoul MA, Yousif F, Razykov TM, Amin N, Sopian K. Research and development aspects on decentralized electrification options for rural household. Renew Sustain Energy Rev. 2013;24:314–24.

60. Kirubi C, Jacobson A, Kammen DM, Mills A. Community-Based Electric Micro-Grids Can Contribute to Rural Development: Evidence from Kenya. World Dev. 2009 Jul;37(7):1208–21.

61. Urmee T, Harries D, Schlapfer A. Issues related to rural electrification using renewable energy in developing countries of Asia and Pacific. Renew Energy. 2009 Feb 1;34(2):354–7.

62. GuidesforDevelopment.pdf [Internet]. [cited 2019 Jan 24]. Available from: http://www.nrecainternational.coop/wp-content/uploads/2016/11/GuidesforDevelopment.pdf

63. Eales_Unyolo_2018_Renewable_Energy_Mini_grids_in_Malawi.pdf [Internet]. [cited 2019 Feb 18]. Available from: https://strathprints.strath.ac.uk/64868/1/Eales_Unyolo_2018_Renewable_Energy_Mini_grids_in_Malawi.pdf

64. Kowalski K, Stagl S, Madlener R, Omann I. Sustainable energy futures: Methodological challenges in combining scenarios and participatory multi-criteria analysis. Eur J Oper Res. 2009;197(3):1063–74.

65. Alfaro J, Miller S. Satisfying the rural residential demand in Liberia with decentralized renewable energy schemes. Renew Sustain Energy Rev. 2014;30:903–11.

66. Oteman M, Wiering M, Helderman J-K. The institutional space of community initiatives for renewable energy: a comparative case study of the Netherlands, Germany and Denmark. Energy Sustain Soc. 2014 May 19;4:11.

67. Off-grid Energy Development in India. Econ Polit Wkly. 2015 Jun 5;51(22):7–8.

68. MinigridPolicyToolkit_Sep2014_EN.pdf [Internet]. [cited 2019 Feb 20]. Available from: http://www.ren21.net/Portals/0/documents/Resources/MGT/MinigridPolicyToolkit_Sep2014_EN.pdf

69. IRENA. Renewable power generation costs in 2017. 2018;160.

70. IRENA. Innovation Outlook: Renewable: Mini-grids. :184.

71. Planning and prospects for renewable power: West Africa. :110.

72. Kumar A. Beyond technical smartness: Rethinking the development and implementation of sociotechnical smart grids in India. Energy Res Soc Sci. 2019 Mar 1;49:158–68.

73. Sizing_handbook_150dpi_for_web.pdf [Internet]. [cited 2019 Jan 31]. Available from: https://www.giz.de/en/downloads/Sizing_handbook_150dpi_for_web.pdf

74. Blimpo MP, Cosgrove-Davies M. Electricity Access in Sub-Saharan Africa: Uptake, Reliability, and Complementary Factors for Economic Impact. World Bank Publications; 2019. 160 p.

75. Kumar A. Energy Access in an Era of Low Carbon Transitions: Politicising Energy for Development Projects in India. :355.

76. Bhattacharyya SC. Energy access programmes and sustainable development: A critical review and analysis. Energy Sustain Dev. 2012 Sep 1;16(3):260–71.

77. Nerini FF, Broad O, Mentis D, Welsch M, Bazilian M, Howells M. A cost comparison of technology approaches for improving access to electricity services. Energy. 2016 Jan 15;95:255–65.

78. Tariffs - energypedia.info [Internet]. [cited 2019 Feb 4]. Available from: https://energypedia.info/wiki/Tariffs

79. Bigsten A, Soderbom M. What have we learned from a decade of manufacturing enterprise surveys in Africa? World Bank Res Obs. 2006 Aug 2;21(2 (August 1996)):241–65.

80. Mainali B, Dhital RP. Isolated and Mini-Grid Solar PV Systems: An Alternative Solution for Providing Electricity Access in Remote Areas (Case Study from Nepal). In: Solar Energy Storage [Internet]. United Kingdom: Academic Press; 2015 [cited 2019 Feb 14]. p. 359–74. Available from: http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1157398&dswid=-9865

81. Feldmann L. Small-hydro power in Sub-Saharan Africa. :52.

82. Mulder P, Tembe J. Rural electrification in an imperfect world: A case study from Mozambique. Energy Policy. 2008 Aug 1;36(8):2785–94.

83. Sinn M. Cost recovery of isolated microgrids in sub- Saharan Africa: causalities and prerequisites. :47.

84. OccPapers33_Maier.pdf [Internet]. [cited 2018 Jun 11]. Available from: http://www.geo.fu-berlin.de/geog/fachrichtungen/anthrogeog/zelf/Medien/download/OccPapers33_Maier.pdf

85. Taniguchi M, Kaneko S. Operational performance of the Bangladesh rural electrification program and its determinants with a focus on political interference. Energy Policy. 2009 Jun 1;37(6):2433–9.

86. Kamalapur GD, Udaykumar RY. Rural electrification in India and feasibility of Photovoltaic Solar Home Systems. Int J Electr Power Energy Syst. 2011 Mar 1;33(3):594–9.

87. Haanyika CM. Rural electrification in Zambia: A policy and institutional analysis. Energy Policy. 2008 Mar 1;36(3):1044–58.

88. Zhang X, Kumar A. Evaluating renewable energy-based rural electrification program in western China: Emerging problems and possible scenarios. Renew Sustain Energy Rev. 2011 Jan 1;15(1):773–9.

89. Gurung A, Gurung OP, Oh SE. The potential of a renewable energy technology for rural electrification in Nepal: A case study from Tangting. Renew Energy. 2011 Nov 1;36(11):3203–10.

90. Dorji T, Urmee T, Jennings P. Options for off-grid electrification in the Kingdom of Bhutan. Renew Energy. 2012 Sep 1;45:51–8.

91. Mini-Grid-Regulations-2018-1.pdf [Internet]. [cited 2019 Feb 26]. Available from: http://ewrc.gov.sl/wp-content/uploads/2018/12/Mini-Grid-Regulations-2018-1.pdf

92. Swinkels CE. 'Best of both worlds' or in between both worlds. :66.

93. Frame D, Tembo K, Dolan MJ, Strachan SM, Ault GW. A community based approach for sustainable off-grid PV systems in developing countries. In: 2011 IEEE Power and Energy Society General Meeting. 2011. p. 1–7.

94. RMI_Nigeria_Minigrid_Investment_Report_2018.pdf [Internet]. [cited 2019 Feb 19]. Available from: https://www.rmi.org/wp-content/uploads/2018/08/RMI_Nigeria_Minigrid_Investment_Report_2018.pdf

10 Appendices

10.1 Map of research locations

10.2 Assessment table

Below the assessment table is presented.

- First column: sustainability indicator
- Second column: key variables that group the indicators.
- Third column: 34 indicators to evaluate the long-term sustainability
- Fourth and fifth column: indicators values of mini-grid in Yele and Segbwema.
- Sixth column: references to literature and interviews.

			Yele	Segbwema	
Social	*Community involvement*	Community education	0,50	0,75	[S3],[25],[64]
		Support of local leaders and politicians	0,75	0,50	[26,][S4]
		Share of population with electricity access	0,50	0,25	[25]
		Training and employment of local people	1,00	0,50	[26],[64]
	Ownership	Suitability ownership model	1,00	0,50	[4],[29]
	Benefits & Acceptability	Allocation of electricity between customers	1,00	1,00	[27], [S34]
		Awareness about connection and consumption	0,50	0,75	[28],[S31]
		Availability of streetlights	0,50	0,75	[25]
		Ability to pay for electricity services	1,00	0,50	[S11],[25]
		Electricity access public facilities (schools, clinics, etc)	1,00	0,50	[25],[29]
SCORE			**7,75**	**6,00**	
Technological	*Monitoring & management*	Metering system mini-grid	0,00	1,00	[S35],[29]
		Managing of electricity consumption	0,25	1,00	[28],[S13]
		Match of technical design with demand pattern	0,50	0,75	[10],[S31]
	Reliability & efficiency	Availability and utilization of services	0,75	0,50	[25],[29]
		System efficiency	0,25	0,50	[25],[29],[S13],[S24]
	Operation & maintenance	Availability equipment and spare parts in the country	0,50	0,75	[25]
		Dependency on foreign assistance	0,75	0,50	[28]
		Quality equipment and materials	0,50	0,75	[10],[25]
	Modularity	Compatibility with future grid integration	1,00	0,75	[10],[25]
		Adaptability and expandability	0,50	1,00	[S10]
SCORE			5,00	7,50	
Economical	*Costs and investments*	Financial support government	0,00	0,00	[26]
		Operation and maintenance costs	0,75	0,50	[25],[29],[S35]
	Productive use	Industrial/commercial customers with productive use	1,00	0,75	[25],[29]
		Anchor client connections	1,00	0,50	[25],[29]
	Financial	Non-payments or outstanding payments	0,50	1,00	[S10],[S12]
		Tariff lag	1,00	0,75	[S6]
		Micro-credit facilities	0,50	0,50	[25],[26],[27]
SCORE			**6,79**	**5,71**	
Policy / institutional	*Regulations*	National regulation on tariff setting and licensees	0,00	0,00	[10],[25],[S10]
		Tax breaks on imported (spare) parts	0,75	0,75	[25]
	Organization	Capability of staff	1,00	1,00	[24],[27]
		Long-term vision company	0,00	0,50	[S1]
		Defining of responsibilities between stakeholders	0,75	0,75	[10],[25]
	Enforcement & Security	Enforcement of local policy	0,75	0,75	[S10]
		Security of electricity infrastructure	1,00	0,75	[S4]
SCORE			6,07	6,43	

10.3 Interviews

10.3.1 Interview protocol

- **National**
  - What are the characteristics of the energy sector and the energy access rate in Sierra Leone?
  - How is the government of Sierra Leone involved in the development of mini-grids? Which agencies are working on the topic of rural electrification?
  - Is there a national policy for rural electrification and mini-grid initiatives? How robust is that policies? Can it attract private investors, NGO's, etc?
  - Who is responsible for providing permits?
  - How many mini-grids are operational in Sierra Leone? How are they organized? Which actors are active in the field of decentralized power systems?

- **Local**
    - Generic
        - Can you tell more about the mini-grid preparation phase? How was it organized? Who have taken the initiative? Is it a donor project or private funded?
        - What are the main challenges and success factors of the mini-grid?
        - Who are connected to the distribution grid? Household, industrial customers, public services, etc?
        - How is the organization structure of the company?
        - How is the socio-economic situation of the village? What are the population density, income levels, economic activities, local structures?
        - Is there a certain strategy to develop mini-gird(s)?
    - Social
        - What are the characteristics of the community? What are the population density and distribution? Number of households?
        - How do you involve the community? Do you have community meetings or consultations? Is there a frequency in meetings?
        - What is the role of the paramount chief and the community council? Do you have an energy committee and how is it organized?
        - What are the benefits of the mini-grid in the community?
        - What is the opinion of the community people towards the mini-grid? Are they satisfied with the mini-grid?
        - What is the impact of the mini-grid on the social-economic development of the villages?
        - Are the people educated to use the electricity system?
        - Who is owner of the mini-grid? Why is such ownership preferred?
    - Technical
        - How is the mini-grid designed and can you tell more about the performance indicators? What are the generation capacity, efficiency, demand load (behaviour), peaks, load factor?
        - How are the metering and monitoring systems managed?
        - What are the main challenges technically in the daily operation of a mini-grid?
        - Do you stimulate productive use of electricity? How does it affect the system?
        - How do you organize the supply chain of spare parts and qualified products?
        - Which technologies and configurations are used in the mini-grid?
        - Is the capacity enough to supply the whole village? Why is there a scarcity or not? And in case of scarcity of electricity, how is the generated electricity allocated? Who is responsible for the allocation of power? What is the opinion of the community about the allocation?
        - How many generation sources have the mini-grid? Is there an option for hybridization or modularity?
        - What is the frequency of maintenance activities? Do you know the utilization factor?

- Economic
    - What is the average income level? What is the variation between rich and poor people?
    - What are the main working activities? How does it affect the income flow within the community?
    - How is the payment system organized? Is there a prepaid system or are there demand limiters? Who are responsible for the retail and sales of the electricity?
    - What are the ability and willingness to pay of customers?
    - Who are responsible for setting the tariffs? Fixed tariff or pay-as-you-go tariff? Do you have different tariff categories?
    - Is the mini-grid economic viable?
    - Are there micro-credit facilities in the village that help people to finance their appliances?
    - To what extent is the electricity affordable for the people? How many households are connected?
    - What are the commercial and industrial activities and is a growth of these activities possible or expected?
- Institutional
    - Do you a long-term plan for the future planning and asset management?
    - What is the role of the government? Do you receive subsidies, tax fees, etc?
    - Can you tell more the authorities in the community? Who should make the decisions and is responsible for solving conflicts? Is there a relation with the authorities?
    - Is there an enhancement policy for fraud cases, corruption, etc.?
    - How many (local) workers are involved in the company of the mini-grid? What are their tasks and responsibilities?
    - Is there an expectation of central grid arrival?

10.3.2 List of stakeholders

Interview no.	Name	Organization	Function	Categories
1	Hartlieb Euler	GIZ	Director	NGO, knowledge partner
2	Lamin Kamara	Endev	Consultant	NGO, knowledge partner
3	Foday Sheku Dumbuya	Endev	Programme office Endev	NGO, knowledge partner
4	Johannes Weeber	WHH	technical advisor EnDev	NGO, knowledge partner
5	Ylva Kuerten	GIZ/ENDev	Programme manager	NGO, knowledge partner
6	Mustakin Conteh	WHH	Operation manager mini-grid venture	NGO
7	Ezekiel Kamangulu	UNOPS	Technical team lead RREP	NGO
8	Justin Agbakwuru	UNOPS	Project manager	NGO
9	Michael Rohrer	INENSUS	Consultant	Institutional expert
10	Jakob Schmidt-Reindahl	INENSUS	Power systems Engineer	Institutional expert
11	Jacobiene Ritsema	Witteveen+Bos	Consultant sustainability	Consultant

12	Johan Slobbe	Witteveen+Bos	Consultant	Consultant
13	Gerwin Rens	Witteveen+Bos	PV expert	Consultant
14	Abu Abu Koroma	GoSL	Minister of North	Government
15	Kelcise Sesay	GoSL	Head of Electricity	Government
16	Emmanuel Mannag	EWRC	Director General	Government
17	Community council	Yele		Local
18	Arthur Anderson	PowerNed	Local manager	Local
19	Musa Samura	PowerNed	Technical staff member	Local, technical
20	Ibrahim Samura	PowerNed	Technical staff member	Local, technical
21	Shaka Fullah	PowerNed	Laison officer	Local
22	Sahr Kaikai	PowerNed	Accountant	Local
23	John Turray	PowerNed	Waterplant manager	Local
24	Donald Keus	PowerNed	Managing Director	NGO
25	Casper Swinckels	Wagening University	Intern PowerNed	Academic
26	Mohammed Kamara	Natural Habitat/Nedoil	Palmoil plant manager	NGO,
27	Alhaji Mustapha Sesay	Yele	Paramount chief	NGO
28	Andrew Brooke-Smith	Tropical Limited	Director of Agriculture	Business
29	Patrick Blake	Tropical Limited	Vice President	Business
30	Golda Williams	REAL-SL	Office manager	Business, knowledge partner
31	Niccolo Meriggi	Yale University	Research leader minigrid	Academic
32	Kevin Grieco	Yale University	PhD student	Academic
33	Ahmineh Ghorbani	TU Delft	Assistent professor	Academic
34	Daniel Scholten	TU Delft	Assistent professor	Academic
35	Frank Hoogers	Independent Energy	Director Operations	Business
36	Alexander Och	SD Strategies	Director	Business
37	Will Lunn-Rockliffe	Joule Africa	Project Coordinator Seli Hydropower	Business
38	Ciro Serafino	Salini	Director of Bumbuna I	Business, utility
39	Marc Sackoh	JAM Yele	Local manager	Local
40	Community people Yele		Teachers, enterpreneurs, land owners, households, hospital director	
41	Community people Segbwema		Teachers, enterpreneurs, land owners, households	
42	Community people Sumbuya		Teachers, enterpreneurs, land owners, households	

10.4 Scientific Article

Sustainable mini-grids in Sierra Leone: analysing and designing rural electrification from a socio-technical perspective

Sjoerd Janse[a] - 4036719 - j.j.c.janse@student.tudelft.nl

[a]Department of Technology, Policy and Management, Delft University of Technology, Jaffalaan 1, 2828 CN Delft, Netherlands

Abstract: Mini-grids are preferred at rural areas where grid expansion and solar-home-systems are too expensive. In Sierra Leone the potential for mini-grids is large due to the limited central grid infrastructure. To achieve feasible and viable mini-grids in Sierra Leone it is evident to consider not only technical aspects. This research approaches mini-grids from a holistic view, and takes social, technical, economical and institutional aspects into consideration. An evaluative study of two mini-grids in Sierra Leone resulted in some lessons learnt, which can be used for future development of mini-grids in Sierra Leone.

Key words: mini-grids; rural electrification; sustainability indicators; Sierra Leone

Introduction

Sierra Leone is one of the Sub-Sahara African (SSA) countries with a very low electrification rate. The urban electricity access lies at 12,5 % and in the rural areas at 2,5 % [1]. The installed generation capacity (137,2MW) is far below the required capacity. The shortage results in frequent black-outs in the country, brown-outs and low levels of reliability.

Most rural areas are lacking electricity access. People are using solar torches and kerosene lamps. For charging phones and radios, they are dependent on a small amount of shops having a diesel generator. Electrification of rural areas stimulates the socio-economic development of the area, because more people have access to electricity and more generated capacity is available to stimulate electricity demanding activities [2]–[5].

Small-scale off-grid solutions are preferred for electrification of these rural areas [6]–[8]. Quite often grid extension is not feasible for the rural areas. The high investment costs of extending the transmission lines to these areas, which are hard to reach due to the deplorable infrastructure and geographic conditions, makes it extremely costly [9]. Solar Home Systems (SHS) are popular to give people access to electricity, but the prices are for most people in Sierra Leone not affordable. While SHS are not able to generate energy for a productive use, stimulating income-generated activities by means of SHS is difficult. For rural villages with a medium to high density of households per area, mini-grids are a better option to give access to electricity. Mini-grids (or micro-grids) can be defined as isolated electricity systems with a generation source and a small distribution grid that supplies electricity to a small group of customers [2]. For Sub-Saharan Africa, the renewable generation sources of most off-grid systems are solar photovoltaics (PV), mini-hydro and biomass gasification [10]. If a mini-grid has more than one generation source, the system is defined as hybrid mini-grid.

Although mini-grids can change the socio-economic situation, the failure risk of mini-grids in SSA is high. The system needs to be embedded in the community and multiple criteria that are linked to livelihoods, regulation and economic standards have to be analysed in order to design proper electricity access [12]. To enhance the long term sustainability of mini-grids, Akinyele [11], Ahlberg [12], Ilskog [13], Katre [14], Mainali [15] listed several sustainability indicators that help to evaluate mini-grids and to detects factors for success and failures of mini-grids [11].

Knowledge gap

There is a lack of knowledge about the electricity situation and electrification of rural areas in Sierra Leone. This paper is aiming to expand the knowledge by discussing a research to sustainability aspects of mini-grids in Sierra Leone. The research is answering the following research question:

How to achieve sustainable mini-grids in Sierra Leone that can give rural communities an affordable and reliable power supply?

Methodology

The research consists of three parts. The first part is discussing challenges in achieving long-term sustainable mini-grids by reviewing literature articles and reports. Outcome of the first part is a framework to assess and discuss the sustainability of mini-grids (table). The second part are evaluations of two mini-grids in Sierra Leone. For mini-grids in Yele and Segbwema, a descriptive and evaluative study is conducted by analysing the main success and failure factors of the mini-grids by doing data research and conducting interviews. The assessment framework helps to evaluate the mini-grid in a systematic manner. The findings of the first part are in this way compared with experiences from the Sierra Leonean context. Based on the evaluative case studies, some lessons learnt, and requirements are formulated to recommend and advice future mini-grids in Sierra Leone. These requirements and recommendations as outcome of the second parts are exemplified by discussing a potential location for a mini-grid a in Sierra Leone, which completed the research.

Case study research is useful to generate knowledge of complex situations, which are dynamic processes of socio-economic, institutional and technological variables [26]. For mini-grids, an holistic approach is essential that considers 'technologies not simply as designed and engineered material objects' but as an entanglement of 'producers, infrastructures, users, consumers, regulators and other intermediaries' [17]. In the evaluative case studies all relevant aspects are researched in order to come up with requirements that can be used for a design-oriented analysis.

Case studies

The case studies are executed in Yele, Segbwema and Sumbuya (see appendix A1). Yele, located approximately 150 kilometres from the capital city Freetown, has a mini-hydro station with distribution grid that supplies 300 households with electricity. In Segbwema (Kailahun District) started a solar mini-grid their operation 2017. The Segbwema solar park is part of the PRESSD-SL project, a cooperative project between the Ministry of Energy and Welthungerhilfe. In Sumbuya,

Indices	**Yele**	**Segbwema**	**Sumbuya**
Population	8000	12000	8000
Economic activities	Fishing and Farming: palm oil, cassava, potatoes, plantain, bananas, pepper		
Commercial activities	Welding, retail, palm oil processing, telecommunication tower, hospitals	Welding, retail, grain milling, processing, telecommunication tower, hospital	Large pineapple plantation and processing company, welding, construction companies, clinic
Households energy use	Electric bulbs, fans, radio sets, cell phones, refrigerators		
Technology	Mini-hydro (250kW)	PV (127kW)	?
Owner	PowerNed	WHH, COOPI	?

there is a potential of developing a mini-grid, while a large anchor customer has started their business activities.

Literature review

Despite their promising social impacts, mini-grids in rural areas with low socio-economic standards pose technical, economic and institutional challenges. Underperformance and high failure rates are common. Poverty, seasonal incomes, unfamiliarity with paying monthly bills, wrong electricity connections, illiteracy and a lack of education are factors that are affecting the sustainability of mini-grids [22].

Various articles have been presented about critical factors for off-grid generation in rural Africa [2], [4], [7], [11], [18]–[21]. Sometimes inappropriate installation of equipment, low qualified staff or poor maintenance led to the failure of the mini-grid. But, more frequently failures are more a complex combination of technical, financial and governance aspects [22], [23]. The technical design was developed without interaction with the institutional and social context at both national and local level [24]. The lack of community participation, for example, can result in low awareness of customer, lower demand levels, lower efficiencies, less profit and less investments. For mini-grids it is essential to include the societal dynamics. Electricity is not a product, but a service to stimulate the development. If the service is not aligned with the needs of the community, the mini-grid will fail.

Assessment framework

Mainali [22] developed a framework with five sustainability aspects to address the critical dimensions and features of a mini-grid. And Ilskog [13] discussed the success of rural electrification using 39 indicators, categorized into five dimensions: social, technical, economic, environmental and policy sustainability. Based on the literature and reports [25]–[31], [31], [32], the STEEP framework of Akinyele [11] and the work of Ahlberg [12] and Ilskog [13], a list with 34 indicators is developed to access two mini-grids in Sierra Leone. The list is shown in appendix A. The indicators are reflecting all aspects that are affecting the socio-technical dynamics of mini-grids. The indicators are grouped through some key variables, which are linked to the already used sustainability aspects: social, technological, economic and policy aspect.

The indicators are assessed at a scale of 5 steps between 0 and 1. If the indicator is met in the case study, one point is given, if the indicator is not met the in the case, a zero is given. 0.25, 0.5 or 0.75 will be awarded if the indicator has a low, medium or high level of achievement. The higher the score of the sustainability aspect, the more the aspect is contributing to the long-term sustainability of the mini-grid. The lower the score, the more attention is required. Below the indicators are discussed and compared with the local situation of two mini-grids in Sierra Leone. It is important to mention that the framework has no weighting factors. Although the indicators may have different weights, the framework has more a checklist character than a final score of the different mini-grids. It rather expresses the level of closeness or disparities in performance level than exact differences.

Sustainability dimensions

In this sections, first the sustainability dimension is introduced, followed by the results from the case studies.

Social sustainability

Participation of the local community support the awareness of the customers and provide priceless information about the customer needs [7], [18], [19]. The community as end-users will use, pay for and assess the electricity system. Customers can provide useful data about consumption and their willingness to pay and can assists in the construction and maintenance of the mini-grid, for example by means of providing local materials for pools [33]. Community involvement is not only important during the development phase, but also during the operation of the mini-grid [5]. From the perspective of the local energy supplier, respecting local structures and leaders are required for doing business. It also moderates to solve local conflicts [34] [46]. From the customer perspective, awareness and responsibility are required for proper connections, maintenance of the meter and payments of bills. The community can use radio shows and workshops to educate people on electricity consumption and explain the limitations of the electricity system. Based on the local situation the sort of ownership should be determined. In general, the following four models are used:

- Community-based model
- Private sector operator model
- Utility-based model
- Hybrid business model: a combination of the above kind of ownerships

In many cases, there is a tension between local ownership of the mini-grid and functioning as a business company that wants to recover the costs and have some reserves unforeseen expenses [18]. The strong collectivist nature makes it also difficult to make the business independent [23], [26].

Case studies

The scores are relatively higher for the mini-grid in Yele than Segbwema. This can be declared by the fact that the mini-grid in Segbwema is implemented by a large, international NGO, while the grid in Yele is implemented together with the hospital and the palm-oil plant by a small NGO. Local people were attracted to join one of the companies. In Segbwema the mini-grid has more a stand-alone position, strengthened by the ownership structure of a management layer that is also responsible for the mini-grids in Gbinti and Panguma. The mini-grid in Yele is operating longer, which results in more embeddedness in the community and more connections to public services (water plant, community hall). In Segbwema, they are still busy with the expansion of the grid, which explains the lower connection rate. In Yele the awareness has grown that PowerNed is a business stakeholder, while in Segbwema the company is still considered to be an aid-partner. It is pitiful that PowerNed decreased its focus on

			Yele	Segbwema
Social	*Community involvement*	Community education	0,50	0,75
		Support of local leaders and politicians	0,75	0,50
		Share of population with electricity access	0,50	0,25
		Training and employment of local people	1,00	0,50
	Ownership	Suitability ownership model	1,00	0,50
	Benefits & Acceptability	Allocation of electricity between customers	1,00	1,00
		Awareness about connection and consumption	0,50	0,75
		Availability of streetlights	0,50	0,75
		Ability to pay for electricity services	1,00	0,50
		Electricity access public facilities (schools, clinics, etc)	1,00	0,50
SCORE			**7,75**	**6,00**

organizing community meetings and radio shows. Participation of the community was a key factor in the beginning but got less attention during the operation of the hydro-network, especially in Yele. During the start of the mini-grid, workshops have been organised for educating and training local people. Now there are no more specific activities to engage the local community. In Segbwema the management has more attention on engaging and educating people to increase customers awareness of their electricity connection and consumption.

Technical sustainability

The design and technology must be a result of the customer's needs [36]. Population density, consumption pattern and willingness to pay are key parameters for the scale and generation source(s). For regular maintenance a supply chain of spare parts is essential as well as qualified technicians [37]. Load demand management is often underestimated in mini-grids. The small scale of the system makes the system vulnerable for voltage drops, brownouts and black-outs [23]. Storage capacity and demand management can insure a reliable power supply.

Case studies

Focus on load demand management is essential for the reliability and stability of the mini-grid. In Yele the monitoring and metering possibilities of the technical system are limited and should be improved. The hydro in Yele is lacking a central control and monitoring unit. At this moment the mode of operation is dependent on technicians that visit the control panels in the power station to see the frequency, generation and consumption. The frequency is regularly instable, and the voltage is fluctuating a lot, which makes appliances vulnerable.

In Segbwema they can remotely manage the system, which is also expensive. In both systems they have only one generation source, although Segbwema has a storage capacity. A hybrid configuration decreases the dependency on a single generation source and increases the reliability and income flow. Incentives to stimulate productive use during off-peak hours is important to increase the efficiency of the system. Nevertheless, both mini-grids cannot meet the demand continuously. In Segbwema this is caused by the minimum level of batteries; in Yele the water level limits the generation capacity. Spare parts for PV-system are increasingly available in the country, due to the development of solar mini-grids in West-Africa. The spare parts for the hydro-mini-grid are often not available in the country and need to be imported. The mechanical character of the hydro make maintenance for the local staff less complicated. The PV-system in Segbwema can be upscaled easily, while the system is modular. Nevertheless, the lack of a diesel generator in Segbwema decreases the efficiency in Segbwema. In Yele, a second turbine can be installed to double the

			Yele	Segbwema	
Technological	*Monitoring & management*	Metering system mini-grid	0,00	1,00	[S35],[29]
		Managing of electricity consumption	0,25	1,00	[28],[S13]
		Match of technical design with demand pattern	0,50	0,75	[10],[S31]
	Reliability & efficiency	Availability and utilization of services	0,75	0,50	[25],[29]
		System efficiency	0,25	0,50	[25],[29],[S13],[S24]
	Operation & maintenance	Availability equipment and spare parts in the country	0,50	0,75	[25]
		Dependency on foreign assistance	0,75	0,50	[28]
		Quality equipment and materials	0,50	0,75	[10],[25]
	Modularity	Compatibility with future grid integration	1,00	0,75	[10],[25]
		Adaptability and expandability	0,50	1,00	[S10]
SCORE			5,00	7,50	

			Yele	Segbwema	
Economical	*Costs and investments*	Financial support government	0,00	0,00	[26]
		Operation and maintenance costs	0,75	0,50	[25],[29],[S35]
	Productive use	Industrial/commercial customers with productive use	1,00	0,75	[25],[29]
		Anchor client connections	1,00	0,50	[25],[29]
	Financial	Non-payments or outstanding payments	0,50	1,00	[S10],[S12]
		Tariff lag	1,00	0,75	[S6]
		Micro-credit facilities	0,50	0,50	[25],[26],[27]
SCORE			**6,79**	**5,71**	

generation capacity, but it is recommended to make mini-grid hybrid to satisfy the future demand.

Economic sustainability

In order to cover the system's running and replacement costs, a suitable setting of tariffs and subsidies must be designed. It depends of the local procedures and the ownership-model which actor has the responsibility to set the tariffs. A tariff that is able to cover the cost is referred to as break-even tariff [3], [38]. The way to operate a mini-grid without subsidies is by stimulating productive use of energy by commercial and anchor customers. Anchor and business customers are essential to stimulate productive use of energy. If economic activities raise, the viability of the mini-grid business case will increase [39]. Productive use can be stimulated by supporting local entrepreneurs, flexible tariffs and load scheduling. The tariffs should be able to cover the running cost and affordable for most customers. In most African countries prepaid systems or current limiters are preferred and are effective as metering systems in a low-resource and seasonal-influenced setting. These systems allow customers to pay electricity in advance dependent on their available cash money [22], [36].

Case studies

Both mini-grids are dependent on grants and subsidies to cover their investments costs. In the case studies, there are no flexible tariffs, while using flexible tariffs can increase the affordability and the increase load factor. Commercial and industrial customers are a pillar for the economic viability. Stimulating productive use is done in Yele and Sumbuya. The mini-grid in Yele is connected to more industrial and commercial customers, resulting in a higher rate of productive use of energy. For Segbwema it is important to attract more businesses customers to the community and connect them to the grid.

The post-paid systems in Yele resulted in more non-payments and outstanding payments. Although PowerNed will banish the post-paid meters for residential customers, at this moment the non-technical losses in Segbwema are lower. In both communities a bank is housed, but for most people acquiring credit and loans is difficult.

Policy or institutional sustainability

Low institutional quality is a barrier for investors to finance rural electrification projects or mini-grids [28]. For successful rural electrification by mini-grids, stable and durable support from the central or national

			Yele	Segbwema	
Policy / institutional	*Regulations*	National regulation on tariff setting and licensees	0,00	0,00	[10],[25],[S10]
		Tax breaks on imported (spare) parts	0,75	0,75	[25]
	Organization	Capability of staff	1,00	1,00	[24],[27]
		Long-term vision company	0,00	0,50	[S1]
		Defining of responsibilities between stakeholders	0,75	0,75	[10],[25]
	Enforcement & Security	Enforcement of local policy	0,75	0,75	[S10]
		Security of electricity infrastructure	1,00	0,75	[S4]
SCORE			6,07	6,43	

government is essential. Ministries of Energy and rural agencies should develop national policy, rural electrification strategies and clear regulations related to quality standards, tariffs, financial support, and position of mini-grids with respect to the central grid [33]. Non-energy ministries and public agencies should refine policies related to taxation, land rights, environmental protection and banking [40]. Besides the national regulations, the electricity company has the responsibility to allocate the generated power fair and cost-effective. This requires appropriate and accountable leadership. Appropriate leadership can be achieved by local training and a certain distance between the community and the company.

Institutional aspects case studies

The Ministry of Energy (MoE) and the Electricity and Water Regulatory Commission (EWRC) are the main stakeholders for rural electrification projects. Sierra Leone, unlike other countries, has no rural electrification agency. The MoE is responsible for the strategic plans and the reform of the electricity sector. The EWRC is regulator for energy licences and tariff settings [41].

On national scale the government is working together with NGO's on a policy document regarding mini-grids, the SLEWRC Mini-grid regulations. The framework has to lineate a smooth and sustainable enrolment of mini-grids in Sierra Leone [42]. Based on the conceptual text [43] the policies and regulations provide formal regulation for licensing procedures, tariff determinations, bidding procedures and give clearness about interconnection and coverage issues. On community level, the policies should provide transparency in order to prevent scepticism or mistrust amongst the customers. Mini-grids with a capacity below 100 kW have a simplified procedure, can mutually negotiate between consumers about the tariffs without intervention of the EWRC. This document has finished the public consultation rounds and is waiting for approval by the national government.

The mini-grid in Yele is dependent of foreign assistance, which makes the company vulnerable and not-sustainable. Both mini-grids benefit from qualified technicians and a capable manager. Nevertheless, in Segbwema the policy, standards and briefings are more professional. But, the mini-grid is dealing with the interests of local and national politicians. In Yele the company has more independence than Segbwema, resulting in a better enforcement policy. To enhance the support of the community, both companies update regularly the community elders, the board of the community. The latter, together with the Paramount Chief, have the most powerful position in the community.

Assessment

The table below presents and summarizes the results of the sustainability assessment of the 34 indicators in Yele and Segbwema. The main difference are the scores of the socialand technological dimension. The Segbwema grid has better equipment and more monitoring tools that support the technological management of the system. The mini-grid in Yele has a higher embeddedness in the local community. The difference in economic

	Yele	Segbwema
Social indicators	7,75	6,00
Technological indicators	5,00	7,50
Economical indicators	6,79	5,71
Policy / institutional indicators	6,07	6,43

sustainability can be explained the mini-grid in Yele has more anchor customers (hospitals, water plant) and more commercial and industrial customers that have a productive use of energy.

Conclusion

Findings from literature are combined with evaluations from mini-grids in Sierra Leone to assist and support the mini-grid business in Sierra Leone. Although, the literature about mini-grids in Sub-Sahara Africa is expanding rapidly, there is almost no literature of the energy situation in Sierra Leone. This research highlighted different aspects that are essential for the long-term sustainability of mini-grids in Sierra Leone. The literature study helps to evaluate the complex situation of mini-grids in an analytic and systematic way. Case study research gives insights in the local and country specific characteristics, in which the socio-economic and institutional context is included. The holistic and systematic review includes the social and technical interactions to stress the socio-technical dynamics within the system.

The following recommendations can be given for new developed mini-grid:

- Before starting to develop a mini-grid an extensive research on the technical feasibility, financial viability, community willingness and the chosen technology is important.
- The design must not be technology driven, but have to be based on the socio-economic needs of the community and can be adapted technically.
- Community participation from the inception of a mini-grid till operation is essential. Communication with communities by radio-shows and community helps to make people aware of the efficiency of their appliances and the limitations of the electricity supply.
- A community energy committee is very useful, for solving conflicts, gathering information from the community, spreading information, and support form the whole community.
- Load demand management is essential for a sustainable operation of a mini-grid. The system will achieve higher efficiencies and is economically more favourable.
- The electricity revenues of household customers are often too small due to the low levels of electricity consumption. Connecting commercial and industrial customers is essential for achieving economic viability of the grid.
- Hybridisation has a positive impact on the reliability and cost-effectiveness of the grid.
- Modularity and flexibility of mini-grids prevents overspending of capital. The size and amount of generation assets can be increased (or decreased) during operation. The flexibility increases also the reliability and viability of the system.
- An anchor client with a high and stable load consumption, can increase the cost-effectiveness of mini grids substantially. The presence of locations in Sierra Leone that have a significant daytime productive load and a potential household consumption are rare. Most people are living from small agriculture activities. In small villages SHS remain more economic competitive than mini-grids.
- Pre-paid meters or current limiters can be used for metering, because of the dependency of seasonal flows and volatile income patterns. Prepaid meters are preferred above current limiters, because of the fact they can provide more knowledge about the consumption pattern by remote monitoring.

- Mini-grids require capable companies or (private) utilities that have a high level of technical knowledge and are able to allocate the available power and to set tariffs economically strategic and fair.
- Bill collection is at times a difficult task. Some customers want special favours or have no financial resources to pay. It is important to emphasize that the behaviour of one customer can affect the sustainability of the whole system.

Discussion

It seemed that the situation Sierra Leone is not very different from other SSA countries. The used approach of the evaluative case studies is analytical and descriptive rather than statistical. This makes that the lessons learnt can be used to make some generalisations instead of one specific quantitative solution.

Large projects like rural electrification take a long time to develop. This makes the project susceptible for changing circumstances. Especially in developing countries like Sierra Leone, the political situation or disasters (for example Ebola) can slow down or change the process. Political instability can keep off foreign investors. Secondly, worldwide factors can influence the situation, such as the diesel price or evolving technology. If the diesel price decreases, the LCOE of the generation technologies will change. Thirdly, financing of such projects is dependent of foreign investors, who can change their strategies. At this moment large energy corporates enter the sector in some countries by investing in mini-grids. If the profit margin seems too low, they may stop their investments in this sector. Thus, the project is dependent on political, resource price variability and payment risk. Although some risks can be mitigated by hybridization (resource price variability) or ownership model (political risks), an uncertainty analysis or risk strategy in not included in this researchs. The research can be strengthened by adding an uncertainty analysis and a description of the different pathways to achieve feasible mini-grids in the country. Also a financial aspects can be researched more in depth. Access to finance is a critical issue, that needs more research.

Reference list

[1] Access to electricity (% of population) | Data [Internet]. [cited 2018 Aug 10]. Available from: https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?view=chart

[2] Md. M. Rahman, J. V. Paatero, en R. Lahdelma, “Evaluation of choices for sustainable rural electrification in developing countries: A multicriteria approach”, *Energy Policy*, vol. 59, pp. 589–599, aug. 2013.

[3] S. C. Bhattacharyya, “Mini-grid based electrification in Bangladesh: Technical configuration and business analysis.”, *Renewable Energy*, vol. 75, pp. 745–761, 2015.

[4] S. Feron, R. R. Cordero, en F. Labbe, “Rural electrification efforts based on off-grid photovoltaic systems in the Andean Region: Comparative assessment of their sustainability”, *Sustainability (Switzerland)*, vol. 9, nr. 10, 2017.

[5] R. Holland, L. Perera, T. Sanchez, en R. Wilkinson, “Decentralised rural electrification: Critical success factors and experiences of an NGO”, *Refocus*, vol. 2, nr. 6, pp. 28–31, jul. 2001.

[6] P. Alstone, D. Gershenson, en D. M. Kammen, “Decentralized energy systems for clean electricity access”, *Nature Climate Change*, vol. 5, pp. 305–314, apr. 2015.

[7] R. Deskmukh, J. P. Carvallo, en A. Gambhir, “Sustainable development of renewable energy mini-grids for energy access: A framework for policy design.”, Lawrence Berkeley National Laboratory and University of California–Berkeley, Berkeley, CA, 2013.

[8] A. Hirsch, Y. Parag, en J. Guerrero, “Microgrids: A review of technologies, key drivers, and outstanding issues”, *Renewable and Sustainable Energy Reviews*, vol. 90, pp. 402–411, jul. 2018.

[9] Wiemann, M. Rolland, S. Hybrid mini-grids for rural electrification: lessons learned. Alliance for Rural electrification, USAID., 2014

[10] Cherni JA, Dyner I. e.a. Energy supply for sustainable rural livelihoods. A multi-criteria decision-support system. Energy policy 2017 vol. 35 p. 1493-1504.

[11] D. Akinyele, J. Belikov, Y. Levron, D. Akinyele, J. Belikov, en Y. Levron, “Challenges of Microgrids in Remote Communities: A STEEP Model Application”, *Energies*, vol. 11, nr. 2, p. 432, feb. 2018.

[12] H. Ahlborg en M. Sjöstedt, “Small-scale hydropower in Africa: Socio-technical designs for renewable energy in Tanzanian villages”, *Energy Research & Social Science*, vol. 5, pp. 20–33, jan. 2015.

[13] E. Ilskog, “Indicators for assessment of rural electrification : an approach for the comparison of apples and pears”, *Energy Policy*, vol. 36, nr. 7, pp. 2665–2673, 2008.

[14] A. Katre en A. Tozzi, “Assessing the Sustainability of Decentralized Renewable Energy Systems: A Comprehensive Framework with Analytical Methods”, *Sustainability*, vol. 10, nr. 4, p. 1058, apr. 2018.

[15] B. Mainali, “Sustainability of rural energy access in developing countries”, KTH Royal Institute of Technology, Stockholm, Sweden, 2014.

[16] G. Morra, Friedland, A.C.. Case study evaluations, 2004

[17] G. Walker en N. Cass, “Carbon reduction, ‘the public’ and renewable energy: engaging with socio-technical configurations”, *Area*, vol. 39, nr. 4, pp. 458–469, dec. 2007.

[18] Guta DD, Jara J, Adhikari NP. e.a. Assessment of the Successes and Failures of Decentralized Energy Solutions and Implications for the Water–Energy–Food Security Nexus: Case Studies from Developing Countries. Resources no. 6, 2017

[19] E. Ilskog, “And then they lived sustainably ever after?: experiences from rural electrification in Tanzania, Zambia and Kenya”.

[20] M. Schäfer, N. Kebir, en K. Neumann, “Research needs for meeting the challenge of decentralized energy supply in developing countries”, *Energy for Sustainable Development*, vol. 15, nr. 3, pp. 324–329, sep. 2011.

[21] J. R. Hogarth en I. Granoff, “Speaking truth to power: Why energy distribution, more than generation, is Africa’s poverty reduction challenge.”, Overseas Development Institute (ODI), London, 2015.

[22] B. Mainali en R. P. Dhital, “Isolated and Mini-Grid Solar PV Systems: An Alternative Solution for Providing Electricity Access in Remote Areas (Case Study from Nepal).”, in *Solar Energy Storage*, United Kingdom: Academic Press, 2015, pp. 359–374.

[23] M. P. Blimpo en M. Cosgrove-Davies, *Electricity Access in Sub-Saharan Africa: Uptake, Reliability, and Complementary Factors for Economic Impact*. World Bank Publications, 2019.

[24] Eales_Unyolo_2018_Renewable_Energy_Mini_grids_in_Malawi.pdf [Internet]. [cited 2019 Feb 18]. Available from: https://strathprints.strath.ac.uk/64868/1/Eales_Unyolo_2018_Renewable_Energy_Mini_grids_in_Malawi.pdf

[25] Mandelli, S., Barbieri, J. Mereu, R. Colombo, E., “Off-grid systems for rural electrification in developing countries: Definitions, classification and a comprehensive literature review. Renewable and Sustainable Energy Reviews, Vol. 58, pp. 1621-1646”, 2016. [Online]. Beschikbaar op: https://ideas.repec.org/a/eee/rensus/v58y2016icp1621-1646.html. [Geraadpleegd: 05-jun-2018].

[26] M. Taniguchi en S. Kaneko, “Operational performance of the Bangladesh rural electrification program and its determinants with a focus on political interference”, *Energy Policy*, vol. 37, nr. 6, pp. 2433–2439, jun. 2009.

[27] G. D. Kamalapur en R. Y. Udaykumar, “Rural electrification in India and feasibility of Photovoltaic Solar Home Systems”, *International Journal of Electrical Power & Energy Systems*, vol. 33, nr. 3, pp. 594–599, mrt. 2011.

[28] P. Mulder en J. Tembe, “Rural electrification in an imperfect world: A case study from Mozambique”, *Energy Policy*, vol. 36, nr. 8, pp. 2785–2794, aug. 2008.

[29] C. M. Haanyika, “Rural electrification in Zambia: A policy and institutional analysis”, *Energy Policy*, vol. 36, nr. 3, pp. 1044–1058, mrt. 2008.

[30] X. Zhang en A. Kumar, “Evaluating renewable energy-based rural electrification program in western China: Emerging problems and possible scenarios”, *Renewable and Sustainable Energy Reviews*, vol. 15, nr. 1, pp. 773–779, jan. 2011.

[31] A. Gurung, O. P. Gurung, en S. E. Oh, “The potential of a renewable energy technology for rural electrification in Nepal: A case study from Tangting”, *Renewable Energy*, vol. 36, nr. 11, pp. 3203–3210, nov. 2011.

[32] T. Dorji, T. Urmee, en P. Jennings, “Options for off-grid electrification in the Kingdom of Bhutan”, *Renewable Energy*, vol. 45, pp. 51–58, sep. 2012.

[33] M. Oteman, M. Wiering, en J.-K. Helderman, “The institutional space of community initiatives for renewable energy: a comparative case study of the Netherlands, Germany and Denmark”, *Energy, Sustainability and Society*, vol. 4, p. 11, mei 2014.

[34] L. Gollwitzer, D. Ockwell, B. Muok, A. Ely, en H. Ahlborg, “Rethinking the sustainability and institutional governance of electricity access and mini-grids: Electricity as a common pool resource”, *Energy Research & Social Science*, vol. 39, pp. 152–161, mei 2018.

[35] J. A. Moncada, E. H. P. Lee, G. D. C. N. Guerrero, O. Okur, S. T. Chakraborty, en Z. Lukszo, "Complex Systems Engineering: designing in sociotechnical systems for the energy transition", *EAI Endorsed Transactions on Energy Web*, vol. 3, nr. 11, jul. 2017.

[36] MinigridPolicyToolkit_Sep2014_EN.pdf [Internet]. [cited 2019 Feb 20]. Available from: http://www.ren21.net/Portals/0/documents/Resources/MGT/MinigridPolicyToolkit_Sep2014_EN.pdf

[37] A. Kumar, "Beyond technical smartness: Rethinking the development and implementation of sociotechnical smart grids in India", *Energy Research & Social Science*, vol. 49, pp. 158–168, mrt. 2019.

[38] A. A. Lahimer, M. A. Alghoul, F. Yousif, T. M. Razykov, N. Amin, en K. Sopian, "Research and development aspects on decentralized electrification options for rural household", *Renewable and Sustainable Energy Reviews*, vol. 24, pp. 314–324, 2013.

[39] A. Bigsten en M. Soderbom, "What have we learned from a decade of manufacturing enterprise surveys in Africa?", *The World Bank research observer*, vol. 21, nr. 2 (August 1996), pp. 241–265, aug. 2006.

[40] IRENA_mini-grid_policies_2018.pdf [Internet]. [cited 2018 Dec 6]. Available from: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Oct/IRENA_mini-grid_policies_2018.pdf

[41] Sustainability for all, Rapid assessment Sierra Leone [Internet]. [cited 2019 Feb 11]. Available from: https://www.se4all-africa.org/fileadmin/uploads/se4all/Documents/Country_RAGAs/Sierra_Leone_RAGA_EN_Released.pdf

[42] IRENA, "Policies and Regulations for Private Sector Renewable Energy Mini-grids", p. 112, 2018.

[43] EWRC, Mini-Grid Regulations 2018, ministry of Energy, Sierra Leone.

[44] M. F. E. Wauben en E. van Druten, "Feasibility study small hydro power in Sierra Leone", Witteveen en Bos, Rotterdam, sep. 2017.

Appendix

A.1 Research locations

A.2 Framework

			Yele	Segbwema	
Social	*Community involvement*	Community education	0,50	0,75	[S3],[25],[64]
		Support of local leaders and politicians	0,75	0,50	[26,][S4]
		Share of population with electricity access	0,50	0,25	[25]
		Training and employment of local people	1,00	0,50	[26],[64]
	Ownership	Suitability ownership model	1,00	0,50	[4],[29]
	Benefits & Acceptability	Allocation of electricity between customers	1,00	1,00	[27], [S34]
		Awareness about connection and consumption	0,50	0,75	[28],[S31]
		Availability of streetlights	0,50	0,75	[25]
		Ability to pay for electricity services	1,00	0,50	[S11],[25]
		Electricity access public facilities (schools, clinics, etc)	1,00	0,50	[25],[29]
SCORE			**7,75**	**6,00**	
Technological	*Monitoring & management*	Metering system mini-grid	0,00	1,00	[S35],[29]
		Managing of electricity consumption	0,25	1,00	[28],[S13]
		Match of technical design with demand pattern	0,50	0,75	[10],[S31]
	Reliability & efficiency	Availability and utilization of services	0,75	0,50	[25],[29]
		System efficiency	0,25	0,50	[25],[29],[S13],[S24]
	Operation & maintenance	Availability equipment and spare parts in the country	0,50	0,75	[25]
		Dependency on foreign assistance	0,75	0,50	[28]
		Quality equipment and materials	0,50	0,75	[10],[25]
	Modularity	Compatibility with future grid integration	1,00	0,75	[10],[25]
		Adaptability and expandability	0,50	1,00	[S10]
SCORE			5,00	7,50	
Economical	*Costs and investments*	Financial support government	0,00	0,00	[26]
		Operation and maintenance costs	0,75	0,50	[25],[29],[S35]
	Productive use	Industrial/commercial customers with productive use	1,00	0,75	[25],[29]
		Anchor client connections	1,00	0,50	[25],[29]
	Financial	Non-payments or outstanding payments	0,50	1,00	[S10],[S12]
		Tariff lag	1,00	0,75	[S6]
		Micro-credit facilities	0,50	0,50	[25],[26],[27]
SCORE			**6,79**	**5,71**	
Policy / institutional	*Regulations*	National regulation on tariff setting and licensees	0,00	0,00	[10],[25],[S10]
		Tax breaks on imported (spare) parts	0,75	0,75	[25]
	Organization	Capability of staff	1,00	1,00	[24],[27]
		Long-term vision company	0,00	0,50	[S1]
		Defining of responsibilities between stakeholders	0,75	0,75	[10],[25]
	Enforcement & Security	Enforcement of local policy	0,75	0,75	[S10]
		Security of electricity infrastructure	1,00	0,75	[S4]
SCORE			6,07	6,43	