Developing Mini-grids in Zambia How to build sustainable and scalable business models?

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ENEA combines economic performance with social engagement in a hybrid model creating new values: advising public and private leaders worldwide about energy transition while doing volunteer work with social entrepreneurs and NGOs.

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This publication is part of ENEA's policy to share essential knowledge, with the aim to propose keys to understanding the main challenges of energy transition and sustainable development at the global scale.

Executive summary

In rural Zambia, less than 5% of households are connected to the electricity grid. Increasing this ratio is critical for the economic development of these populations. According to the International Energy Agency, mini-grid and off-grid systems will provide electricity to up to 70% of those gaining access to electricity in African rural areas by 2040 [1]. Up to now, mini-grids have struggled to grow beyond pilot projects. Today, raising awareness about the main hurdles and learning from successful experiences is imperative in order for mini-grids to make a meaningful contribution to electricity access. ENEA and Practical Action are convinced that building sustainable and scalable business models is the key to strengthen the adoption of mini-grids. Both organizations have worked together to provide a common view on what works and what does not, based on evidence gathered from the field.

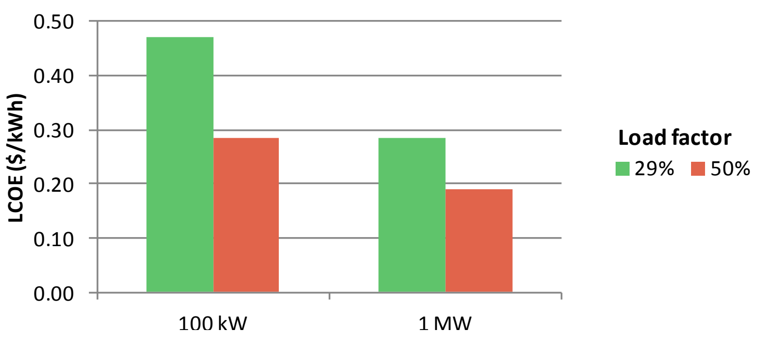
As part of this study, key learnings were derived from a selection of micro-hydro mini-grids, implemented by Practical Action or other organizations in Zimbabwe, Malawi and Zambia. While the schemes have their own specifics, the same barriers hamper their sustainability:

1. Mini-grids fall in a grey area when it comes to regulatory frameworks; administrative procedures are generally complex, with multiple points of contact;
2. Grant-funding can be a key enabler to finance the first mini-grids, as developers are bound by socially acceptable tariffs but limit scalability as new grants are needed for each new project;
3. Due to the current legal framework and the lack of feedback on an appropriate and socially accepted tariff structure, the revenue stream of the mini-grids are usually quite low and insufficient to cover curative maintenance costs
4. Load factor optimization is a key success factor to reach financial sustainability: this requires matching supply with demand from the initial design to the day-to-day operations;
5. Construction, management, operation and maintenance of the schemes require working with highly qualified personal on the long run, which have been lacking in some of the mini-grids surveyed.

Because of these difficulties, we believe that the mainstream community-based mini-grid models are not suited to tackle the various rural electrification challenges. Such models without private profit do have some advantages, such as a lower regulatory barrier and easier access to traditional grant funding, but they fail to produce sustainable actors, both on the financial and skill levels. Few if any community mini-grids surveyed generated enough cash to pay the CAPEX back or to maintain the necessary skills, usually leading to equipment degradation.

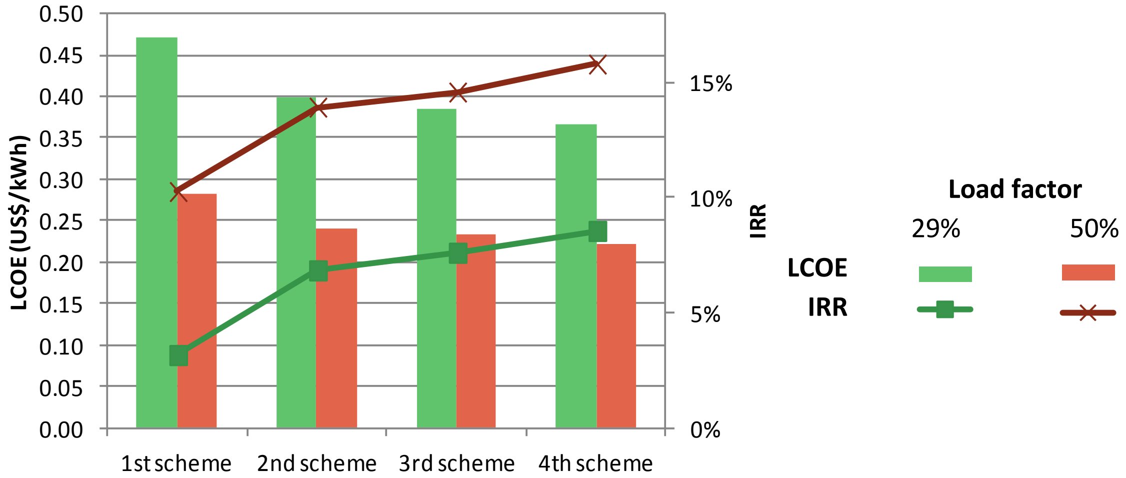
A new model must be built. Our point of view is that involving the private sector is necessary to overcome the sustainability issues hampering the community-based models. To successfully do so, ENEA and Practical action propose the following guidelines to lower the regulation and profitability barriers and thus allow the development of mini-grids in Zambia.

Improve mini-grid's financial profitability through stronger revenues: One of the best options to increase revenues of mini-grids is simply to sell more of the energy produced. Thus, optimizing the load factor should be one of the main targets for mini-grid operators. The LCOEs (Levelized Costs Of Electricity), which is the main metrics of the company's costs, can be massively decreased with a higher load factor (going from around 30% to a 50% load factor for instance), whatever the scheme size.



Increasing electricity consumption can be done by supporting the customer side (anchor businesses, productive uses, etc.) with either material, financial and/or human resources. However, their involvement in all economic activities in a location raises governance issues. Moreover, private developers usually do not have the capacity nor the willingness to allocate these resources. The best option may well be the involvement of development organizations and public institutions; Practical Action and SNV in Southern Africa, for instance are already involved in this type of work. Demand management actions should also be undertaken to smooth the load curve and thus increase the load factor (e.g. by promoting non-electrical cooking equipments).

Improve mini-grid's financial profitability of mini-grid through cost decrease: Clustering mini-grids is the most efficient way to significantly decrease the cost of the scheme by aggregating key activities (such as management and operation). The cases we modelled showed a sharp increase of the internal rate of return (IRR) of clustered projects, which can gain 5%, from 10% to 15% (for a cluster of 4 mini-grids, with a variable charge of about US$ 0.20/kWh, see §2.3.1 for details on tariffs).



Mobilize the appropriate resources and skills: Highly qualified teams, with both technical and management skills, must be involved in these endeavours to successfully manage clustered mini-grids with increased load factors.. Maintaining them around the projects on the long run usually proves a particular challenge. NGOs such as Practical Action can play a role as they hold valuable knowledge and experience to develop and design mini-grids. They can be involved in capacity building activities at project launch to ensure a sustainable local development; on the longer run, in-house training of employees is certainly one of the key activities of the entity operating the grid. The profitability of the first projects should allow sustaining the national eco-system to enable a long term growth of the national mini-grid sector.

Initiate a structured program to foster the development of mini-grids: In Zambia, the currently complex regulatory framework prevents the involvement of private actors, and we recommend launching a structured program to overcome current barrier.

First, the clustering strategy we favour will work better within a concession framework, consequently requiring a global assessment of potential sites across the country to identify the concessions. This assessment is still incomplete today and lacks consistency. Information is scattered among stakeholders like REA (the Rural Electrification Agency), ZESCO, OPPPI (the Office for Promoting Private Power Investment), etc. A better collaboration between all stakeholders is of utmost necessity.

Second, current tariff approval process is a relatively complex procedure at the ERB (Energy regulation board) and prevents private actor to freely set their tariffs. Contrarily to current practise, mini-grid tariffs should not be set to main grid tariffs. Indeed, the main grid has been built to serve the most dense, and hence economical to serve, areas; as a result, any new rural electrification project will likely be more expensive than the current average costs of the grid (embodied into the main grid tariffs).

For the interest of the community (currently electrified and would-be electrified), the most economical projects should be preferred. In particular, mini-grids should be preferred when they are more economical than grid extension. The way the costs are spread over the customers is a political question, with two possible orientations: whether the newly electrified customers pay a differentiated cost-reflective tariff, or all customers pay a non-differentiated (and a little higher) tariff. Tariff increases, for some or for all, is the only option since the cost per customer of the electricity system will increase.

Furthermore, pay-as-you-go solar kits have demonstrated that the willingness to pay of customers can be relatively high (up to 13$/month). Preventing the launch of projects with a total cost lower than the customer willingness to pay is not efficient, and imposing a reference to main grid tariffs to new projects will simply prevent such projects to emerge. We think the best option is a differentiated tariff between the main grid and mini-grids as it seems politically easier to implement. Tariffs should then be set only according to the value created out of the energy service and/or the flexibility of the customers.

Finally, the mini-grid sector is today a risky bet for a private actor. The development of the first schemes thus also requires some financial support from government institutions and/or international funders, via subsidies (e.g. from the Rural Electrification Fund managed by REA) and / or concessional loans (e.g. from the Renewable Energy Fund of the Development Bank of Zambia). To make the best use of those fund and leverage them to improve the sustainability of mini-grid projects and actors, we proposed an innovative funding mechanism, associating NGOs and private actors. This mechanism is based on grants and on concessional loans for the first project. The interests paid from this first project are capitalized in a support fund and reinvested as grants into the next ones, forming a cluster. NGOs would act as promoting entities of the program to develop customer side applications, to manage the support fund which collects the reimbursement of the concessional loans, and possibly through capacity building. Private actors would build and operate the mini-grids, setting a sustainable base for the long term development of the sector in Zambia.

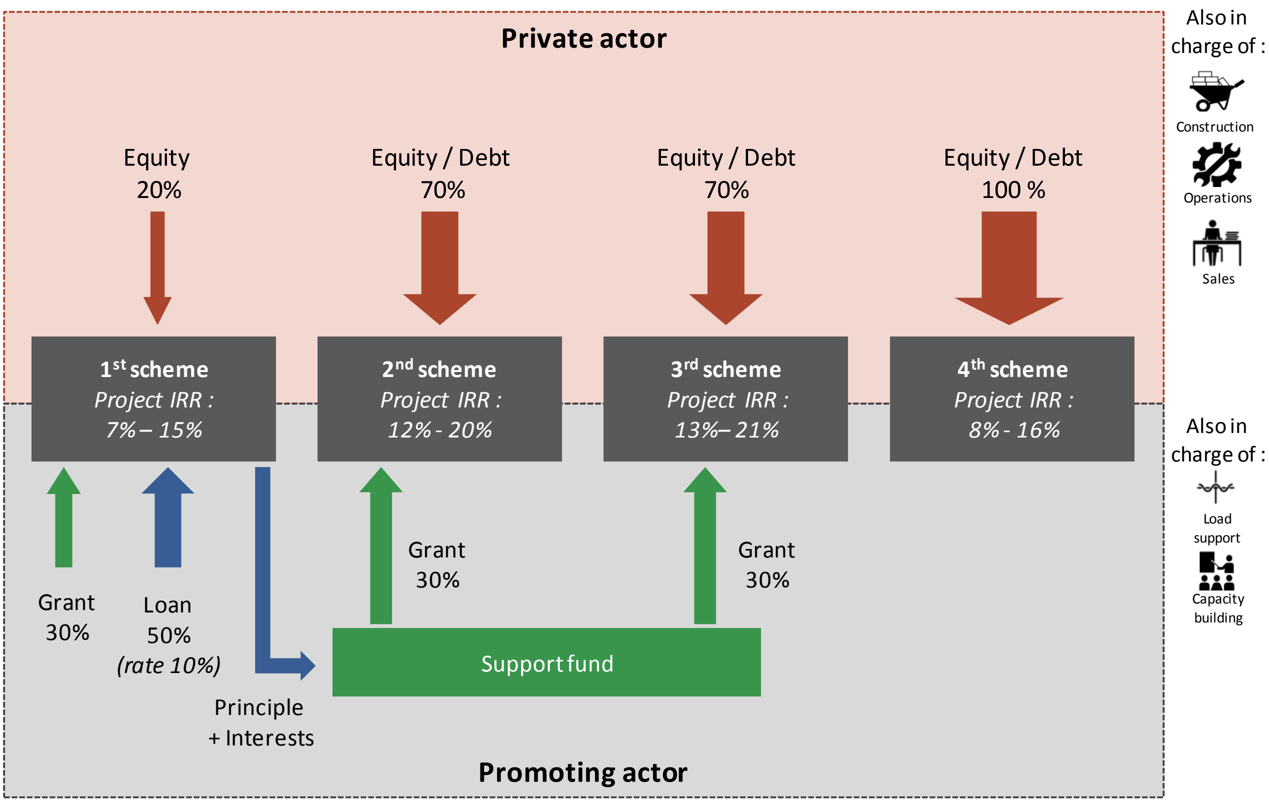


Figure 1 - Scheme of a support mechanism with a private actor and a promoting actor with a support fund

We believe that such a strategy can provide a long-term vision, needed by private investors to decrease their risk, and thus attract new private stakeholders in the mini-grids sector.

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Introduction

In rural Zambia, less than 5% of households are connected to the electricity grid. Increasing this ratio is critical for the economic development of these populations. Establishing decentralized energy supplies is a solution the Government of the Republic of Zambia is trying to implement as an alternative to the high cost of installing transmission networks to remote and sparsely populated areas.

Practical Action has been implementing mini-grids in Southern Africa for more than 20 years and has extensive experience in setting up and running small-scale projects. Practical Action projects' business models have primarily been based on grant-funded schemes, rarely involving the private sector. The fast changing patterns of financing and funding in international development require new business models to reach scalability and financial sustainability. Thus Practical Action, assisted by its partner SNV Netherlands, would like to develop a more ambitious proposal that could be replicated in Zambia and potentially in other SADC (Southern Africa Development Community) countries.

In this context, Practical Action asked ENEA Consulting *pro bono* assistance to propose a sustainable framework to develop micro-hydro mini-grids in Zambia. The objective of the joint project between Practical Action and ENEA is thus to identify such a pathway based on an analysis of the Zambian energy context and on past experiences from existing schemes in the region. To have an extensive and durable impact, the pathway should be sustained by both replicable and financially sustainable business models.

The project was carried out in several phases. After an initial literature analysis, the project team organized country visits in Zimbabwe, where Practical Action's Southern Africa head office is located, and in Zambia. Meetings with several key stakeholders (see Appendices for the complete list) of the energy sector in both countries helped to understand the local context and to collect feedback from existing projects. A field visit with the whole project team was also organized at the Zengamina micro-hydro scheme in North Western Zambia. Finally, the project team focused on drafting proposals for an innovative approach to developing mini-grids. To strengthen the analysis with quantitative data, simulations were carried out to evaluate the economics of micro-grids.

This document outlines the main findings of this work including key learnings of the projects, an economic simulation of mini-grids and guidelines to set up an ambitious program in Zambia. It is based on a deep analysis of micro-hydro powered isolated mini-grids but is relevant for all mini-grids based on renewable energy sources.

1 Key learnings from existing mini-grids in Southern Africa

Off-grid electricity systems are not new. They have been used for decades to supply remote areas and isolated sites (villages, islands, industrial sites, telecommunication towers, military facilities, etc.). Mini-grids are defined in the *Mini-grid policy toolkit* [2] as electrical systems which "involve small-scale electricity generation (10 kW to 10 MW) which serves a limited number of consumers via a distribution grid that can operate in isolation from national electricity transmission network". While most mini-grids are run on fossil fuels, renewable energies (solar, hydro, etc.) offer great opportunities to provide clean and cheaper energy access in developing countries. According to the International Energy Agency [1], mini-grid and off-grid systems could provide electricity to 70% of those gaining access to electricity in African rural areas by 2040.

Up to now, mini-grids have struggled to grow beyond pilot projects. Many actors including Practical Action [3] have identified multiple barriers that hamper their development in developing countries. The major hurdles are related to socio-economic, policy, regulatory and financing issues [2]. Today, raising awareness about the main hurdles and learning from successful experiences is imperative in order for mini-grids to make a meaningful contribution to electricity access. ENEA and Practical Action are convinced that building sustainable and scalable business models is the key to enhancing the large adoption of mini-grids. Both organizations have decided to provide a common view on what works and what does not, based on the evidences gathered from the field.

1.1 Presentation of mini-grid case studies

Practical Action has been implementing mini-grids in Southern Africa for more than 20 years. The organization has been recently involved in several regional programs:

- ***Regional Micro Hydro Project*:** 11 hydropower mini-grids have been implemented in Zimbabwe, Mozambique and Malawi. The schemes were primarily designed to power domestic customers and social services; parts of them are community-based (in Zimbabwe and Malawi) while others are privately owned (in Mozambique). The project was funded by the European Union.
- ***Rural Sustainable Energy Development – RuSED*:** Practical Action partnered with Oxfam to develop two community-based solar and micro-hydro schemes targeting productive uses of energy. The project was funded by the European Union.
- ***Sustainable Energy 4 Rural Communities - SE4RC*:** Practical Action partnered with SNV and Hivos to establish four community-based mini-grids in Zimbabwe and Malawi targeting social services, irrigation and other productive uses of energy. The project was funded by the European Union and the GEF[1].
- ***Mulanje Energy Generation Authority - MEGA*:** Practical Action set up a social enterprise in Malawi, which owns and operates mini-grids. The first scheme was implemented within the previous *Regional Micro Hydro Project* and the second one was funded by the OFID[2]. Several other schemes are planned (the target is to reach nine). MEGA is now supported by funding from the GEF and the Government of Scotland.

In this document, lessons were derived from the following selection of mini-grid schemes, considered to be representative of Practical Action's experience:

- ***Chipendeke*** (25 kW), a community-based micro-hydro scheme in the Mutare district, Zimababwe, implemented by Practical Action within the Regional Micro Hydro Project.
- ***Himalaya*** (80 kW), a community-based micro-hydro scheme in the Mutare district, Zimbabwe, implemented by Practical Action and Oxfam within the RuSED project.
- ***Lower Bondo*** (80 kW) and ***Upper Bondo*** (56 kW), a cluster of micro-hydro schemes implemented by Practical Action and operated by MEGA (social enterprise) in Mulanje, Malawi.

Finally, mini-grid schemes were reviewed in Zambia, where Practical Action and SNV are currently focusing their effort. Lessons were derived from the **Zengamina** mini-grid, a 750 kW privately owned and operated micro-hydro schemes in the Ikelenge district (North-West province of Zambia), which is a first-of-its-kind in the country.

[1] GEF: Global Environment Fund
[2] OFID: OPEC Fund for International Development

1.1.1 Chipendeke scheme, Zimbabwe

Power plant: 25 kW micro-hydro
Consumers: clinic, school, small shops, grind mill, > 250 households
Funding: ~ US$ 200 k, 100% grant-funded by the EU
Ownership and operation: Local community cooperative
Tariffs: US$ 0.10 to 0.32 /kWh (+connection fees: US$ 70 to 100) *Fixed charges are under implementation: US$ 3 to 15 per month*

Chipendeke is one of the first mini-grids implemented within the Regional Micro Hydro Project. It is located in the Mutare district in Zimbabwe. Practical Action got involved in 2008 after the first feasibility study was made by the Ministry of Energy in 2005. The NGO's staff supervised the development of the project and contracted a local manufacturer to build the turbine. Civil works were undertaken by community member and were completed in 2008; the official commissioning was done in 2012. The development of the scheme cost around US$ 195,000 and was 100% grant-funded by Practical Action through the EU Energy Facility. After completion, the scheme was handed over to the community, a 250 shareholder cooperative, which is now operating it.

The mini-grid is powered by a 25 kW run-of-river hydropower plant; a ballast-tank is used to consume excess power when the demand falls. Due to defective locally sourced equipments, the performances of the power plant are far below international standards: the efficiency of the turbine and generator is estimated at 50% in average. A 11 kV line of 2.5 km connects the hydro plant to the lower voltage distribution lines (but the line length causes efficiency issues in distribution). No license was required to operate the scheme since the plant capacity is less than 100 kW. For the same reason, tariffs have been set up without validation by the regulator (who was only consulted).

While the initial target was to power social services (a school and a clinic), the distribution grid was developed to connect residential consumers and businesses (shops, grind mill, etc.) as well. The cooperative was involved during the initial studies (needs assessment, ability to pay, etc.) and the shareholders were the first connected. The number of connected consumers has been growing from the start of the operations. Today the scheme is the victim of its own success with peak demand exceeding supply; hence load shedding is usual.

If the governance of the scheme seems to be a relative success, the financial sustainability is not convincing. Electricity sales are barely covering the regular O&M costs, which are around $ 1,500 per year (half of that are the taxes for using the river water). Yet, the tariffs are above the national level: $ 0.10/kWh for social services, $ 0.16/kWh for residential consumers (plus $70 for connection) and $ 0.32/kWh for businesses (plus $ 100 for connection). A pre-paid system was implemented by the Ministry of Energy. However, revenues are not sufficient to cover exceptional expenses (replacement of equipments, upgrade of the plant, extension of the grid, etc.). One of the reasons is that a lot of connected households are consuming only a few kWh per year. Thus, the cooperative is currently trying to implement fixed charges ($ 3 per month for residential consumers and $ 15 for businesses) to increase the revenues.

1.1.2 Himalaya scheme, Zimbabwe

Power plant: 80 kW micro-hydro
Consumers: Irrigation, saw mill, grind mill, energy kiosk, school, clinic
Funding: 100% grant-funded by the EU
Ownership and operation: Local community association
Tariffs: US$ 0.10 to 0.28 /kWh

Himalaya is one of the two mini-grids implemented by Practical Action and Oxfam within the RuSED project, in the same area as Chipendeke in the Mutare district, Zimbabwe. Based on the lessons learned from the Regional Hydro Project, the scheme was designed to power mainly productive use of electricity (ABC – anchor, business, and consumer model). The first studies started in 2011 on seven sites before selecting Himalaya; the scheme was finally commissioned in 2015. As in Chipendeke, Practical Action's staff supervised the development of the project. The scheme was finally handed over to the local community, The Himalaya Micro Hydro Association, consisting of 196 shareholders. The project was 100% grant-funded by the European Union and a substantial part of the funding went to demand-side equipments (irrigation, grind mills, etc.). The association has been operating the scheme since the commissioning. In addition, several committees were created: Marketing committee, Maintenance committee, etc.

The scheme is based on a 80 kW run-of-river hydropower plant. The first turbine ordered to a local manufacturer was defective, which required ordering a new one. The mini-grid was designed to feed commercial activities and social services with a demand driven approach. No households were connected to the grid at the start of operations: a new transformer and an extension of the distribution grid would be required to connect residential consumers but the initial funding is not sufficient to cover this cost (~ US$ 30,000). The development of the customer base is one of the challenges to increase the load factor and the revenue stream.

With the collaboration of the Rural Electrification Agency (REA) tariffs have been set up based on local energy expenses (kerosene / paraffin consumption, etc.), without validation by the regulator (since plant capacity is less than 100 kW): US$ 0.28/kWh for businesses, US$ 0.12/kWh for residential consumers and US$ 0.10/kWh for social services. Revenues from electricity sales are supposed to cover the OPEX only. The irrigation scheme (15 kW) is the main anchor business and is operated by the Irrigation Committee, representing a group of around 100 farmers. The committee pays around US$ 5,000 per month for electricity, equivalent to US$ 50 per farmer (a quarter to a half of their monthly revenues). Other business consumers are saw mills (10 kW), grind mills (10 kW) and an energy kiosk (2 kW). A school and a clinic are also connected to the scheme.

1.1.3 Lower Bondo & Upper Bondo schemes (MEGA), Malawi

Power plant: 88 kW (L.B) and 56 kW (U.B) micro-hydro
Consumers: Businesses, schools, clinic, 400 households (L.B.)
Funding: ~ US$ 400 k (L.B.) and ~ US$ 300 (U.B.), 100% grant-funded MEGA's donors include: EU, OFID, GEF and Government of Scotland.
Ownership and operation: Social enterprise (MEGA)
Tariffs: US$ 0.09 to 0.17 /kWh (+connection fees: US$ 9 to 12)

Lower Bondo (funded through the Regional Micro Hydro Project) and Upper Bondo (funded by OFID) are both located in the Mulanje district, southern Malawi. The schemes were initially planned to be managed by communities, which was the case of Lower Bondo during the first years of operation. In 2015, the two mini-grids were severely damaged by intense flooding; they are out of operation until repair works can be undertaken. Beyond this natural disaster, Practical Action realized that the local community didn't have the appropriate skills (whether technical or financial) to run the schemes in a sustainable way. The NGO then decided to change its traditional approach by creating a social enterprise, the Mulanje Energy Generation Authority (MEGA), which owns and operates the mini-grids.

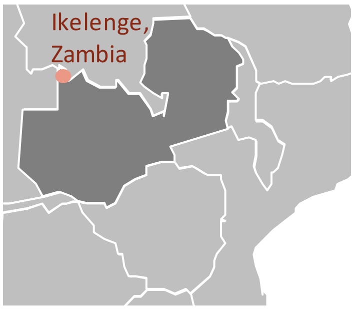
Lower Bondo is powered by a 88 KW run-of-river hydropower plant. During the first year of operation, the reliability of the scheme was rather low because of the bad quality of the locally sourced turbine. The 12 km of distribution lines connect a range of consumers: a health clinic, two schools, several enterprises and nearly 200 households (200 more connections are expected). Upper Bondo also relies on a micro-hydro plant (56 kW). It was not in operation at the moment of the flooding, since the electro-mechanical equipment had not been installed yet. The turbine has been ordered to a supplier in Nepal, but the delivery is taking more time than expected.

MEGA is currently run with a small team: a general manager, a maintenance officer and 2 technicians. Until now, the enterprise has been financed through donor money only. The targeted business model is a cluster of nine mini-grids (~500 kW) owned and operated by a unique entity. The tariffs will be set to reach financial self-sustainability after 6 years: US$ 0.17/kWh for businesses (plus US$ 12 for connection), US$ 0.09/kWh for households (plus US$ 9 for connection). A percentage of the turnover will be paid annually into a Community Trust for local energy projects. According to Practical Action in cooperation with BIF[3], at least six grant funded schemes should be implemented before the model starts to be profitable.

[3] DFID Business Innovation Facility (BIF) provided support to undertake business planning for MEGA

Today, MEGA is partly owned by Practical Action but the NGO plans to hand over shares to the local communities. After the flooding disaster, the company is now intending to complete the repair work and to start operations on the right tracks. Investors have already committed to funding two new schemes (the Government of Scotland and the GEF). MEGA has recently obtained a generation license from the regulator and is now the first licensed independent off-grid power producer in Malawi. The distribution license should be obtained soon without major issues.

1.1.4 Zengamina scheme, Zambia



Power plant: 750 kW micro-hydro
Consumers: Large farm, telecom towers, stone crushing, pineapple drying, small businesses, hospital, schools, >500 households
Funding: ~ US$ 3m, 100% grant-funded by various donors (Vardy charity, etc.)
Ownership: Charity (Northern Western Zambia Development Trust) ***Operation:*** Registered Company (Zengamina Power Limited)
Tariffs: US$ 9/mth + US$ 0.06 to 0.13 /kWh (+ connection fees: US$ 90 to 130)

Zengamina is a mini-grid located in the Ikelenge district, in the North-West province of Zambia. The project was initiated in the early 2000's by a charity, the Northern Western Zambia Development Trust (NWZDT), originally to provide power to the Kalene Hill Mission and its hospital. Zengamina Power Limited (ZPL) was created to operate the scheme as a registered company; NWZDT owns the mini-grid assets and 90% of ZPL. The feasibility studies were run in 2002 - 2003. The construction started in 2004 and lasted 3 years, in parallel with administrative paperwork. The first step was to get the land use authorization: a 99-year lease for the hydro plant was obtained from the government, but the use of land for the distribution lines depends on an agreement with local communities. An Environmental Project Brief was then required, as well as an agreement from the Water Resources Management Authority (WRMA). Finally, the Energy Regulation Board (ERB) granted the license for the generation, the distribution and the supply of electricity. The ERB was also in charge of setting the electricity tariffs, which was a two-year process including a stakeholders' consultation. Operations finally started in 2007.

The scheme is powered by a 750 kW run-of-river hydropower plant. The grid mainly consists of 11 kV distribution lines, but a 15 km length 33 kV line had to be built to feed a large commercial farm. During the construction phase, the local population was massively involved in the civil work. The project development was managed by members of the charity, with the *pro bono* assistance of international experts. The scheme cost around US$ 3 million (1/3 for the distribution network), entirely funded with international donor money gathered by the NWZDT, but hidden costs are probably substantial (up to 50%). The direct financial support from national institutions was marginal: a US$ 25,000 subsidy was obtained from the Rural Electrification Agency (REA). However, the company benefited from import duty exemptions on equipments (and would have been exempted from profit taxes during the first 5 years of operation, if they had been profitable).

The customer base of ZPL consists of anchor businesses previously relying on diesel generators (a farmer and two telecom towers), small businesses (welders, hammer mills, bakeries, cold rooms, etc.) and around 500 households (~3 new connections each week). To increase the revenue stream, the Director of ZPL (Daniel Rea) decided to create his own businesses: a pineapple drying factory and a stone crushing business. The tariffs set in 2007 have recently risen by ~30%, with the agreement of the ERB. For residential customers, two different tariffs are available: a fixed tariff of US$ 7/month (up to 1.5 amps) and a stepped tariff of US$ 9/month (first 150 kWh) plus US$ 0.06/kWh to US$ 0.13/kWh. For businesses, a time-of-use tariff has been set: a fixed charge of US$ 9/month plus US$ 0.08/kWh (standard rate) or US$ 0.06/kWh (off-peak rate). Community services pay US$ 9/month plus US$ 0.06/kWh. Connections cost around US$ 90 for a single phase and US$ 130 for three phases.

The break-even was reached after 7 years of operations (on OPEX only). Regular O&M cost around US$ 10,000 per month; half of it is for ZPL's staff salaries: one manager, six technicians, four watchmen and three representatives. Money collection is made by the representatives since no pre-paid system has been installed. The development of the customer base is essential to increase the revenue stream: the load factor is currently below 30%, with a maximum peak load around 400 kW (mostly due to domestic appliances use at 7 pm). Nonetheless, the level of water is low during the dry season, which decreases the plant capacity and involves load shedding. To fix the problem, the company is studying the possibility to build a new power plant upstream of the river.

1.2 Key learnings

Various lessons can be learned from the four mini-grids studied. While the schemes have their own specifics, the same barriers hamper their sustainability and scalability. Similarly, successful practices are generally common and should be replicated.

1 - Mini-grids fall in a grey area when it comes to regulatory frameworks; administrative procedures are generally complex, with multiple points of contact

Developing mini-grids is broadly unusual for the stakeholders in the energy sector. On the one hand, state utilities have been used to developing centralized generation and to extending the grid by adding poles and wires. The liberalization of the electricity sectors and the development of decentralized generation are altering their historical model in-depth. Opportunities have emerged for the private sector along with evolutions in the policy and regulatory frameworks, but only for assets connected to the main grid: concessions, feed-in tariffs, Power Purchase Agreement (PPA), etc. On the other hand, individual off-grid solutions have found a market outside regulatory frameworks. Mini-grids have historically been limited to very specific schemes, whether owned and operated by the state utility or by industrial consumers (e.g. mining industry). While the civil society and the private sector are now interested in mini-grids, the inappropriate policy and regulatory framework is still a major hurdle in many African countries.

Mini-grids owners/operators fall in a grey area when it comes to the regulatory framework, in between grid operators, independent power producers and electricity suppliers. Administrative procedures are generally unclear and sometimes nonexistent. A single point of contact could facilitate these procedures, which isn't the case in Zimbabwe, Malawi nor Zambia. Rural electrification agencies are usually providing technical and financial assistance. The regulation agencies are in charge of issuing all legal documents regarding the production, the distribution and the supply of electricity. Various other institutions need to be consulted: environmental authorities, water management authorities, business registration agency, etc. Even if procedures are often simplified for small-scale schemes, they can be time-consuming for developers, in particular when they require frequent travels between central administrative offices and remote areas where the mini-grids are located. A long development time may have significant cost implications, especially when the project has been financed through debt (without grace periods). Conventional procedures encountered are the following (non-exhaustive list):

- Land use authorizations and concessions: land use right is unclear depending on the country. For example, in Zambia, Zengamina obtained a lease for the power plant but has no title for the distribution network (informal agreements are made with local communities to use the land to install poles and wires).
- Water use authorizations and concessions: they are delivered by water management authorities to implement hydropower plants, and can be associated with fees. In Chipendeke, half of O&M costs are water use taxes.
- Environmental impact studies: they are mandatory most of the time, but can be simplified for small scale projects (e.g. Environmental Project Brief in Zambia)
- Licensing: Distinct licenses can be required for the generation, the distribution and the supply (e.g. in Malawi); some regulation agencies also provide a unique license (e.g. In Zambia). Depending on the country, licensing procedures can be avoided for small scale projects (e.g. below 100 kW in Zimbabwe).
- Company registration: most of the time, only registered companies can obtain licenses (e.g. In Zambia)
- Tariff setting: the regulation agencies are in charge of tariff approval (sometimes after a public consultation, as for Zengamina). This approval can be avoided for small scale projects (e.g. below 100 kW in Zimbabwe), but the consultation of local communities is generally required.

2 – Grant-funding can be a key-enabler to finance the first mini-grids, as developers are bound by socially acceptable tariffs

Mini-grids are structurally equivalent to "macro-grids" but individually expensive without economies of scale. It is necessary to look at a bigger picture to assess the financial attractiveness: mini-grids can make economic sense compared to grid extension in lot of isolated areas. Most of the time, individual developers are not able to capture this systemic value. They are also unable to capture more value through electricity sales since regulation and social acceptance are limiting factors to set the tariffs at the appropriate levels. In these conditions, access to finance, mainly grants at this stage, is a major stake for mini-grids developers.

The four mini-grids studied have all been 100% grant-funded, which is representative of the non-sustainability of current business models. The break-even point of the schemes on OPEX is generally reached after several years of operation. In most of African countries, it is very likely that all mini-grids developed in the coming years will require a substantial amount of subsidies. That being said, current project developers (mostly NGOs) try to improve their models to increase their impacts with their limited funding:

- The schemes can be optimized to be as efficient as possible, whether on the technical, on the financial or on the management sides (appropriate tariffs structure, load factor optimization, skilled staff, etc.). These topics are discussed hereafter in this section.
- Mobilization of public / donor money can be focused on specific aspects, such as grid distribution assets or customer-side equipments. Indeed, private companies will be more willing to finance the generation side which is a one-shot investment. State utilities or rural electrification agencies are theoretically able to pay for poles and wires, but they are still reluctant to finance private mini-grid assets. In Zambia, the Rural Electrification Agency (REA) has theoretically put in place a "smart subsidy" scheme to support the private sector, but Zengamina has only been granted US$ 25,000. Demand-side investments (productive equipments, energy efficient appliances, etc.) can also be included in the project scope (as in Himalaya) and supported by governments or NGOs.
- Finally, access to concessional loans from development banks is critical to attract private investors, since local banks do not offer acceptable conditions (interest rates above 20%).

3 – Due to the current legal framework and the lack of feedback on an appropriate and socially accepted tariff structure, the revenue stream of the mini-grids are usually quite low and insufficient to cover curative maintenance costs.

Electricity tariffs are a major issue for electrical systems. In many countries, tariffs are not cost-reflective because rate increases are not easily accepted by populations. State utilities are generally loss making and subsidized with public money. Tax increase (which are more or less clear for electricity consumers) is often a way to raise effective tariffs without changing the nominal rate. For mini-grid developers, setting the tariffs depends on the same kind of social acceptance issues. However, without any support from the governments, mini-grid electricity tariffs should be intrinsically much higher than the main rates. In most cases, tariffs levels prevent reaching financial self-sustainability.[4]

Approval of the tariffs by national authorities is generally not required for small-scale schemes. In Zimbabwe, the local communities of Chipendeke and Himalaya have been consulted to assess the right tariff level, based on past energy expenses (kerosene, candles, etc.). For these community-based schemes, representatives of the population are in charge of setting the rates. They are often in the best position to assess the ability and willingness to pay of customers. With regard to larger schemes, an approval has to be obtained from electricity regulation agencies which are defending customers' interest. Negotiations between the regulator and the project developer can be complex and long: for Zengamina, tariff approval took more than two years instead of the 90 days written in the law.

There is no unique legal framework to establish tariff structures, which must be adapted to each situation. Here are some examples of observed parameters:

- A lot of schemes keep tariffs low for residential customers or public services (clinics, schools) and charge much higher rates to businesses (Chipendeke, Himalaya or MEGA).
- Zengamina proposes a non-metered tariff, suitable to power basic appliances and thus attractive for new customers, and a metered tariff with a fixed charge and stepped prices. An off-peak rate has been also set for businesses, which is useful to optimize the load curve (cf. hereafter).

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[4] In Zimbabwe, residential main rate is US$ 0.11/kWh (up to US$ 0.15/kWh). Mini-grid residential tariffs are US$ 0.10/kWh in Himalaya and US$ 0.16/kWh in Chipendeke. Higher rates apply to businesses (US$ 0.28/kWh and US$ 0.32/kWh respectively).

In Malawi, residential average main rate is US$ 0.08/kWh. MEGA has set the tariff slightly higher at US$ 0.09/kWh (but US$ 0.17/kWh for businesses).

In Zambia, the residential main rate is very low at US$ 0.065/kWh (and ~ US$ 0.04/kWh for the mining industry). Zengamina has set stepped tariffs from US$ 0.06/kWh to US$ 0.13/kWh (but with a fix charge).

- Fixed charges could be a good solution to strengthen the revenue stream and to limit the financial impact of customers with no or very low consumption, as is the case in Chipendeke.
- Most of the time, connection rates apply to all customers but the range is broad: from around US$ 10 to US$ 100.

4 - Load factor optimization is a key success factor to reach financial sustainability: this requires matching supply with demand from the initial design to day-to-day operations

Although hydropower offers a flexible way to supply electricity, it is also geographically bound. The design of hydropower based mini-grids often depends more on the energy resource available than on the local needs. However, a demand-driven approach is compulsory to properly design the schemes and avoid major sizing issues. The evaluation of energy needs is usually done during feasibility studies (Practical Action and SNV are paying very much attention to end-user needs), but its influence on financial sustainability is broadly underestimated. Most of mini-grid schemes studied are reaching very low load factors (20% to 50%), even after several years of operation.

Identifying anchor consumers from year one is a solution to overcoming this issue. These anchor consumers should preferably be productive businesses with a constant load (e.g. telecom tower in Zengamina) or a flexible load (e.g. irrigation scheme in Himalaya). If the load of existing businesses is not sufficient, demand-side components should be included in the project scope. In Himalaya, the initial project budget included the funding of productive uses. Even if the customer base grows at a smaller rate than expected, anchor customers are a way to secure the revenue stream. In Zengamina, the grid operator had to create his own businesses (pineapple drying and stone crushing) to consume the excess of electricity.

Beyond the load factor, mini-grids are also facing peak load issues. The evening peak (between 7pm and 9pm) is generally due to the use of domestic appliances. When the residential customer base reaches the critical size (e.g. in Chipendeke), load shedding becomes usual. The decrease of hydro plant capacity during dry seasons also increases the risk of load shedding. Moreover, all power plants surveyed in this study are run-of-river hydro schemes with no storage capacity. Solutions exist to optimize the demand but they are rarely implemented in the mini-grids studied. Here are some examples:

- No alternatives to electrical cooking (improved cook stoves, gas cookers, etc.) are provided to households so as to decrease the evening peak described above.
- There is usually no time-of-use tariffs (in Zengamina, an off-peak tariff has been set for businesses only).
- No system to manage the demand has been developed (load shifting, peak shaving, etc.)

5 – Construction, management, operation and maintenance of the schemes require both the appropriate skills and the knowledge of local contexts; private structures can effectively collaborate with NGOs and local communities

There is no unique business model for mini-grids. Development, ownership and operation can be split between different stakeholders or not: the state utility, NGOs, private companies, local community cooperatives, etc. Chipendeke and Himalaya are two community based schemes, developed by an NGO (Practical Action) and handed over to the local communities. Lower Bondo and Upper Bondo were initially supposed to be community-based but they are finally part of the private structure MEGA, created by Practical Action. Zengamina is owned by a charity (NWZDT) but is operated by a registered company (ZPL).

The involvement of local communities is essential, from the first studies to the day-to-day operations. During the feasibility studies, they can partner with the project developer to identify the customer base and to the assess energy needs. Their local knowledge can also facilitate day-to-day operations (e.g. money collection if there is no pre-paid system). More generally, community representatives can deal with social conflicts along traditional, political and religious affiliations. Communities are often grouped together into cooperative or association which can take in charge the management or operation of the mini-grids. While community-based models can make sense for very small-scale schemes (below 50 kW), they are not well-suited to larger ones in the majority of cases. Without the appropriate skills and resources on management, financial or technical aspects, mini-grids fail to be sustainable and scalable.

Professional technical skills are mandatory to guarantee the robustness and the reliability of mini-grids. Only private companies or specialized NGOs have the technical skills to build, operate and maintain the schemes in an effective way, with the appropriate procedures: documentation, quality control, data compilation, spare part replacement, etc. Regarding micro-hydro schemes, international standard electromechanical equipments should be chosen: among the four mini-grids studied, three have very low efficiency (below 50%) or are experiencing frequent failures due to locally sourced turbines. Still, the local workforce should be mobilized effectively. In Zengamina, a good quality civil work has been done with the support of the local population, at a lower cost than with traditional contractors.

With regards to management and financial skills, local communities usually do not have the necessary capacities. One of the main issues is the lack of anticipation (e.g. there is generally no budget in case part break). To reach sustainability, an experienced manager supported by a skilled staff is required (part of the staff can be recruited locally and trained). Such a manager can also provide the vision and the ambition to scale, in order to improve the business sustainability. The clustering approach followed by MEGA in Malawi is a way to decrease operating costs and to reach profitability.

2 How to design sustainable and scalable business models?

Taking into account the difficulties identified on the mini-grid business, the objective of this study is to draft practical proposals that could help overcoming them. This part will thus build a model of a future hydro mini-grid sector in Zambia which could rely on private companies and investors to help electrify the country.

2.1 A business model for an independent mini-grid company

A business model highlights the factors enabling a company or a project to be successful. The success factors are usually twofold. The first category explains how the company interacts efficiently with the customers and fulfills one of their needs. The second category focuses on the way the company is organized to be the most efficient and sustainable as possible. Both categories of factors are integrated into a financial business plan to analyze the profitability of the model.

The mini-grid business models proposed in this document focus on independent initiatives, thus excluding utility based models. Independent developers and operators can be private companies, NGOs, local communities or a combination of them. In the case studies described in section 1, mini-grids are developed by NGOs or charities and three of them are operated by local communities. In this section, the company refers to the entity developing and operating the scheme. One of the main objectives is to identify the models which are best suited to attract the private sector and to ensure scheme's sustainability and scalability. Still, NGOs and local communities should keep a major role within or beside the company.

The company's business model is based on key activities, which underlie the success of the project in the long run as well as on the company's growth. According to the lessons learned from existing mini-grids, the project's key activities are:

Project sustainability: section 1 highlights the difficulties of running a hydro scheme in the long run. First of all, it requires a good operation and maintenance of the system. The organization operating the system must thus be very well managed to ensure that skilled technicians will continuously be maintaining the scheme, including the consequences this may have in terms of human and financial resources. The long run aspect of the management, especially the HR, favours a private organization but do not exclude a community based system.

Customer support and demand-side management: it is needed to effectively increase the level of economic activities and hence the wealth of the community. It is also necessary to create the demand matching the load of the scheme. It is nonetheless worth mentioning that it is mostly a cost centre and, in line with traditional capacity building programs, it is usually handled by NGO. Then it seems important that the same economic actor does not concentrate the production and the use of energy. As a consequence, the NGO seems to be the appropriate actor for this activity.

Money collection: this is another important activity for the project. The profitability of the hydro scheme is linked with its service payment rate. Several options are available, including prepaid meters, smart meters or local teams of money collectors. The organization should select the best option considering several factors: its relationship with the local community, the capacity to manage potential load shedding or /and the metering of CAPEX.

Future projects development: developing other hydro schemes around the first project requires both capabilities and a strategic intent which are usually lacking in current community based models. Community councils indeed lack legitimacy to develop a project outside their territories but also the motives to do so. Maintaining this kind of human resources is furthermore quite expensive and not necessary for small communities. Today, it is usually borne by NGOs or national energy companies. Defining this activity as essential for the success of the project is a turning point to selecting a private company to operate the hydro scheme.

Community involvement: it is very important for hydro mini-grids and usually adequately integrated in current projects (based on communities). However involving a private company in the process increases the need of community management. A partnership between an NGO and the private company can be fruitful here.

2.2 The cost of electricity

The profitability of the mini-grid company is mandatory to reach sustainability and scalability. Electricity sales are the only revenue stream of the company; hence the cost of electricity is a crucial parameter of its financial model. Evaluating the cost of electricity requires a global assessment of the company costs.

The costs structure of a company operating a hydro mini-grid is composed of three main components: the hydro scheme costs, the distribution network costs, and the customers-related company costs (sales and administrative costs). To analyse the costs of the electricity produced and sold, it is also necessary to work with the relevant energy metrics. Hence, an analysis was undertaken to assess the losses at each step, either grid losses or "losses" due to the low demand at some hours of the day. The different steps of this analysis are shown in Figure 2.

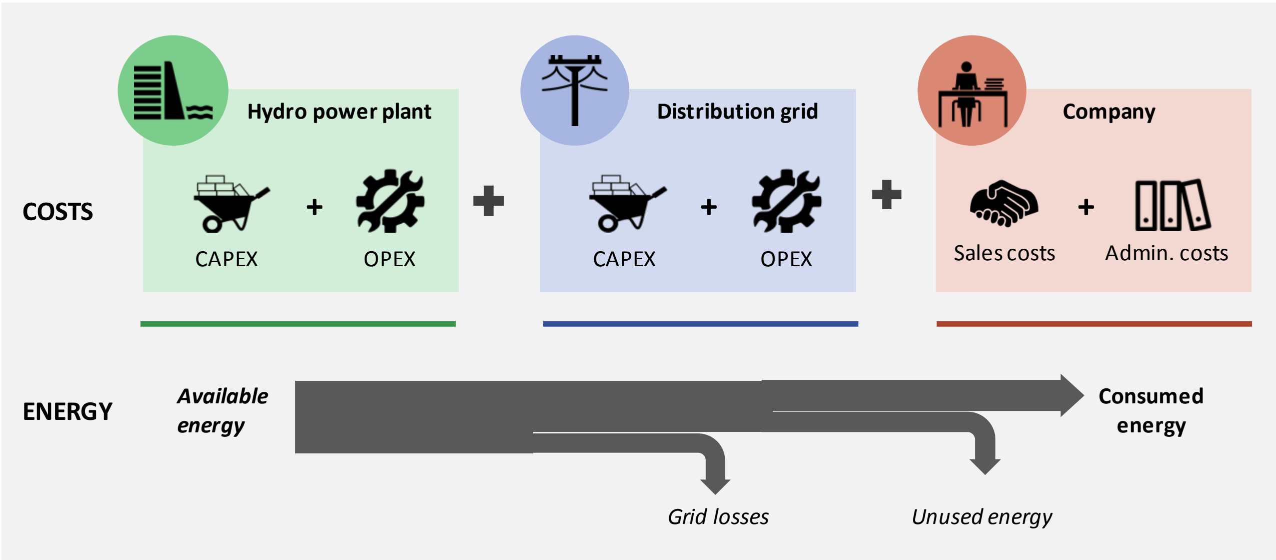


Figure 2 - Main costs factors of a hydro mini-grid company and relevant electricity metrics

These costs are analysed in the following paragraphs, based on past projects data which are used as an example to support the analysis. The context of any specific project may impact the values presented in the following paragraphs without affecting the reasoning. The Levelized Cost Of Energy (LCOE), was used as the reference metric. The LCOE metric takes into account the costs over the project whole lifetime (20 years) : studies on the first year, then building, then consumption increase and lastly a *plateau* during the last years of the project. The cost of capital is taken into account when computing the LCOE approach and an initial hypothesis of 10% discount rate is used throughout the analysis on costs. The detail of the costs, their explanation and the sources used to set some numeric values are available in the Appendices.

The idea is to look at a hydro plant at a very limited scope in the first place and then to go each step towards a more complete scope. At each stage, additional hypothesis will be integrated in the model, either by adding extra costs or by introducing different and more relevant energy metrics. The costs considered in the text are, if not mentioned otherwise, the sum of all the considered costs, which consequently increases at each step of the analysis.

2.2.1 Building a hydropower scheme

In the first step of the analysis, only the costs of the hydro scheme are taken into account; investment costs (CAPEX) as well as operating costs (OPEX). It helps to understand the potential costs of the energy produced if all the energy was sold to the main network. It is the relevant cost if the scheme was connected to the main grid and sold to an off taker. At this stage, the hydro technology proves its advantages and is very cheap. The cost of the energy produced is indeed quite low, between US$ 0.076/kWh (100 kW) and US$ 0.05/kWh (1 MW).

Hypothesis

***CAPEX* :**

100 kW	US$ 3,500/kW
1 MW	US$ 2,500/kW

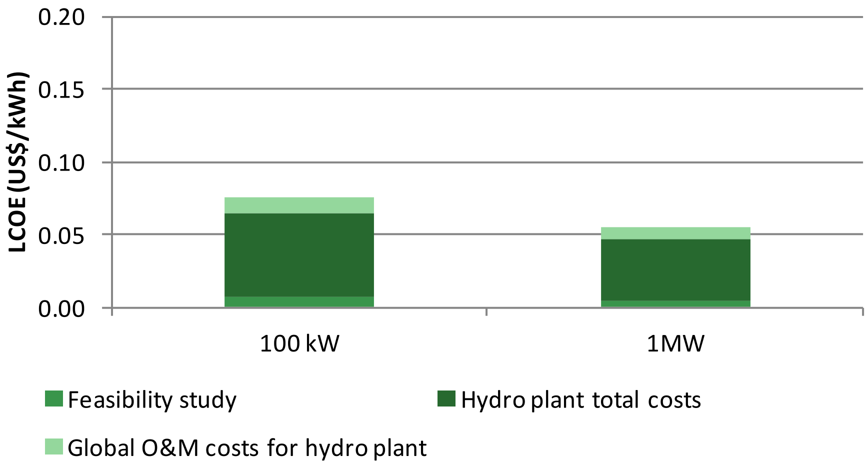
OPEX : *2% of CAPEX/year*

Capacity factor: *80%*

Feasibility study: *10% of CAPEX*

Project life : *20 years*

See Appendices for more details on data sources



2.2.2 Building a grid to reach the community

The grid is the second major cost of a hydro mini-grid project. Contrary to grid-connected projects which would rely on the main grid to off take their power, a mini-grid project must build its own distribution network which adds both CAPEX and OPEX to the system. It generates some losses as well, which decrease the amount of energy available for consumption. The costs of the energy available (energy produced and distributed minus the losses) increases by about 30% compared to the cost of energy with the hydro plant only, around US$ 0.12/kWh (100 kW) and US$ 0.09/kWh (1 MW).

Hypothesis

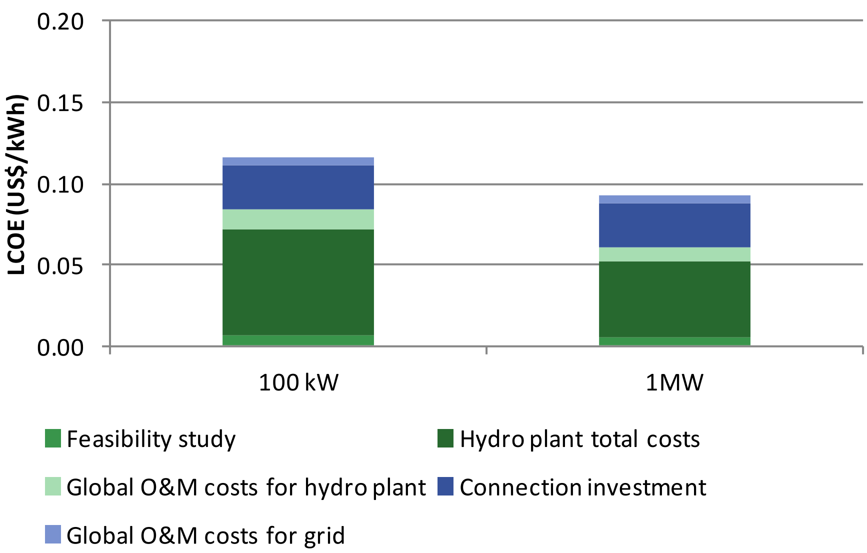
***Grid CAPEX*:**
US$ 200/customer

Connexion CAPEX:
US$ 100/customer

OPEX: 2% of CAPEX/year

Grid losses: *10%*

See Appendices for more details on data sources



2.2.3 Building a company to sell the energy

The third component of the cost structure is the company costs. These costs are mostly made up of the commercial activity of the company: dealing with customers and especially with costumers who are not used to paying regular bills. At last, successfully managing such a company and unlocking its growth requires qualified managers.

Hypothesis

Management wages:
US$ 20,000/year

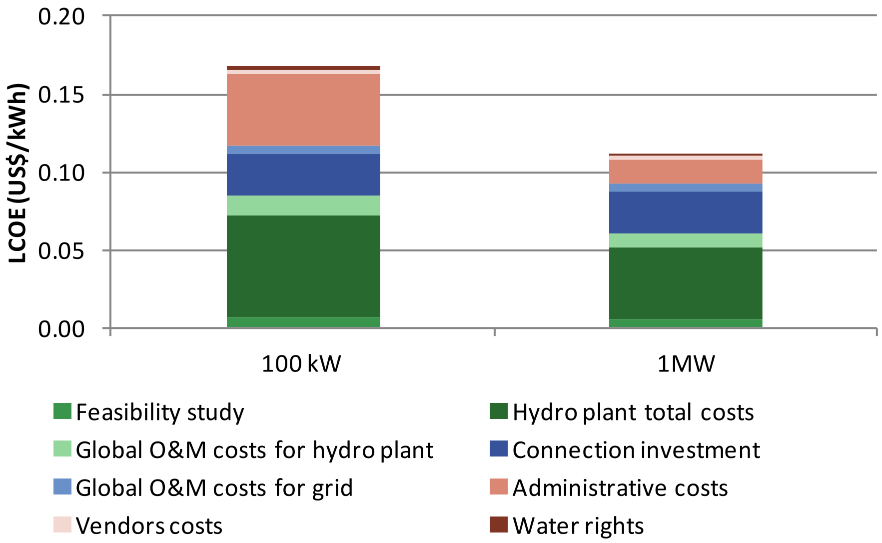
Offices costs:
10% of the turnover

Water right: *US$ 1,000/year*

Vendors:
1 sales agent for 200 customers (US$ 4.5/cus.year)

Company creation costs:
US$ 15,000

See Appendices for more details on data sources



The administrative costs have a significant impact on the total cost of the energy available (energy produced and distributed minus the losses), increasing the cost by a further 60%, slightly above US$ 0.17/kWh for the 100 kW system, where the fixed management cost are the heaviest. The cost of the 1 MW system increases by 10% to reach US$ 0.11/kWh.

2.2.4 Charging only the consumed energy

The main constraint of supplying electricity to a small community with a hydroelectric plant is to adjust the production to the load curve. This load curve is rarely flat over the day (contrary to the hydro potential production) and thus a large part of the production is usually lost, either in ballasts of hot water or by adjusting the water stream. Most of the hydro plants are conceived as run-off the river systems (the cheapest) and cannot store the water as energy potential. The energy is thus usually lost and cannot be sold to customers. To increase the use of the energy produced, the construction of the hydro plant must be associated with a plan of productive use promotion, through local capacity building and incentives to invest in machineries. Productive use can indeed help building a flatter load curve, through flexible demand (demand for water pumping, or battery charging for instance) but also create wealth in the community to afford the consumption of the electricity.

An analysis of the possible energy uses in a remote village was done, based on field visits and on a literature review. The analysis mainly focuses on energy and does not primarily focus on capacity. Working on capacities would require a much more detailed analysis that is hardly possible given the lack of data on the proposed plans. However, the capacities required remain consistent and the sum of the non flexible uses is kept below the available capacity. This analysis is detailed in the Appendices; Table 1 shows an example of the results for a 100 kW system. It is worth highlighting the high share of businesses use, which consumes more than 80% of the production in the model.

Category	Consumption (MWh/year)
Households	20 - 30
Businesses	220
Institutions	20
Total	~ 265[5]

Table 1 – Example of consumption hypothesis for a 100 kW system with a 29% load factor

A hypothesis of progressive consumption is also taken into account. The initial load is supposed to amount to 60% of the final load, with a yearly increase of 5%, leading to a full load and a *plateau* only after 9 years of operation.

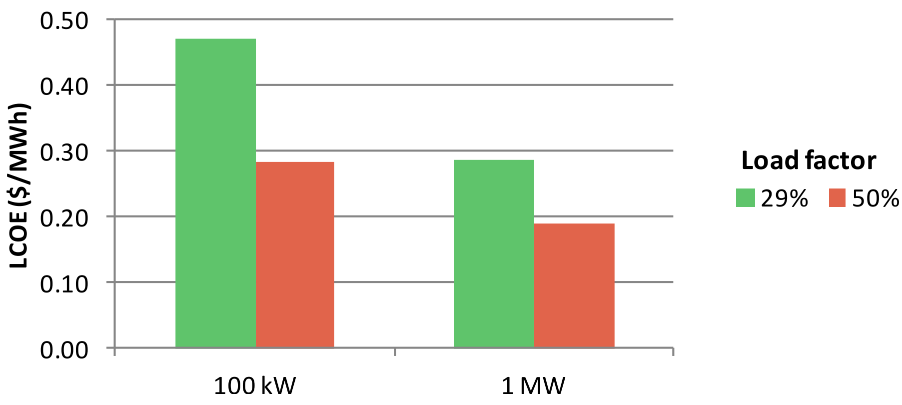
With a 29% load factor[5] (43% effective load factor see Table 1), the energy costs of the 100 kW system soar to around US$ 0.44/kWh. The same load factor is used here for the 1 MW system, resulting in a cost of around US$ 0.3/kWh. The context of a bigger system is however slightly different. Indeed, on the one hand, the bigger the system, the less loads curves should peak, and thus would be more likely to reach higher load factor. On the other hand finding customers to off-take 1 MW of production in remote Zambia seems complex and unlikely. Increasing the load factor to 50% (optimal scenario) helps putting these costs down, to around US$ 0.27/kWh for a 100 kW system.

Hypothesis

Load factor: *29% and 50%*

Progressive Consumption: *Initial consumption of 60% of the final consumption and yearly increase of 5% leading to a consumption plateau after 9 years.*

See Appendices for more details on data sources



[5] 265 MWh equal to 29% of the total theoretically producible energy (876 MWh = 100 kW * 8760 hours/years) or 43% of the available energy (after maintenance, flow fluctuation and grid losses). From a load optimization point of view, the 43% figures is the best metric, since it highlights that 57% of the power could still be used and charged for if the demand was there. However, it is common to find comparison of load factors based on the theoretically producible energy.

2.3 Mini-grid revenues and profitability

2.3.1 Grid tariffs

Based on field visits and literature feedback, the following tariff scheme was modelled for the mini-grid:

- A minimal service offer
  - This offer should supply the minimal electricity service (lights and phone charging) and be charged at the local costs of candles/batteries/petrol
  - A price of 10$/month offer could be acceptable since this is lower than what companies proposing solar kits charge monthly to customers[6].
- A binomial tariff for larger use
  - The binomial tariffs includes both a fixed component and a variable energy-based component
  - The level of prices differs depending on the type of customer (household, institution, businesses), according to the level presented in Table 2
- A connection charge of US$ 40 for any new customer (covering partly the total connection costs of US$ 100)

		Households	Institutions	Businesses
Minimal service		US$ 10/month	Not applicable	
Normal service	Variable energy-based charge index	100%	80%	150%
	Fixed charge	US$ 5/month	US$ 5/month	US$ 5/month
Connection charge		US$ 40	US$ 40	US$ 40

Table 2 - Synthesis of proposed tariffs

The quest for relevant tariffs, a serious challenge for mini-grids

Setting the right tariffs is one of the toughest questions when considering building a mini-grid. It indeed includes multiple parameters and no perfect solution seems to have emerged so far. Such a solution would most likely be the outcome of numerous tests in different mini-grids and integrate national contexts. The mini-grid sector has not yet reached that level. That being said, there are a few parameters to consider in setting a tariffs:

Willingness to pay should not be limited to pre-grid ability to pay

Ability to pay is usually the first one to be identified. The bottom line here is to set a tariff that would be affordable by the rural customers. It usually leads to carry out surveys in the remote communities to assess their current expenses on energy products (disposable batteries, candles, kerosene etc.), and to set the tariffs below these expenses.

However, we identify two biases in this method to set tariffs. The first one comes from the recent development of pay as you go solar home systems like Mkopa or Offgrid Electric. Mkopa systems are priced for instance at around US$ 13 per month during 1 year, which is higher than the usual results of ability to pay analysis. Customers might be ready to pay more to benefit from a smokeless source of lighting for instance, which is usually not taken into account.

The second bias is that the ability to pay is not static. It highly depends on the economic activities which exist in the village and from which the families get paid. The economic activities will (and should) be developed by the electricity supply and thus this ability to pay of customers and businesses will increase.

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[6] E.g. M-Kopa solar kit: 8 Wp with two led lamps, 13$

Comparison with the main grid tariff creates a wrong reference

The second parameter which is usually taken into account is the current price of the main grid in the country, whether as a simple reference or because a regulation imposes to use the same tariff in the whole country. Contrarily to current practise, mini-grid tariffs should not be set to main grid tariffs. Indeed, the main grid has been built to serve the most dense, and hence economical to serve, areas; as a result, any new rural electrification project will likely be more expensive than the current average costs of the grid (embodied into the main grid tariffs).

For the interest of the community (currently electrified and would-be electrified), the most economical projects should be preferred. In particular, mini-grids should be preferred when they are more economical than grid extension. The way the costs are spread over the customers is a political question, with two possible orientations: whether the newly electrified customers pay a differentiated cost-reflective tariff, or all customers pay a non-differentiated (and a little higher) tariff. Tariff increases, for some or for all, is the only option since the cost per customer of the electricity system will increase. We think the best option is a differentiated tariff between the main grid and mini-grids as it seems politically easier to implement.

Pricing according to service, value creation and flexibility are the best options

One other parameter is, beyond the price value of the tariffs, its policy regarding flexibility. Some main grids in Africa can be simply averaging total costs of the electric system without incentivizing flexibility or other grid support mechanism. Modern grids on the other hand implement time-of-use tariffs to reflect a price signal to the consumers. This price signal is usually a consequence of the production cost of the marginal production unit used at each time of the day to meet the demand. This marginal cost is not relevant for mini-grids which rely on only one production unit. Yet flexibility has a tremendous value for mini-grids to increase their load factor. Usually, for productive use, the less flexible needs are the one creating the highest value, supplying a telecom tower previously relying on Diesel for instance. On the other hand, water pumping for irrigation is quite flexible and can be charged at a lower tariff. For private customers, pricing services (lighting, phone charging) at a fixed price instead of units of energy is another way to make it easier for the customers.

2.3.2 Financial profitability

Given that hydro schemes are very capital intensive, the minimum tariffs to reach a certain level of profitability are highly sensitive to the WACC (Table 3). With no subsidies, the case modelled needs to apply high tariffs, at US$ 0.25/kWh (plus the fixed charge) to reach a limited profitability (10% of IRR, 100 kW system, 29% of load factor). Larger system can apply lower tariffs but, as mentioned before, their actual feasibility remains complex.

Target IRR			5%	10%	15%	20%	25%
HH Energy price level ***US$/kWh***	**100 kW**	***29% LF***	0.17	0.25	0.34	0.45	0.56
	100 kW	***50% LF***	0.10	0.15	0.20	0.26	0.32
	1 MW	***29% LF***	0.07	0.13	0.19	0.27	0.35
	1 MW	***50% LF***	0.05	0.07	0.11	0.16	0.20

Table 3 – Minimal Households (HH) energy price level to reach project's IRR[7] levels

Increasing the load factor is a very efficient way to increase the profitability of a scheme and/or to decrease the variable energy-based charge. For instance, only US$ 0.15/kWh (plus the fixed charge) need to be charged to reach 10% of IRR for a 100 kW system if the load factor increases to 50%.

[7] The IRRs presented in this document do not take corporate taxes into account.

2.3.3 Improving the business case through clustering

Administrative costs represent a major cost factor for small systems (almost 30% for a 100 kW system). They are due to the need of attracting highly qualified staff to manage the company, and costs linked to building a system in a new environment. For instance, working on a cluster of 4 mini-grids decreases the LCOE to US$ 0.33/kWh (from about US$ 0.44/kWh for a 100 kW system), and increases the marginal project IRR from almost 9% to 15% (depending on load factor) for the 4th system[8].

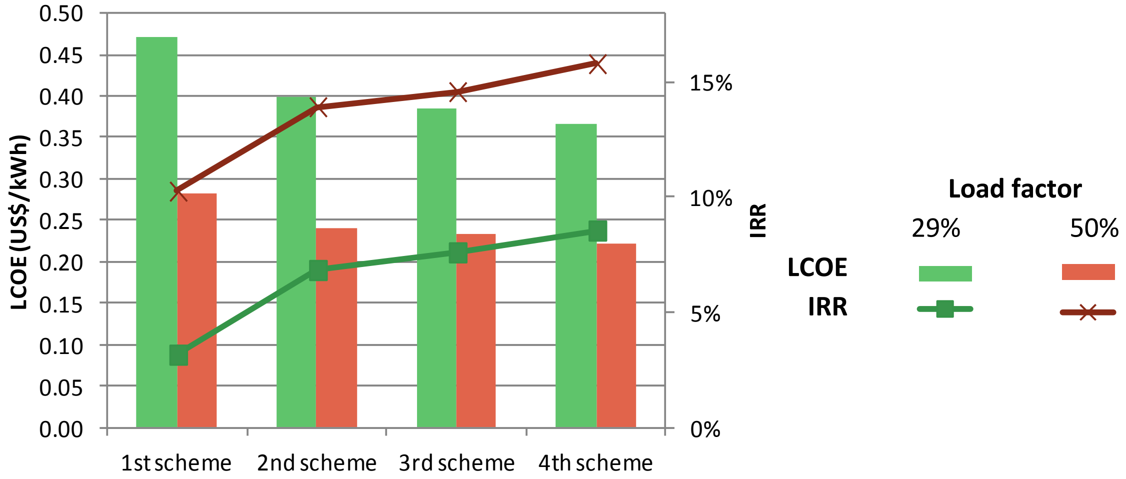

Figure 3 – Changes in IRR and in LCOE through clustering (with a variable charge at US$ 0.15/kWh)

In this case, we assume that the management costs are split equally between the 4 schemes. No company creation cost is taken into account any more. We also consider that efficiency can be achieved during the building phase: the feasibility study can be carried out by the staff and it can thus be integrated in the cost structure of the company. The building costs decrease by 10% for the last project. We did not add any productivity improvement for the offices costs which could further lighten the cost structure.

Moreover, clustering several micro hydro schemes on the same rivers of a valley seems technically feasible. It is the path chosen by MEGA (see section 1) in Malawi.

For both economic and technical reason, clustering seems to be the most realistic approach for an ambitious strategy of rural electrification based on hydro mini-grids. With this strategy, data shows that it is possible to make profit on a 100% private hydro scheme. Still no one would invest in the first scheme, which is bound to be unprofitable. A support mechanism is thus required to cross this chasm.

[8] Based on a variable charged fixed at US$ 0.15/kWh

2.4 Involvement of private money

Involving private money is critical for the success of an electrification program, since public and aid money and means will hardly be enough to quickly harness the potential of mini-grids in Zambia.

2.4.1 Choosing the right tools

A hydro mini grid industry could be financially sustainable, provided subsidies are granted for the first scheme to one or several actors. These subsidies should be designed to incentivize the private sector to get involved and to focus on the growth of the sector. Looking for growth would be natural for a completely private venture but subsidies may alter this trend and attract investors only interested in the profit of the first scheme with the subsidies. It is thus very important that the subsidies are used to achieve the objective of launching a sector.

To meet these goals, several tools can be used, like grants and concessional loans. Based on our analysis, concessional loans cannot be the only tool, since cash flows from the project are low at the beginning and cannot meet the down payments. Such loans must be associated either with a grace period or with initial (investment) subsidies. However, grace periods present the main drawback to have a looser control over the project during the first years, at the end of which other plants should be built to cluster the schemes. Concessional loans, on the other hand, can offer interesting incentives schemes. An initial interest can indeed be collected and given back as investment subsidies for further hydro schemes.

2.4.2 Setting the right level of incentives for private funds

Setting a certain level of profitability for a project involves working on a three-dimensional problem. Three levers can indeed be used to adjust the financial needs/return of the other:

- The tariffs levels and structure
- The amount of subsidies
- The rate of return on private investment

The tariffs structure must take into account the ability and willingness to pay of the customers. The recent development of solar kits and solar home system companies in the region help determining the willingness to pay of the population not connected to the grid. Their prices are cost reflective and often much higher than centralized initiatives. As a consequence, they are more sustainable and can scale up faster. That being said, the grid tariffs in Zambia are still very low and represent a reference for the population which should not be forgotten.

Neighbouring countries have higher tariffs, of up to US$ 0.24/kWh in Rwanda. Such costs seem however very high and not easily acceptable in Zambia. The cost structure adopted in two community based systems in Zimbabwe, Chipendeke and Himalaya, gives good hints of the level of prices which are already accepted in some communities. Their variable costs for households are respectively US$ 0.17/kWh and US$ 0.12/kWh, with lower costs for institutions and higher costs for businesses.

Hence, US$ 0.15/kWh (plus a fixed charge) was considered to be an acceptable level and was used in the following financial model.

Setting the costs leads to decreasing the number of dimensions to two (the level of subsidies and the rate of return on investment). As usual with incentives schemes, the level of subsidies is a balance to be found between setting it high enough to incentivize private investors but making sure it is as low as possible.

Consequently, it is necessary to define the appropriate rate of return on investment first. There are two ways of doing so. The first one would be to set a return considered to be fair for a project that is partly subsidized by public/aid money[9]. On the other hand, the financial community can be asked to understand these types of IRR. Our discussions with private actors in Zambia highlighted expectations of about 20+% IRR. Literature analysis confirms these levels [4][5]. Further analysis stresses the high level of national sovereign debt (6-8%), the normalised renewable project equity investment premium (5.5-7.5%) and a premium for illiquidity (5-7%) to explain an expected equity output

[9] This is the path chosen for instance by the Rhiviere Project in Madagascar, supported by the ONG Gret and Jamana, the national energy company in Madagascar. For this project, the fair return has been set at around 12%. It is however important to precise that the amount of investment (a few hundred thousands) of this program are usually brought by local actors.

ranging from 16.5% to 22.5% for standard projects with Power Purchase Agreements (less risky than rural hydro project)[6]. On the other hand, a rate of return higher than 20% of for a subsidized development project seems very high.

Example of a possible scheme

In order to go beyond simple concessional loans or grant projects, an innovative pattern is explored here to fund micro hydro mini-grids.

The scheme is based on two actors, a private actor and a promoting actor, in our view an NGO. The promoting actor receives money from donors, is in charge of the program at a macro level and assists the private actor locally to support the customer side. The private actor is in charge of developing mini-grids on a given territory.

The main goal is to incentivize the private actor in the long run. The private investor only needs to bring in 20% of the investment of the first scheme. The support money (80% of the amount) is split between a grant (30% of the amount) and a loan (50%). The loan is interest free if and only if the company develops other hydro schemes. Some interests are indeed perceived and transferred to a support fund managed by the promoting actor. They are given back to the private actor as grant for the next schemes, as shown on Figure 4. 30% of the second and third schemes can indeed be brought by the support fund at a rate of one scheme every five years. The fourth scheme hypotheses embed investment savings linked with improved know-how in micro hydro building at the company and the country level.

The IRR of the first project is very high when the interest free loan is taken into account. The IRRs of the three first projects together are lower but still range between 10% and 18%. Additional support can be given like other concessional loans for the other schemes but they would require raising additional money from donors and might be harder to guarantee at the beginning of the project.

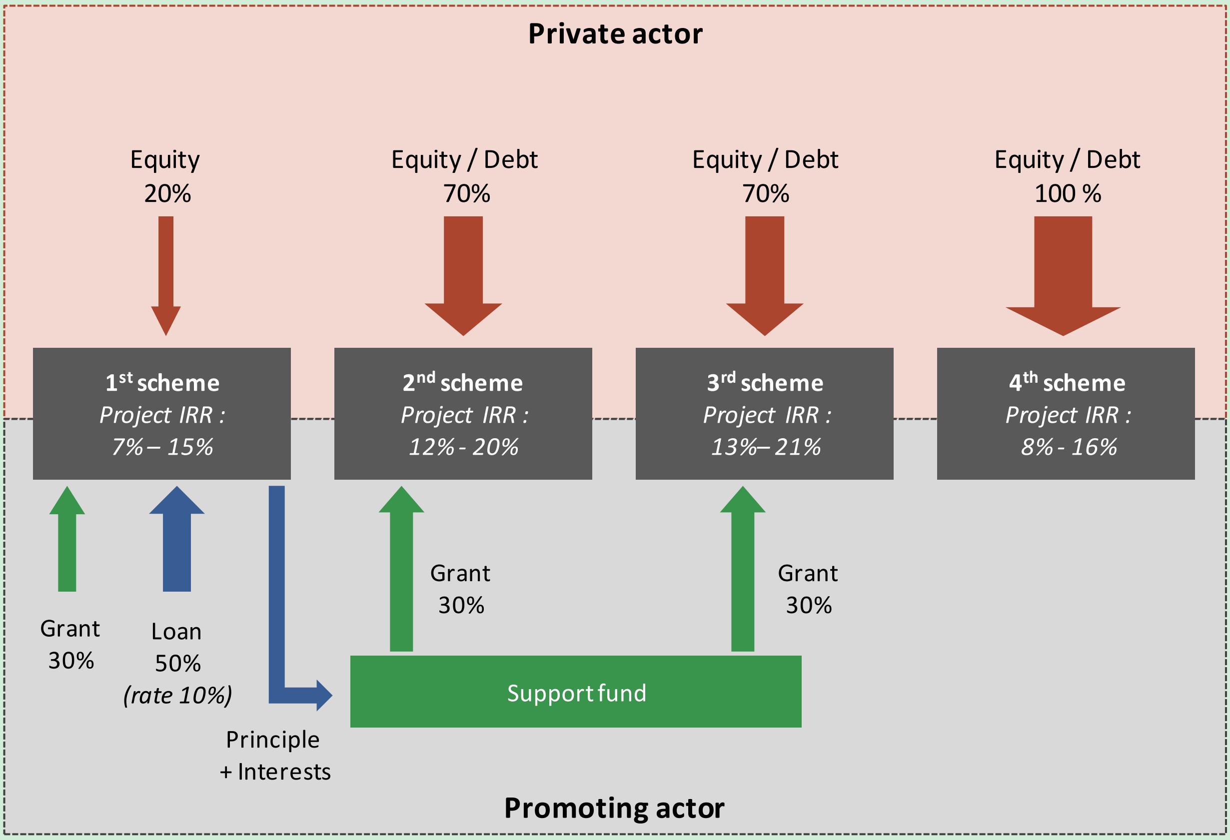

Figure 4 - Scheme of a support mechanism with a private actor and a promoting actor with a support fund

3 Guidelines for developing mini-grids in Zambia

Mini-grids are certainly one of the key enablers to increase the access to electricity in rural Zambia. At a systemic scale, off-grid electrification makes economic sense in lot of remote areas compared to grid extension. At a local scale, the need for affordable, reliable and clean energy access is urgent to ensure the socio-economic development of communities. That being said, major hurdles are still hampering the development of mini-grids in Zambia (as described in section 1).

Section 2 of this report provides insight on how to overcome difficulties in designing sustainable and scalable business models. Still, innovative approaches in business modelling won't be enough if the policy and regulatory frameworks do not evolve. At this stage, a pragmatic approach is required to make the first projects emerge. This approach requires bringing together the skills, the experience and the resources of all the stakeholders: development organizations, financing institutions, private companies and local communities.

3.1 Initiate a structured program

Mini-grids based on renewable energy sources are not broadly diffused in Zambia. The national utility ZESCO is operating several mini-grids powered by diesel generators across the country (~ 8 MW in total). ZESCO is currently studying the opportunity to hybridise or replace these schemes with hydro or solar plants, as well as developing greenfield schemes. A first 1 MW micro-hydro mini-grid, owned and operated by ZESCO, was developed in Shiwang'andu in the Northern Province. ZESCO is investigating new sites in the same area. The 750 kW Zengamina scheme in the North-West Province (described in section 1) is unique in the country, as a privately-owned isolated mini-grid of this scale. Smaller scale schemes have also been developed or are planned, including a 60 kW solar scheme in Mpanta (run by a cooperative) and a 25 kW biomass gratifier scheme, both developed with the support of UNIDO-GEF (as Shiwang'andu).

While these first projects are encouraging, renewable based mini-grids are still isolated initiatives. A more consistent and long-term approach is now required. ZESCO obviously has an important role to play as a national state-owned utility. In parallel, initiatives from the private sector and the civil society could catalyze the diffusion of mini-grids. The Government of the Republic of Zambia has shown its willingness to foster the participation of the private sector in developing electricity generation capacities across the country. Electrification through mini-grids deserves an equivalent interest, but this requires proving their sustainability and scalability with first pilot schemes.

Zambia's hydropower potential is a great opportunity to develop micro-hydro mini-grids. Site identification is a first critical step: as described in the first part of the document, matching demand with supply is a prerequisite to make business models work. With regards to hydropower, this is a major aspect since the energy resource is not necessarily in the same location as consumption centres. The process of identifying and qualifying potential sites was initiated by the REA (Rural Electrification Agency), based on The Rural Electrification Master Plan (REMP) [7] published in 2008. A survey on the feasibility of running micro-hydro mini-grids on a range of around 40 sites in selected districts of North-western, Muchinga, Northern and Luapula provinces was launched.[10] However, the assessment of mini-grids' potential across the country is still incomplete and lacks consistency; information is scattered among stakeholders:

- REA is in charge of the rural electrification plan in Zambia and may establish the guidelines to develop mini-grids across the country. The REMP [7] identifies RGCs (Rural Growth Centres) which could be electrified with off-grid solutions. Even so, the level of information is often inadequate for project developers (e.g. no GIS with potential sites, etc.)
- OPPPI (Office for Promoting Private Power Investment) is the privileged interlocutor for private developers of power plants (above 10 MW). A data base of hydropower potential sites is under development and may identify small scale sites (below 10 MW).
- ZESCO carries out its own investigations on potential micro-hydro sites, and is currently working on a data base. It is still unclear to what extent ZESCO is willing to share information with other stakeholders.
- WARM (Water Resource Management Authority) should also provide information about Zambia's hydrology.

Beyond this, developers are generally faced with scattered information and complex administrative paperwork (as described in section 1). Initiating a program to develop mini-grids in Zambia requires structuring the approach. This

[10] 12 feasibility studies have been carried out by Practical Action and SNV for REA, and a concept note was prepared for developing 1 to 5 schemes

means a better collaboration between all stakeholders, in particular regarding the sharing of information and the agreement on clear guidelines. Recommendations for a structured approach are the following:

- Mapping of potential sites:
  - Information sharing would strongly facilitate the development of new projects
  - A unique entity should be in charge of gathering data
- Evaluation / feasibility studies:
  - Site assessment requires a global approach which tackles geophysical, technical, economical and social aspects. Public institutions and development organizations could collaborate to set up a structured approach.
  - Financing of feasibility studies is a key aspect. Private developers are generally not keen on supporting these costs (without any guaranty of project achievement). Financial support could come from public institutions (through REA) or international funders.
- Legal framework:
  - Legal aspects around mini-grid ownership and operation should be clarified to improve risk perception among developers and investors. This includes land / water use authorization and concession, licenses for electricity production / distribution or tariff settings.
  - In the perspective of a mini-grid clustering strategy, concessions and authorizations should be requested for basins / river sections.
  - The possibility of connecting the mini-grids to the main grid should be anticipated and the takeover process (by ZESCO) must be well defined.

3.2 Implement sustainable and scalable financing schemes

Until now, mini-grids have struggled to grow beyond pilot projects due to the lack of profitability of existing schemes. Section 2 of this report highlights the difficulties of designing financial models which could be attractive for investors and sustainable / scalable without a large support from grant funding. Revolutionary solutions in business modelling must not be regarded as a panacea, since regulatory and socio-economic aspects are major drivers. Still, innovative approaches can create opportunities to attract investors while progressively decreasing the need for public / donor money.

As described in section 2, a clustering strategy aggregates key activities in order to decrease mini-grid costs. It's also a way to progressively improve the schemes, to build capacity, to simplify legal and administrative paperwork, etc. This strategy provides a long-term vision which is expected by public institutions and international funders (to reach electrification targets), as well as by private investors (to decrease the risk of investment). Where isolated initiatives struggle to attract the private sector, mini-grid clusters could provide better opportunities in terms of financial returns. To initiate a program, promoting entities like NGOs are generally necessary. For instance, these can create holding structures to raise funds from various sources (grants, loans, equity, etc.) and support the development of projects (see section 2.4). In any case, designing the financial models requires adjusting three main dimensions: tariffs levels / structures, public and aid support (subsidies / concessional loans) and rate of return on private investment.

In Zambia, grid electricity tariffs are relatively low (around US$ 0.065/kWh for residential customers) compared to other countries in the area. This is partly due to the country's electricity mix which is dominated by large hydropower plants constructed decades ago. The Government's willingness to increase electricity access involves new investments in T&D assets, as well as electricity generation capacities. Independent producers are currently negotiating power purchase agreements with the national utility ZESCO at higher prices (above US$ 0.12/kWh) than the current retail tariffs. The REFIT[11] policy under development by the Department of Energy should create an incentive framework for renewable generation assets connected to the grid. Unfortunately, off-grid assets are not concerned by this policy. Setting acceptable retail tariff levels while ensuring schemes' profitability is a challenge for independent mini-grid operators (as experienced by Zengamina's developers, cf. section 1). Within this process, two main factors must be taken into account:

- The socio-economic factor: Local communities have to be consulted during feasibility studies to assess as precisely as possible the ability and willingness to pay of customers. Tariff levels / structures can be derived from baseline energy expenses for each category of customers. This assessment provides valuable inputs on how to design smart tariff structures (fixed charges, stepped energy tariffs, peak/off-peak tariffs, etc.).

[11] REFIT: Renewable Energy Feed-In Tariff

- The legal factor: In Zambia, retail tariffs must be negotiated and approved by the ERB (Energy Regulation Board). Tariffs proposed to the ERB must be backed by a solid business plan (tariff increases must be also renegotiated).

In many cases, mini-grid operators are not able to set adequate tariff levels (see tariff calculation in Section 2). Development of the first schemes requires the financial support from governmental institutions and/or international funders. Using public money to fund distribution assets could make sense in a framework of tariff equalization for instance. In Zambia, REA is managing the Rural Electrification Fund which could theoretically be directed toward mini-grid projects through a "smart subsidies" scheme (at least 20% contribution on project costs expected from private developers). However, subsidies granted to private developers have been scarce so far. REA is currently reviewing its financing framework to better include mini-grids in the scope of the Fund. Other sources of funding could come from international institutions. In January 2015, US$ 40 million were allotted to Zambia by the World Bank within the SREP[12] program to finance both the public and the private sector. Part of this allowance could go to off-grid electrification, including mini-grids.

Loans are generally more efficient tools than grant funding to ensure scheme's sustainability and scalability. Local commercial banks are not able to offer loans with acceptable terms for mini-grids developers, with interest rates sometimes above 20%. Access to concessional loans from development banks should be a key enabler. With regards to the Shiwang'andu scheme, the DBZ (Development Bank of Zambia) provided a free interest loan to ZESCO via a loan facility agreement with UNIDO-GEF. DBZ is now working on a new vehicle, the Renewable Energy Fund, supported by international funders. The scope of intervention is not fully defined yet but it will certainly take the form of concessional loans for project developers.

In the perspective of a clustering strategy, the need for grant funding and concessional loans should progressively decrease. Innovative tools can be chosen to incentivize private investors in the long run (e.g. "support funds" managed by promoting actors; see section 2.4 for more details). Nevertheless, private investors have high expectations concerning the rates of return and the attractiveness of investing in mini-grid still needs to be proven.

3.3 Mobilize the appropriate resources and skills

Mini-grids are very specific assets. On the one hand, they can be complex electrical systems which require professional skills for the design, construction, operation and management. On the other hand, they need to be integrated in local contexts and to involve all stakeholders.

Major issues identified (cf. section 1) come from the lack of professional skills in small-scale community-based schemes (defective locally sourced equipments, absence of long run vision in the management, etc.). NGOs such as Practical Action hold valuable knowledge and experience to develop and design mini-grids. However, the hand-over to local communities is often not the best solution when the scheme's size exceeds a few dozen kW. The involvement of private actors is mandatory to attract investors for whom the perception of risk is already high for this kind of assets. Professional skills and resources must be mobilized in particular for:

- Initial studies (feasibility, design) and construction: an efficient and reliable scheme is a prerequisite to reach financial profitability. Quality equipments must be selected even if they are not sourced locally (e.g. electromechanical equipments for hydropower).
- Operation and maintenance: while some day-to-day tasks could be basic, various standard and exceptional procedures require experimented engineers. The scheme's sustainability depends on rigorous O&M procedure enforcement.
- Management: scheme's managers must have professional skills to ensure business profitability and to follow a long run vision.

That being said, local communities cannot be bypassed either. Successful implementation of mini-grids requires finding the appropriate level of involvement of local stakeholders, including customers, authorities, land owners, contractors / suppliers and employees. Here are some examples:

[12] SREP: Scaling-up Renewable Energy Program in low income countries

- Participation of electrification beneficiaries could take the form of regular consultations of stakeholder committees (e.g. tariff, grid development, reliability, etc.). Customers' representatives can be intermediaries to facilitate relationships with the grid operator (e.g. for money collection, conflict solving, etc.).
- In Zambia, agreements with local authorities or inhabitants could be necessary to use the land (e.g. for distribution assets).
- Local contractors / suppliers / workers should be mobilized as much as possible. Beyond the impact on the local economy, it's also a way to decrease the costs of mini-grids.

Capacity building is a key success factor to ensure a sustainable local development. Skilled employees are generally difficult to find in the areas targeted. In-house training of employees must be part of the key activities of the entity operating the grid. This involves several key measures, including skills redundancy (i.e. avoiding the dependence on one employee on key activities) and / or attractiveness of the job position (i.e. keeping trained employees in the organization the longest possible to sustain the internal know how).

At last, independent developers should investigate the opportunities to collaborate with local institutions or companies. Information, experience and resources held by ZESCO could be highly valuable for project developers.

3.4 Support the customer side

Optimizing the load factor must be one of the main targets for mini-grid operators. As noticed in sections 1 and 2, a demand-driven approach is compulsory to properly design the schemes, to set the appropriate tariff structures and to develop the customer base. Various strategies can be adopted to maximize the electricity production. One of the well-known approaches is the ABC model: Anchor customers who provide a reliable cash flow, Businesses with substantial consumption and residential / small businesses Customers, as a top-up to the revenues. [2] While this should theoretically work, in reality the economic activity is generally limited in mini-grid areas, hence so is the existing load.

Increasing electricity consumption can be done by supporting the customer side: this is the approach promoted by Practical Action and SNV in Zambia, based on their past experience. This approach involves the allocation of specific resources whether material, financial or human. The main objective is to develop productive activities with high (and ideally flexible) electrical loads: irrigation schemes, grind mills, saw mills, welders, cold rooms, energy kiosks, etc. The support can take various forms, including incentives for the acquisition of equipments as well as capacity building. However, private developers usually have neither the capacity nor the willingness to allocate resources to support the customer-side. Hence the involvement of development organizations and public institutions can make sense. An alternative solution could be to reinvest a share of the mini-grid profits into the customer side (e.g. via a support fund).

Increasing the global electricity demand is not the only way to optimize the load factor. Smoothing the load curve is also necessary when peak demand exceeds grid capacity. Smart tariff structures can be part of the solution (e.g. time-of-use tariffs). Demand management actions also include the promotion of non-electrical equipments, in particular for cooking purposes (improved cook stoves, biogas cookers, etc.).

The need to support the customer-side should not be underestimated by mini-grid developers and operators. It is often required to strengthen the revenue stream and to ensure scheme's profitability.

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Appendices

Stakeholders consulted

Name	Organization
ZIMBABWE	
Mr. Tim Young	Practical Action
Ms. Gigi Davis	Practical Action Southern Africa
Mr. Godfrey Sibanda	Practical Action Southern Africa
Mr. Hopewell Zheke	Practical Action Southern Africa
Mr. Killron Dembe	Practical Action Southern Africa
Mr. Clement Kalonga	Practical Action Consulting Southern Africa
Ms. Chandi Makuyana	SNV Zimbabwe
Mr. Senga Senga	Chipendeke community hydro scheme
Mr. Chakanuyaka	Himalaya community hydro scheme
Mr. Cliff Nhandara	Rural Electrification Agency (REA)
Mr. Lewis Makurumure	Rural Electrification Agency (REA)
ZAMBIA	
Mr. Victor Mundende	ZESCO
Mr. Ernest Banda	ZESCO
Mr. Clement Sasa	Office for Promoting Private Power Investments (OPPPI)
Mr. Benny Bwalya	Energy Regulation Board (ERB)
Mr. Nkusuwila Silomba	Energy Regulation Board (ERB)
Mr. Geoffrey Musonda	Rural Electrification Authority (REA)
Mr. Patrick Mubanda	Rural Electrification Authority (REA)
Ms. Martinent Malyo Sefuke	Zambian Development Agency (ZDA)
Mr. Innocent Melu	Zambian Development Agency (ZDA)
Mr. Daniel Rea	Zengamina Power Limited
Mr. Chilambwe Lwao	Development Bank of Zambia (DBZ)
Mr. Duncan Bwalya Mfula	Development Bank of Zambia (DBZ)
Ms. Stephanie Peters	KfW Zambia
Ms. Sue Ellis	SNV Zambia

Economic model data sources

This part presents the details of the hypothesis taken for the economic model of the hydro mini-grid.

A. Mini-grid cost hypothesis

a. Hydro scheme

The hydro-electrical plant is the most important costs factor of a hydro mini-grid. The following subpart will summarize the different costs hypotheses used in this study.

Hydro scheme CAPEX

A Hydropower plant is usually composed of three main steps:

- The water intake is usually built around a dam
- The water deviation, composed of a canal and a penstock
- The electrical conversion in the powerhouse with a turbine and a generator.

The investment costs of such a plant mainly depend on two parameters:

- The head: for a given power, the height of the head induces the type of civil works needed, a small height being more expensive to exploit.
- The power capacity of the plant: the main electrical components have economies of scale enabling lower cost per unit (kW) for larger turbines and generators.

The cost of each site also depends on the geologic characteristic of the region which can make comparison hard. The IRENA provides international data comparison [8]. However, the costs end up being much more expensive than international available data from rural electrification projects. Other data, as displayed in Table 4, focuses on hydro project costs in emerging countries and may be closer to Zambian costs.

Location/Country	MHP size (kW)	Year	Average Capital Cost (US$/kW)	Source of Financing of MHP Development
Indonesia	≥ 20	2012	1,821	MHP PNPM
Rwanda	25	2011	2,043	District authority/local entrepreneur
Indonesia	25	2011	4,000	Government grant projects
Peru	33	2005	3,400	Grant through NGO (Practical Action)

Table 4 - Micro Hydro CAPEX Costs in previous rural projects [9]

The field visit and local data collection carried out confirmed the relative overestimates of the IRENA costs but did not lead to the relative low cost of the 25 kW scheme. This study will take the data displayed in Table 5.

	100 kW	1 MW
CAPEX costs	US$ 3,500/kW	US$ 2,500/kW

Table 5 – Hydro plant CAPEX costs used in the study

Hydro scheme OPEX

Operation and maintenance costs of micro hydro costs have a very high share of fixed component. Schemes are usually secured by watchmen and maintained by an operator.

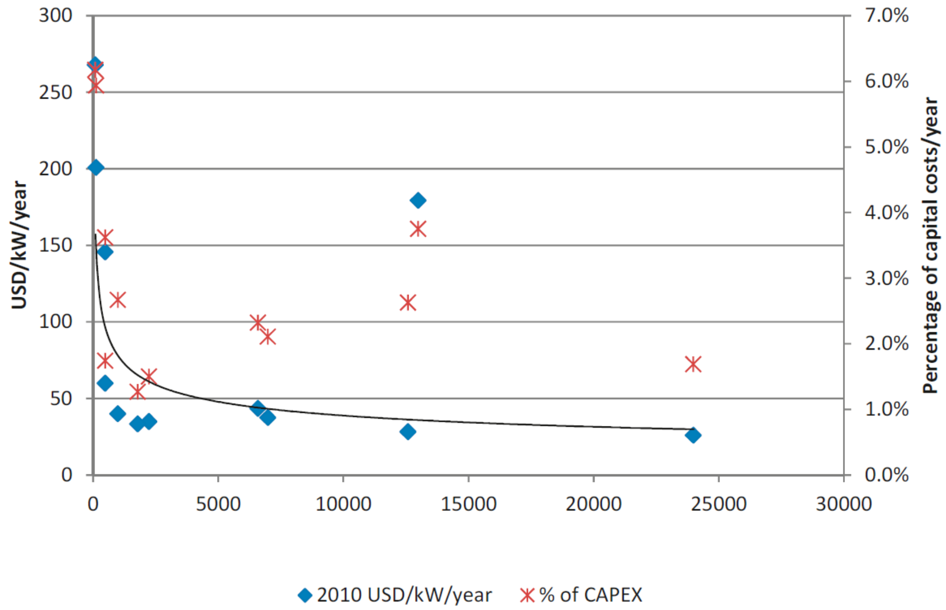

Figure 5 – Operations and maintenance costs for small Hydro in developing countries, depending on the plant capacity (in kW) [8]

Based on this data a global cost of 2% of plant maintenance will be used in this study. For a 100 kW unit, this is in line with the O&M costs incurred in the scheme we heard of, including 2 watchmen and 2 operators for a 100 kW site.

This has been compared with the data used in the maintenance and operational cost model developed by the PSP Hydro team of GIZ in the study: Privatization of the Management of Existing Micro Hydro Power Plants: Feasibility analysis and strategy.

b. Grid

Grid CAPEX

Distribution grids are usually composed of two types of lines: low voltage lines (230/400 V, between 5,000 and 8,000$/km) and medium voltage lines (11 or 33 kV, about 15 000 $/km). The total costs of a network highly depend on customer distribution. A project backed by DFID provides an interesting ratio to size a virtual network, assessing that a distribution grid is relevant only where customer density is above 30 customers/km. Assuming the network relies both on LV and MV lines, we retained a hypothesis of 30% of MV lines and 70% of LV lines. This leads to 270 to US$ 340/customer [9]. We will use the later costs to be conservative.

Connection costs vary highly depending on the countries. Some countries impose very high quality standards for rural connection; thus increasing the costs of the connection like in Kenya (see Figure 6).

The price level of Uganda, Mauritania and Cote d'Ivoire (about US$ 100) will be used in this study.

The total grid CAPEX thus amounts to about US$ 440/ customer.

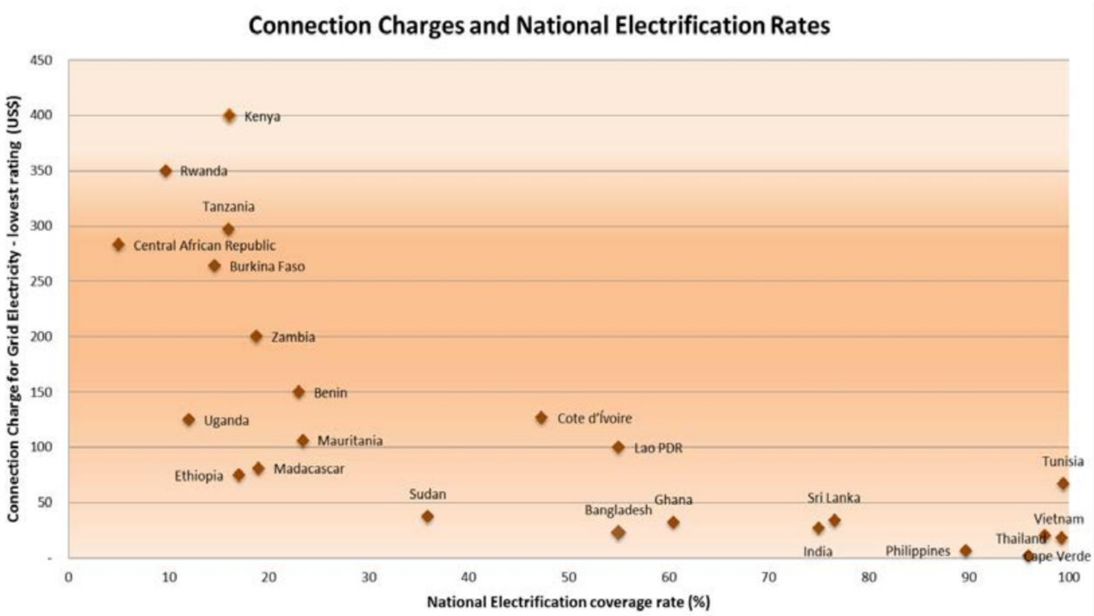

Figure 6 - Connection charges in developing countries with regard to their national electrification rates [10]

Grid OPEX

Grid OPEX includes two different types of costs:

- O&M costs: It is quite hard to find data on specific grid O&M costs for isolated mini-grids. Most of the time, O&M costs are not differentiated between plant O&M and grid O&M. Thus the same ratio of 3% of CAPEX will be used for grid O&M
- Grid Losses: Electricity transportation and distribution through connectors also leads to losses. Depending on the quality of the installation, the amount of energy lost can range from 5% to 15+%. A 10% hypothesis will be taken into account.

c. Company costs

Administrative and commercial costs

Administrative and commercial costs are much harder to assess. They are composed of money collection costs, management costs and office costs.

Management costs & Office costs

Management costs are mostly fixed, with a general manager and a technical manager needed to overview the management of the company. For two highly qualified managers we provisioned US$ 30,000/year. Office costs have been assumed to be variable at 15% of the turnover of the company. A fixed company creation cost of US$ 10,000 is also accounted for in the model.

Money collection costs

Money collection costs are an important parameter in an energy service company business plan. Two different strategies can be implemented to recover the fees from customers, either via a prepayment system with smart meters or via collection agents.

- The prepayment system involves an investment in prepaid meters and variable commissions on the sales. The prepayment meter can increase the connection cost of about US$ 50 and the commissions may vary but range from 5 to 20%.

- The collection agent goes door to door to collect money from customers and manually disconnects them in case of delayed payments. Fields visits reported that one agent can handle between 150 to 200 customers for a monthly payment scheme. This solution will be used in the model.

B. Consumer consumption habits

The types of consumers and their consumption habits are a major factor for the scheme business model and profitability. Precisely planning the consumption needs of a community is necessary to adequately size a system. Very few reports analyse the consumption per types of use or of customers. The most common figure which is published is the load factor[13] of the plant. In a lot of isolated micro hydro mini-grid schemes, the system load factor ranges from 20% to 30%. For a 100 kW system, this equals to around 260 MWh per year. There are three types of potential customers:

- Businesses : of a limited number, they can represent a high share of the consumption where productive uses are promoted
- Households : usually the highest numbers but with limited consumption
- Institutions (usually clinics and schools)

The data collected on their consumption habits will be detailed in the three following paragraphs. The analysis mainly focuses on energy and does not primarily focus on capacity. Working on capacities would require a much more detailed analysis that is hardly possible given the lack of data on the proposed plans. However, the capacities required remain consistent and the sum of the non flexible uses is kept below the available capacity.

a. Households

The level of energy consumption by the households depends on two parameters, the number of households connected and their level of consumption.

The number of households a hydro scheme can connect is very dependent on the population density and the village composition. It is frequent that a mini-grid connects at least 250-300 people ([9]).

Households' consumption can depend on the prices but the literature offers several feedbacks, ranging from 50 to 150 kWh.

Context	Value	Source
Tanzania, IREP projects [9]	147 kWh/year.HH	IED DFID, includes network losses
MEGA, Malawi	102 kWh/year.HH	Practical action internal documents
GEOSIM Model	54 kWh/year.HH	Averages

Table 6 – Public data on Households consumption in rural electrification project

The data from Practical Action in Malawi, 102 kWh/year. HH is a middle range value and will be used in the study.

Assuming 300 people are connected, this would lead to a consumption of 30 MWh/year for this customer segment. Compared to the potential production, the energy consumed by the households does not represent a limit for a hydro scheme. If people are cooking at the same time, it might however lead to a capacity shortage.

b. Businesses and Productive uses

Businesses represent an interesting profile for mini-grids. Productive uses are usually linked to income generation and are thus more easily paid for compared to private consumption.

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[13] The load factor equals the amount of energy consumed by the amount of potentially produced energy. This is however not a completely standard ratio since grid losses or resource variability might or might not be taken into account.

Business	Rating	Daily op. *Hours/day*	Yearly op. *Days/year*	Yearly consumption	Potential nb in town
Telecom Tower	~ 3 kW [11]	24	365	26 MWh/year	2
Irrigation scheme	15 kW, flexible[12]	8	365	44 MWh/year	1
Cold room (fisheries, vegetables)	3 kW	24	365	26 MWh/year	2
Grinding mills	6 kW) [12]	6	250	9 MWh/year	2
Saw mills	5 kW [12]	6	250	7.5 MWh/year	1
Welder	1 kW [13]	6	250	3 MWh/year	2
Energy kiosk	2 kW, flexible	8	250	3 MWh/year	2
Other processing business (stone crushing, fruit drying ...)	15 kW, [13]	8	250	30 MWh/year	1

Table 7 – Consumption hypothesis from main productive uses of businesses

This first level analysis leads to a potential productive energy consumption of 216.5 MWh/year, i.e. about 33% of the available energy production. This includes 80 MWh of flexible use, which could be operating at night. Other commercial businesses: bakers, shops, bars, hair dresser etc. are not detailed in Table 7 as their consumption is usually not above a few MWh.

c. Institutions

The consumption levels of institutions depend on the size of the village and on its role as a service centre for the surroundings. Rural Clinic consumption in Africa can vary from 5 to 30 kWh/day [14]. An average value of 15 kWh/day will be used in the model. The level of consumption of a school depends highly on the type of school (primary / secondary) or the presence of a boarding school. It is also worth mentioning that there can be several schools in one village.

As a whole, a global consumption of 20 MWh/year, equivalent to 55 kWh/day, will be modelled.

d. Global levels of consumption

Analysing separately the consumption potential for a typical village leads to forecasting a consumption level of about 260-270 MWh, as presented in Table 8. Such consumption levels represent 43% of the available energy production.

	Consumption
Households	20 – 30 MWh
Productive use	220 MWh
Institutions	20 MWh
Total	260 – 270 MWh

Table 8 - Summary of the consumption distribution for a mini-grid

This compares relatively well to other mini-grid projects but highlight a much higher potential for flexible energy consumption. Concerning capacity, the evening is usually the most critical period, due to a peak of households' consumption. Several parameters are limiting the available capacity:

- Network losses and internal consumption
- Seasonal production variability : depending on the local water resources, it is common to have an output decrease up to 30%

Capacity margins must thus be meaningful to cope with these constraints. If capacity is likely to be an issue, it might be relevant not to extend the grid to too many households and to develop energy kiosks instead. Energy kiosks are moreover a flexible load which can help to increase the load factor of the mini-grid.

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