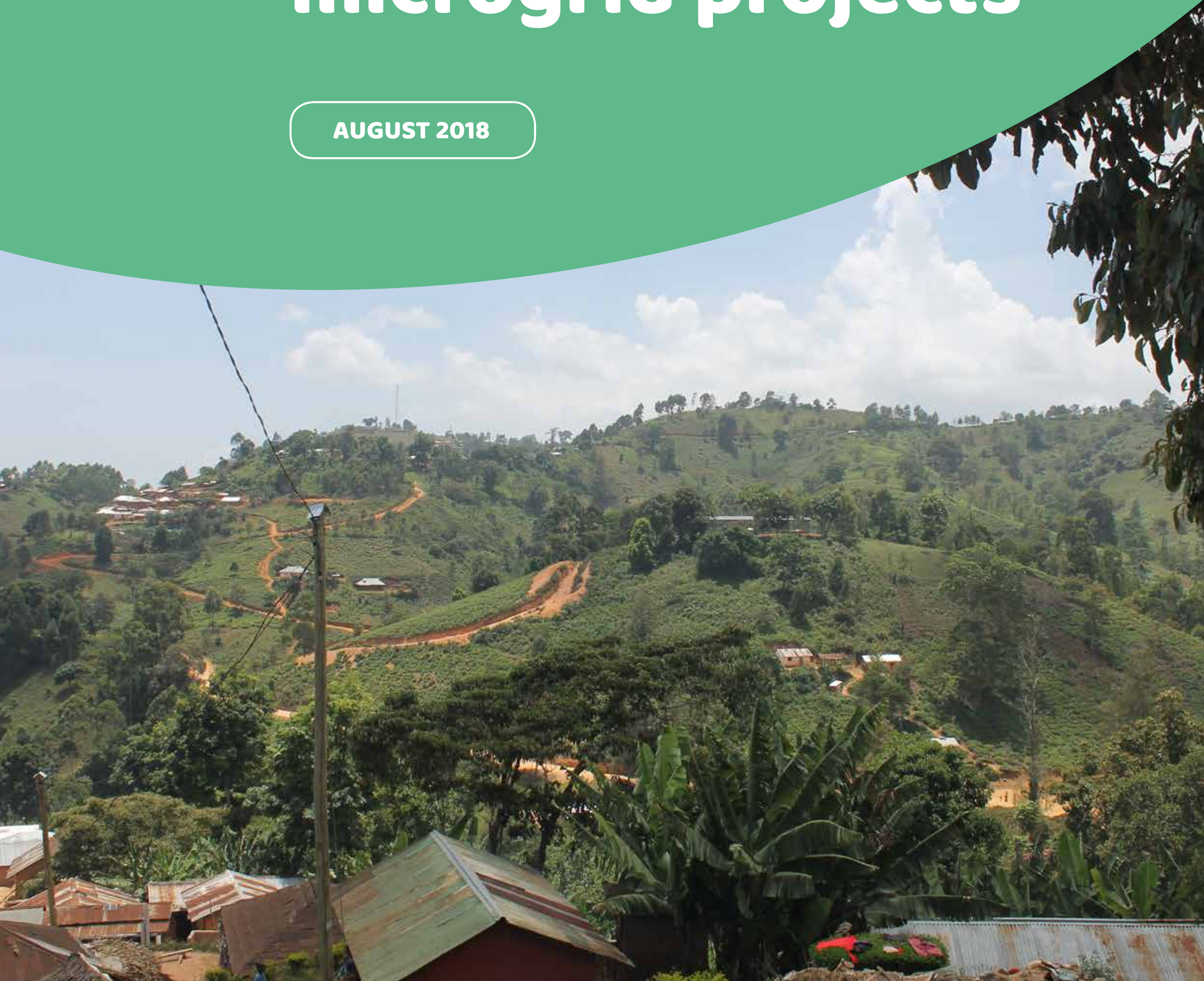
Ensuring steady cash flows in off-grid solar microgrid projects

AUGUST 2018



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This publication is the result of the collaboration between **ENEA and Millennium Microgrid.** Millennium Microgrid was one of the granted organizations of ENEA's call for project 2018.

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.

Millennium Microgrid is a social enterprise that brings affordable, sustainable electrical power to households, small businesses, and community facilities located in communities in Sub-Saharan Africa that are unlikely to have grid-connected power in the near future, if ever. The enterprise is focused on proving that well-structured microgrid projects can attract commercial debt and equity financing at financing costs much lower than presently available in the sector and with much greater depth and predictability than grant financing.

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

Over 1.1 billion people in the world today do not have access to electricity. Approximately 600 million of these people live in Sub-Saharan Africa Bib.1. Distributed renewable microgrids are widely recognized for their potential to bring electricity to hundreds of millions of Sub-Saharan Africans. These village-scale assets range in size from a few hundred watts to hundreds of kilowatts, serving dozens to thousands of customers. Through the aggregation of electricity demand, they can supply electricity at an affordable rate to both household customers and productive users[1].

To enable the rapid and massive development of these solutions, private capital and long-term project financing must be mobilized. For example, a 75-kW microgrid to serve one thousand customers may require an initial investment of up to one million USD Bib.2-3. With 1.8 million households "beyond the reach of a national grid" in areas of medium to high levels of density, Tanzania alone represents a 1.8 billion USD investment opportunity. However, investors and lenders perceive microgrid projects as risky, due to the high capital intensity and lack of creditworthy long-term power purchase agreements. Due to these risks, lenders and investors require a high cost of financing for microgrid projects. Mitigating these risks will help unlock investment opportunities and reach the UN Sustainable Development Goal 7: "Ensure access to affordable, reliable, sustainable and modern energy for all".

Three levers exist to mitigate the risks of non-steady cash flows of solar microgrid projects: mastering operational management, optimizing customer portfolios to reduce demand risks, and adopting a price structure that makes cash flows more resilient to reduced energy consumption.

Project developers can control numerous risks through strong operational management and the use of new technologies. Revenue collection risks, which have often been raised as a major challenge Bib.4, can now be addressed with mobile money solutions. System maintenance costs, which represent 65% of total operational costs, can be scheduled and predicted. Thus, the main challenges faced by project developers concern energy demand, namely low household demand and low adoption of the microgrid by productive user.

To deal with these risks, project developers should first actively support energy demand. As the upfront cost of appliances is the main limitation to increased household consumption Bib.5, project owners can boost demand by supporting the access to affordable equipment. Project developers should also make a commercial effort to connect onsite productive users and foster their development by providing capital and equipment information.

Targeting the right customer portfolio is another effective way to decrease demand risks. The portfolio profile has a significant impact on the risk profile of a project, and the optimal portfolio should be balanced between households and productive users. Relying only on productive users could be challenging as these activities may be limited and prone to change based on the season and economic trends. On the other hand, relying only on households will not maximize asset utilization and requires more storage as households tend to consume mostly at night. Hence, the customer portfolio should balance household evening consumption and the high utilization of productive users. Including residential customers in the portfolio also enables local acceptance of the project

1 Productive uses correspond to "activities that enhance income and welfare [...] typically in the sectors of agriculture, rural enterprise, health and education" Bib.2

and represents most of the microgrid's growth potential as these customers climb the "energy ladder" and increase their consumption over time.

Finally, price structure is another tool to ensure steady cash flows in case of lower demand. Combining a monthly fixed fee and a unit-based top-up is considered the best price structure to reduce this risk. Indeed, a monthly fixed fee enables project developers to secure part of their revenues regardless of energy consumption, whereas customers can control their energy bill with the unit-based top-up. Independent of its structure, the price level should be set together with local communities. Price structure has a strong impact on customer perception, social acceptance of the project and revenue risk, but a limited impact on demand because demand for the first daily kWh is relatively inelastic.

Strong operational management, optimized customer portfolios and well-designed price structure make cash flows steadier and more resilient to uncertainty, opening the door to more accessible and affordable financing. Together with the current development of regulatory frameworks more favorable to microgrid implementation, these evolutions could unlock the potential of massive microgrid replication across Africa to answer the energy needs of rural areas.

Abbreviations

ARPU Average revenue per user

EDA Energy Daily Allowance

EWURA Energy and Water Utilities Regulatory Authority

MFI Micro-Finance Institution

REA Rural Energy Agency

SHS Solar Home System

TANESCO Tanzania Electric Supply Company

Tsh Tanzanian Shilling

USD United States Dollar ($)

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Introduction

Microgrids in the context of energy access

There are several ways to address the energy access challenges. While connecting all citizens to a centralized national grid was the main method for years, recent developments in renewable energy technologies has led to the emergence of decentralized electricity generation units. These off-grid technologies can offer quick and economic solutions to energy access challenges at all levels: from small solar lamps for task lighting to microgrids enabling higher energy uses.

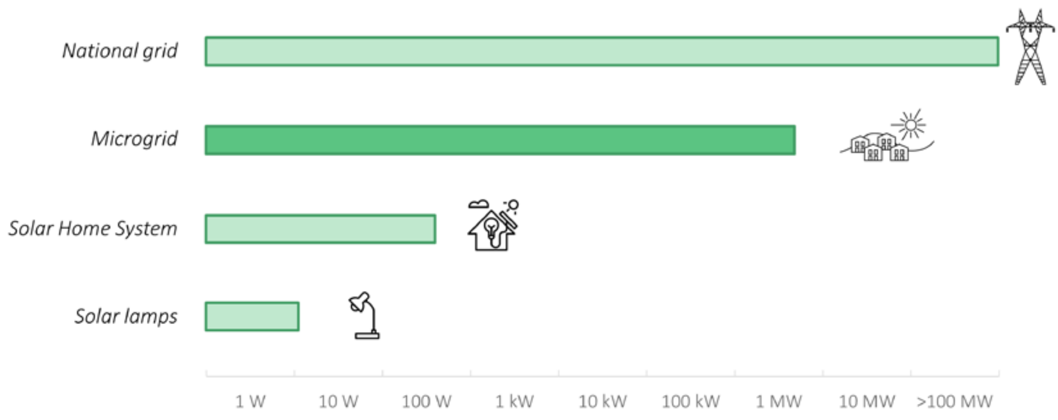
After the rapid development of solar lamps, the model of Solar Home Systems (SHS) quickly emerged to answer basic energy needs (lighting, phone charging, radio). These standalone systems are composed of a personal small PV panel with a controller unit including an inverter, a battery and a controller. The larger systems have been developed with the capacity to power a TV or other medium power appliances. However, they cannot power higher electricity needs like milling or carpentry.

Microgrids can provide these higher electricity needs. They are composed of a bundle of PV panels, a large storage capacity, an inverter, wiring to connect customers, and meters at the customer's location. They can reach a higher asset utilization rate and therefore lower cost of service than SHS by aggregating demand at the village scale and diversifying load profiles (productive users during the day, households in the evening). Depending on the distance from the national grid, microgrids can be a more economic option due to limited wiring investment and lower power losses compared to national grid extension.

The different electricity access options are presented in Figure 1 to compare what scale of energy uses they can serve.

Figure 1

Comparison between energy uses served (W) for various energy access options



Despite the potential impact of microgrids on energy access, the challenge of access to finance slows down the sector's development Bib.6. Indeed, microgrids are capital intensive, long-term assets and investors perceive several risks that could compromise the revenues of the microgrid:

- **Business case –** The sector is relatively new, so few examples are available to give lenders confidence in the microgrid business case.
- **Policy risk and national grid –** As assets are to be reimbursed on a long-term basis, revenues must be secured for several years. Yet the regulatory context could evolve (such as creating restrictions on electricity prices) and potentially impact the project's revenue model. In addition, microgrids are developed in parallel with the extension of the national grid. The connection of a village to the national main grid could result in a sharp decrease of revenues if the national utility electricity rates are lower than the microgrid ones[2].
- **Prediction of demand and offtake risk –** Isolated microgrids have no grid offtake for excess power: they rely only on local demand, which is difficult to evaluate before project commissioning. Furthermore, as electricity is not available to the village before microgrid development, it is difficult for potential customers to predict their future consumption. As microgrid design is linked with demand prediction, demand uncertainty can lead to oversized equipment and thus investment cost. As residential consumption is highest in the evening, overestimating residential consumption leads to more storage capacity than needed.

These challenges need to be carefully considered to establish strategies to mitigate the associated risk

2 This rate is often significantly subsidized for rural customers and not reflective of actual costs.

Figure 2

Key challenges in microgrid development

Are there critical operational pitfalls (technical and organizational) to avoid?	Is there an optimal customer portfolio to ensure regular demand?	Is there an optimal tariff structure limiting the risk of reduced revenues?
ie. pitfalls which would: ▶ Lower quality of service leading to poor customer satisfaction ▶ Impact revenues, such as low demand or difficult revenue collection ▶ Involve important and non expected replacement costs	ie. a portfolio which is: ▶ Balanced between B2C and B2B customers ▶ Not too sensitive to external events ▶ Maximizing asset utilization thanks to matching electricity production and consumption periods	ie. a business model: ▶ Enabling to reach the Bottom of Pyramid ▶ Providing the right incentives to customers ▶ Ensuring customer satisfaction and limiting impact of energy demand reduction on revenues

Report methodology

The International Energy Agency concludes that decentralized systems, led by solar photovoltaic in off-grid systems and mini-grids, are the lowest cost solution for three-quarters of the connections still needed in Sub- Saharan Africa Bib.1. To meet this potential, microgrids must attract private equity capital and non-concessional project finance debt. Investors and lenders, however, perceive microgrid projects as risky, because they are capital intensive and their revenues are not guaranteed.

This report aims to contribute to the understanding of these revenues by recommending how project developers can secure steady cash flows after project commissioning (it thus does not cover CAPEX management and technology choices). Hence, its objectives are to identify the risks in solar microgrid development and operation and how to mitigate these risks, making their cash flows more resilient. The regulatory/political risks are not covered as the project developers do not directly control these aspects (they can still advocate more favorable rules). With the development of the sector, policies also tend to be more and more adapted to solar microgrid projects in several countries.

Three key questions are addressed in this report (detailed in Figure 2), using quantitative and qualitative analysis based on literature and work in Tanzania during January and February 2018

OPERATIONAL PROFITS CALCULATION

*= (volume of energy consumed * price per unit * % revenue collected) + fixed revenue – operational costs*

*= (#customers * energy consumed per customer * price per unit * % revenue collected) + #customers * fixed revenue per customer – maintenance cost – other operational cost*

1

Project developers can control many risks through strong operational management

For the sector to attract private capital, microgrid projects must generate stable profits throughout the lifetime of the asset. To identify the main factors influencing their stability, operational profits can be broken down into their different components

See above formula

This profit breakdown highlights each component to examine the associated risks. Three main types of operational risks can therefore be identified[3]:

- **Demand risks –** either limited adoption (low number of customers) or limited demand per customer (energy consumed per customer) lead to decreased revenues. Depending on the type of customers, the main challenge depends either on adoption (productive users) or demand per customer (households). Proper targeting of the relevant balanced customer portfolio and supporting customers to 'climb the energy ladder'[4] are strategies to put in place to mitigate these challenges.
- **Revenue collection risks –** the challenge for microgrid businesses is the frequent collection of small amounts of money from numerous customers, leading to either important collection staff costs (increase in operational costs) or low revenue recovery (decrease in percentage of revenue collected). The development of mobile money provides an efficient solution for this frequent collection scheme.
- **Maintenance risks –** these risks rely both in the increased replacement costs of the equipment (increase in operational costs), in particular batteries, and the potential customer dissatisfaction due to service breakdown (either decrease in number of customers or in energy consumed per customer).

In this chapter, these three main types of risk are analyzed, broken down into their different components which are evaluated in terms of criticality for the microgrid business. Solutions are then proposed to mitigate the most critical risks to finally obtain a view of these different risks after mitigation.

3 Price level and structure is not considered as an operational aspect. How price per unit and fixed revenues per customer can be used to improve the stability and predictivity of cash flows is analyzed in chapter 3. Other operational costs, such as site rent, agent fees, smart metering fees or mobile money fees represent totally less than a third of total OPEX. They can be considered as incompressible costs and are not analyzed in this report.

4 Climbing the energy ladder' is often used as a metaphor to describe the incremental evolution of energy uses in energy poor communities.

The main challenge for microgrid projects is to ensure adequate electricity demand to generate sufficient revenues

To prioritize efforts and identify clear solutions, each of these risks was described and evaluated based on its probability (1-to-4 scale) and its impact on the revenue model (1-to-4 scale), obtaining a criticality matrix. The details of this analysis for each risk are provided in Appendix 1 - Operational risks. The synthesis of the main findings is developed in the following sections.

Households tend to display lower consumption than expected while microgrid adoption by productive users is a complex process that requires access to capital and information

Two main types of customers with distinct characteristics are identified for microgrid projects: households (residential customers) and productive users. Four main risks relative to demand from these customers were identified:

- **D1 –** low adoption of the microgrid from household customers,
- **D2 –** low demand from household customers,
- **D3 –** low adoption of the microgrid from productive users,
- **D4 –** low demand from productive users.

Adoption is not a significant challenge for households (D1) as most villagers are interested in being connected. However, most households also limit their consumption to basic energy needs, resulting in low average revenues per user, at least during the first months/years of electricity access (D2). This corresponds to the 'climbing the energy ladder' phenomenon, in which the increase of electricity consumption is a dynamic process. This phenomenon leads to two challenges: first, the limited household consumption is often concentrated to a few hours at night mainly for lighting. Consequently, significant battery capacity is needed to store the electricity generated during the day. In addition, the connection cost is difficult to repay with the limited revenues per connection.

Unlike residential users, productive users display high consumption, mostly during the day, but the adoption process can be more complex, as users must acquire electrical equipment and machines (D3). The development of this customer segment is also limited by the economic activity in the villages targeted. Once adopted, few changes to electricity are expected, but seasonality and economic trends can have an impact on consumption (D4).

LEARNING FROM THE FIELD

The microgrid project visited followed the pattern below:

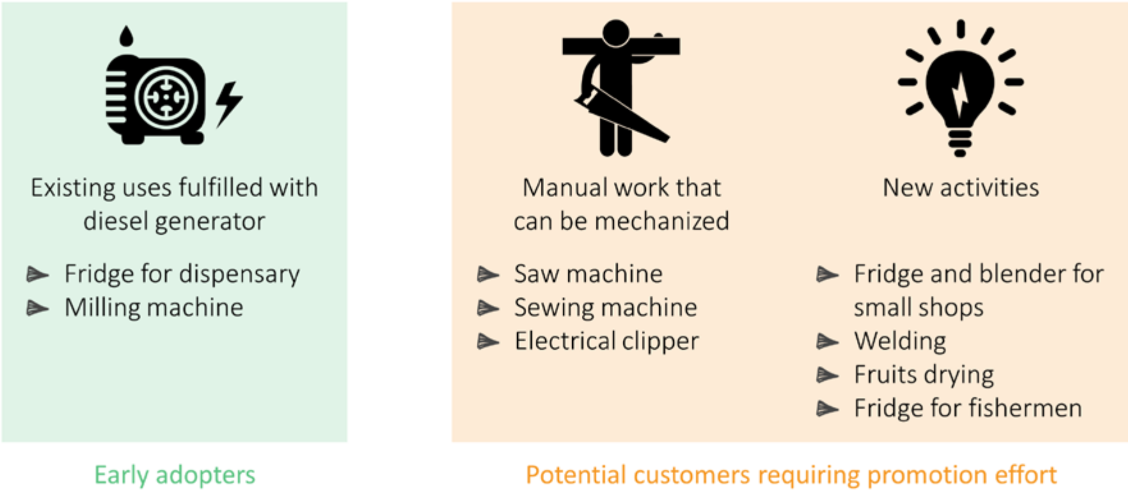
- **Public TV theater and refrigerator for the concession stand,** previously running on diesel and gas respectively, were the first productive users to utilize to electricity see Figure 3;
- **Millers** were very interested in switching to electricity but lacked information on the electrical equipment and its associated costs;
- **Electric clippers for hairdressers** were also adopted thanks to the limited investment required;
- **Carpenters,** who were not using power tools, were interested in electrical tools to ease their work and increase their productivity but were less advanced in their reflections than millers (very limited information);
- **A beverage vendor** (service) showed some interest in new electric activities like a refrigerator for cold beverages and a blender for juice.

Electricity adoption by productive users was slow due to:

- **Lack of information** especially the investment required and financial benefits
- **Lack of capital** to invest in electrical equipment

Figure 3

Electricity adoption among productive users



Productive users running on diesel generators are the first to adopt the microgrid because switching to a different source of power is easier than newly adopting power. The adoption of electric machines to ease manual activities or new activities using electricity generally requires more time and promotion effort from the project developer (D3).

The microgrid customer portfolio consists of all these customer profiles. Understanding the impact of different portfolios on the microgrid utilization rate is important to help the project developer prioritize promotional efforts, including sales, informational support and access to financing.

Collecting frequent but limited payments from a large number of customers is a logistical challenge

Microgrids in developing countries are long-term assets with numerous customers with limited ability to pay for energy. This requires frequent (daily, weekly or monthly) collection of small amounts of money (order of magnitude: 1USD).

Three main revenue collection risks were identified:

- **R1 –** customer default, R2 – late payment,
- **R3 –** electricity theft.

With a post-payment scheme, the project developer is exposed to the risk of delays or defaults in payments (R1 and R2). A Pre-payment scheme can be implemented but may be tedious. Indeed, customers likely have a limited ability to pay and can therefore only pre-pay for a limited number of energy units. Thus, it is important that the project developer handles these small payments and customer top-ups accordingly.

Electricity theft (connection and consumption without agreement and payment) not only affects the revenues, with unpaid electricity, but puts the asset and the people at risk with uncontrolled connections (R3). However, the risk of electricity theft is limited compared to national grid thanks to a reduced extent (easier control) and higher engagement of local populations.

Maintenance issues cause both increased replacement costs and customer dissatisfaction

Microgrids are CAPEX intensive assets with limited OPEX, due to automation. The main cause of expense after commissioning is equipment maintenance and replacement.

Four main equipment ageing/damage risks were identified:

- **O1 –** solar panels,
- **O2 –** batteries,
- **O3 –** distribution lines (direct effect: replacement of the wires),
- **O4 –** distribution lines (indirect effect: dissatisfaction of unserved customers).

Some microgrid components are sensitive to microgrid operation (mainly batteries, O2) and exterior events (distribution lines, O3 and O4; solar panels, O1). Battery maintenance is especially important as poor operation can significantly reduce their lifetime and create significant replacement costs. Vulcan estimates that while batteries represent less than 10% of the initial investment, their maintenance and replacement over the 20- year project lifetime can reach about a third of the initial investment[5] **Bib.2**.

Equipment failure also causes customer dissatisfaction and should be considered in the maintenance plan (O4). Depending on the type of service degradation (limitation of power, limitation of consumption, electricity outage) and its duration, customer satisfaction can be significantly affected. This impact is especially important for productive users, as unreliability could cause losses in their business and prompt them to switch back to their previous power supply (typically diesel generation).

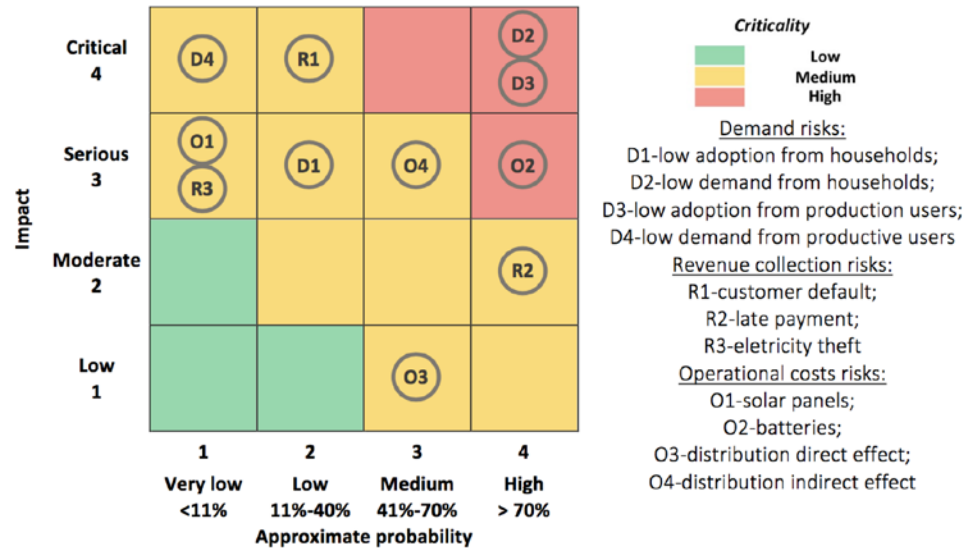
Demand risks are the most critical risks for microgrid businesses

To map the risks mentioned in the previous paragraphs, a probability/impact matrix is used. It enables to visualize the most critical risks that are displayed in the red area on the top right corner of the matrix. Solutions to mitigate these risks should be considered as priorities.

Two demand risks can be identified as critical for microgrid sustainability, namely low adoption from productive users (D3) and low demand from connected households(D2). These phenomena were observed for several microgrids and the

Figure 4

Probability/impact matrix for microgrid operational risks before mitigation strategies implementation



5 Depending highly on the technology chosen, the microgrid characteristics and size and operations.

difference between the expected and actual number of customers and level of consumption can be significant. It highlights the need for careful pre-project planning, with strategies to accurately identify potential customers and quantify their consumption.

Based on a survey of microgrids in Kenya **Bib.5**, the average revenue per user (ARPU) of the top 10 percent of consumers is five-times higher than the remaining 90 percent of customers and generates 40 percent of total revenue. Project developers should thus focus on identifying these customers with a high willingness to pay and connecting them first. The residential customer base can then be extended progressively once a strong customer base has been secured.

In terms of adoption by productive users (D3), as mentioned previously, two main bottlenecks should be highlighted: lack of capital for investment in electrical machines and availability of information about these machines.

The next most important risks are related to equipment failure. Shortened battery lifetime causing frequent replacement usually represents a large part of the costs needed for the microgrid over its lifetime **Bib.2** (O2). Distribution system failure can also lead to customer dissatisfaction due to service breakdown (O4).

Issues with revenues collections were frequently highlighted in past projects in particular with post-payment mechanisms **Bib.4**. Late payments are particularly probable, but they do not affect significantly the model of such long-term assets (R2). Customer default are less probable but impact heavily profitability considering the cost to initially connect a customer (R1).For these critical risks, mitigation strategies can be designed to either reduce their probability or their impact on cash flows. These strategies and their results on risk mitigation are presented in the following chapter. Less critical risk mitigation strategies are presented in Appendix 1 - Operational risks.

Early mitigation strategies alleviate most risks for microgrid projects, with low demand from households and low adoption by productive users the most critical

Mitigation strategies should be planned and implemented before project development to be efficient

The project developer should put a priority on implementing dedicated mitigation strategy to alleviate these six most critical risks (D2, D3, R1, R2, O2 and O4).

The two most critical risks identified are low consumption by household customers (D2) and low adoption by productive users (D3). The project developer should address these risks as early as possible through electricity use promotion.

For households (D2), the project owner should first support customers as they ‘climb the energy ladder’ by helping make electrical appliances affordable and available: it has been highlighted that the main bottleneck is access to appliances rather than the ability to pay for electricity[6] **Bib.5** This challenge was confirmed in the field work interviews. Also, the project owner should prioritize customers able to reach a certain threshold of ARPU (determined by capital expenditures and desired payback period) and customers contributing to a balanced portfolio.

For productive users (D3), projects must address the two bottlenecks identified for adoption: lack of capital and lack of information. The project developer should therefore improve access to capital for productive users and increase their awareness of electrical machines, even before project implementation.

Overall, a balanced portfolio (not relying only on one type of customer) will reduce the impact of low

6 Vulcan has reported that surveys showed that in 44% of the case the limitation was the lack of appliances and the price of these appliances compared to only 17% limited by the ability to pay for electricity.

consumption from one type of customer (D2 and D3).

The development of mobile money greatly simplifies the management of small value transactions and can be applied to microgrid model. As for Solar Home Systems, customers can purchase small energy credits for a few days by phone and repeat the process as needed. This system is called Pay-as-you-go and it works with pre- payment model without the complex management of small top-ups, greatly reducing the risk of revenue collection (R1 and R2).

The risk of battery (O2) degradation should be considered at the design stage. First, the project developer should select relevant technology adapted to its context, taking into account both the initial CAPEX and the lifetime of the equipment and its associated replacement costs. Implementing an energy management system should protect the equipment during peak demand, but it can cause service breakdown for some customers. Globally, the balance of the customer portfolio determines if the asset is at risk. By optimizing the customer portfolio, the project developer can ensure regular demand throughout the day and year, reducing the need for storage capacity without negatively impacting the service provided.

Through a rapid reaction in case of damages to the distribution system (O4), the microgrid owner can limit the time of service breakdown and therefore maintain a high level of satisfaction among its clients.

The likelihood of the identified risks can be greatly reduced with mitigation strategies

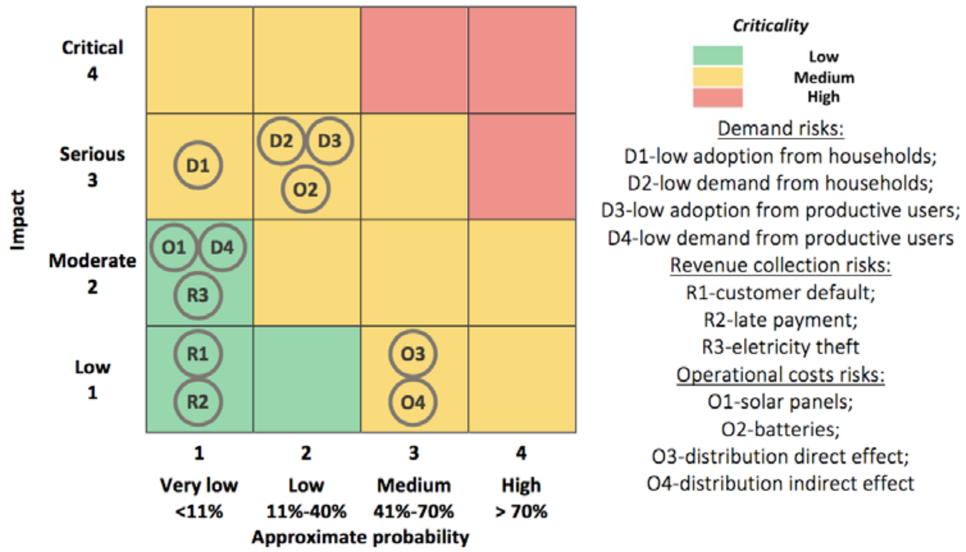
After implementing these various mitigation strategies, either the impact or probability of these risks can be reduced. The situation is presented on the probability/impact matrix in **Figure 5**.

With the mitigation strategies (presented above for the most critical risks and detailed in Appendix 1 - Operational risks), the criticality of most risks can be significantly reduced. Most of these strategies are based on proper design of the microgrid (customers portfolio evaluation, equipment sizing, technology choices), community engagement (evaluation of needs, acceptance of the project, information on opportunities associated to electricity for productive users) and support for the progressive adoption of electricity (by households and productive users). Revenue collection risks are almost nonexistent when pre-paid mobile money (pay-as-you-go) solutions are employed.

These mitigation strategies mainly reduce the probability that a risk will occur. Even with dedicated strategies implemented before project development, the demand risks (D2 and D3) remain serious in the first years. It is expected that on a longer-term basis, their impact will be reduced. The business model of the microgrid project should therefore take these risks into account. The next two chapters highlight these demand risks, focusing on portfolio balance and price structure.

Figure 5

Probability/impact matrix for microgrid operational risks after mitigation strategies implementation



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Demand risk can be mitigated by creating a balanced portfolio

To ensure regular revenues from the project, the potential demand should be as predictable and regular as possible. Indeed, variation of demand can lead to under-utilization of assets, over-utilization of equipment, and reduced life-time, or non-satisfied energy demand. All these effects lead to reduced economic performance of the microgrid.

With a given asset, the project developer attempts to maximize the energy sold, which can be limited by a mismatch between energy generation and demand profiles Bib.7. The matching can be considered on different timesteps:

- **Within each day,** PV production occurs during the day while consumption can be highest at night (especially for household customers Bib.5). In this case, two phenomena lower the amount of energy available to the customers. First, the battery cycle efficiency reduces the energy supply[7] available after storage as some energy is lost during the storage process. In addition, the total storage capacity limits the amount of energy that can be transferred from generation period (day) to consumption period (night)[8].
- **Within each year,** consumption by business customers may be seasonal (such as transformation of agricultural products), and electricity generation is also seasonal due to different sunshine rates. A demand portfolio that follows electricity generation throughout the year would maximize asset utilization and revenues.

The daily load profiles of different portfolios were simulated to evaluate how these profiles correspond to the daytime solar energy generation (see section 2.1 and Appendix 3 - Utilization rates). Modeling steps include:

- **Identify typical customer** categories (households, craft, services, etc.)
- **Define the expected appliances** and corresponding uses for each type of customer
- **Add these consumptions to build** a load profile for each type of customer
- **Build different customer portfolios** by combining these types of customer
- **Evaluate how the portfolio load** profiles correspond with the generation load curve through the utilization rate indicator

7 For 1 Wh generated and stored, only a fraction (80-90%) is supplied by the battery.

8 For 1 Wh generated during the day, if the storage capacity is 0.5 Wh, a part of the energy is wasted if the consumption at the same time is not sufficient.

Seasonality impacts were evaluated qualitatively to understand the medium-term and long-term phenomena that can affect the matching between the generation and the demand (see section 2.2).

The project developer should also take into account other aspects to build a customer portfolio:

- **Number of household customers (including Bottom of the Pyramid[9] customers) –** Ensure that energy access for all is not only a social target but also a way to garner project acceptance by locals and a way to support the economic development of the electrified village.
- **Risk of unpredicted peak demand –** While the consumption associated with many small power appliances can be predicted well (for instance the consumption of lamps at night), it is more difficult to predict the consumption of a few high-power appliances used a few times per day (such as milling or welding machine). An unpredicted peak (for instance several millers processing at the same time) can lead to a power outage, causing customer frustration and damaging the batteries due to fast discharge[10].
- **Number of connections –** The connection process (including hardware, like smart meter and wiring, and manpower) is costly. Limiting the number of connections limits the initial investment and logistical tasks.

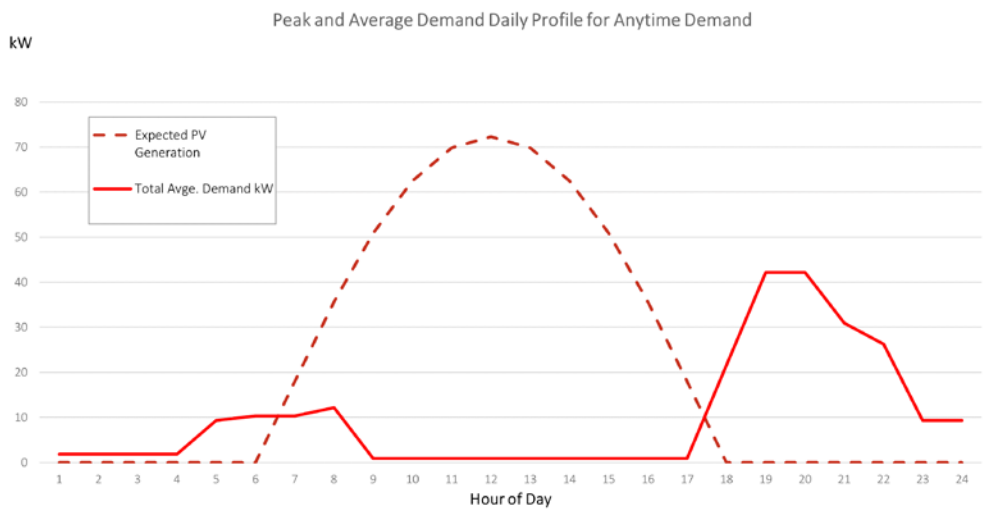
Portfolios with more productive users have a demand curve that is more in-line with generation

Household electricity consumption is concentrated during the evening, unlike electricity generation

The World Bank developed a "tier methodology" which serves as a reference for estimating household energy consumption Bib.8. This methodology classifies distinct types of customers based on multiple criteria (total electric capacity, hours of

Figure 6

Modeling of a 100% Profile A customer portfolio (electricity consumption compared with electricity generation)



9 Bottom of the Pyramid (BoP) refers to the largest but poorest socio-economic group.

10 In the base case, it is considered that there is no control of these high-power appliances peak consumption. To reduce this risk, strategies can be put in place to control these unpredicted peaks. For example, some customers can accept to displace their electrical equipment use in case of overload, potentially against discounted prices.

electricity use, appliances used, etc.) with each tier level corresponding to a set of characteristics (typical consumptions and corresponding appliances are presented in Appendix 2 - Electricity access tier segmentation).

This tier-based approach was adapted to fit the consumption behaviors exhibited by existing microgrids (see Appendix 2 - Electricity access tier segmentation) and the behaviors expected in the Kigoma region. Four profiles are defined, with their corresponding appliances and uses (detailed in Appendix 2 - Electricity access tier segmentation), to represent the potential household customers of a microgrid in Tanzania.

- **Profile A :** use of a phone charger, 1 to 2 small lamps, and a radio, mostly in the evening, corresponding to the first level of electricity use for a microgrid (50 Wh/d, 18 kWh/y);
- **Profile B :** additional use of a small TV and a small ceiling fan mostly in the evening (corresponding to tier 2 in The World Bank, 225 Wh/d, 82 kWh/y);
- **Profile C :** additional limited use of medium-power appliances (food processing, computer) and a higher use of small power appliances, equally distributed throughout the day (500 Wh/, 183 kWh/y);
- **Profile D :** addition of a refrigerator consuming electricity throughout the day (1,500 Wh/d, 550 kWh/y).

To give a reference for comparison, the average electricity consumption of an electrified household in 2014 was 12,305 kWh/y in the United States, 3,600 kWh/y in European Union and 1,432 kWh/y in Tanzania Bib.9.

The four profiles described above all fall between Tier 2 and Tier 4 of the World Bank methodology. Indeed, Tier 1 corresponds to very limited access to electricity and is relevant for solar lamps or small SHS rather than microgrids. At the opposite end, Tier 5 corresponds to very high energy access (including air-conditioners) which relevant for national grid connections rather than microgrids. These two tiers were thus not considered in this study.

The defining feature of household consumption is the concentration of consumption in the evening, especially for profiles A, B and C. This consumption does not match electricity generation and requires significant and costly storage capacity to meet this demand, as displayed in Figure 6 (in line with behaviors reported in literature Bib.1).

Productive uses generally display a demand curve more in-line with PV generation

Productive uses such as small shops, crafts, agricultural product processing, fishing, etc. can represent a significant part of the energy consumption for microgrids. The electricity demand is concentrated during the day for most productive uses. This better fits the electricity generation profile, allowing for higher microgrid utilization. An example of the load curve for 100% craft customers is presented in Figure 7, displaying a better match between generation and consumption.

Figure 8 presents the estimated daily consumption of the different productive users together with the consumption of residential customers.

Considering their consumption patterns, some productive users display shared characteristics :

- **Craft :** high power appliances (0.1 to 10 kW) a few times per day
- **Services :** similar to households (low power appliances, increase at night) with higher consumption
- **Public buildings :** general electricity needs (e.g. light, computer, etc.) for administrative buildings, which can increase sharply if cold appliances (e.g. refrigerator for dispensary) or air-conditioners are added
- **Fishermen :** regular consumption by cold appliances for preservation and storage

Other productive uses that were considered but not mentioned in this analysis include : telecom towers and irrigation. These uses have not been included as they are very site specific. As their impact on electricity consumption is very significant[11], the potential for these applications should be specifically studied in the context of the micro-grid location. Larger industrial units were also not considered in this analysis as case specific.

Figure 7

Modelling of a 100% craft customer portfolio (electricity consumption compared with electricity generation)

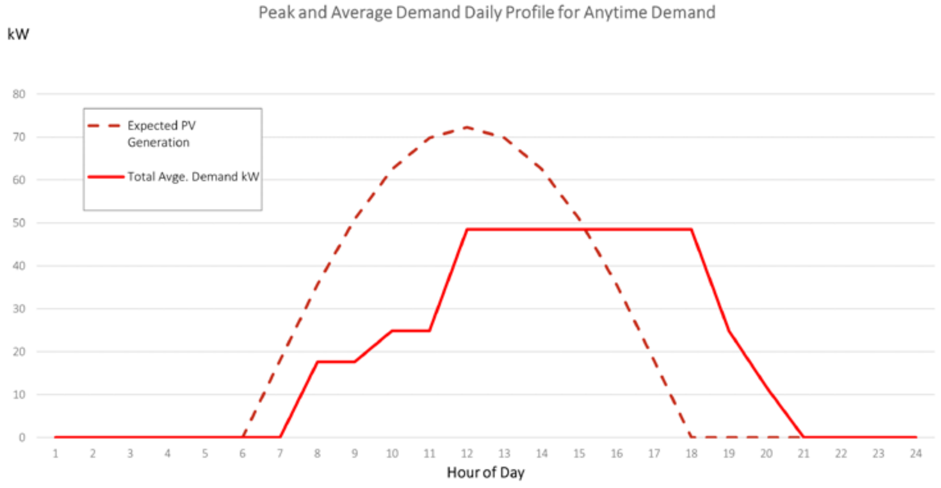
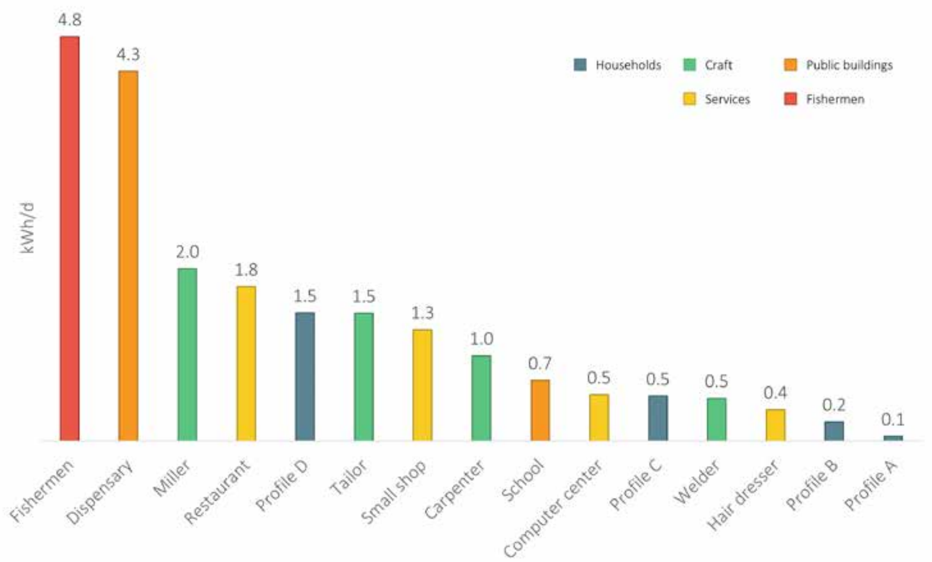


Figure 8

Expected daily electricity consumption per customer profile



11 These two uses can be considered as anchor as they provide a constant, predictable and important consumption throughout the day

A significant share of productive use leads to higher asset utilization

Four standard portfolios were designed to study their characteristics and determine which portfolio best ensures steady cash flows. These portfolios are based on the observed portfolios of actual microgrids and typical socio-economic parameters that are expected for Tanzanian villages (types of productive uses, number of businesses, etc.). The composition of these standard portfolios in terms of number of energy demand (left bars) and number of connections (right bars) is displayed in Figure 9.

The portfolios range from mainly household customers in portfolio 1 (where households represent 80% of energy consumed) to mainly productive users in portfolio 4 (where productive users represent 83% of energy consumed). 98% of customers connected to the microgrid are households in portfolio 1, whereas they only represent 69% in portfolio 4.

Due to better overlap between demand and generation curves, portfolios with more productive users have higher asset utilization rates. The simulation process used to calculate these utilization rates and the detailed analyses are provided in Appendix 3 - Utilization rates. The results are summarized in Table.

Figure 9

Portfolio compositions by share of the total electricity demand (left bars) and share of total number of connections (right bars) for each customer profile

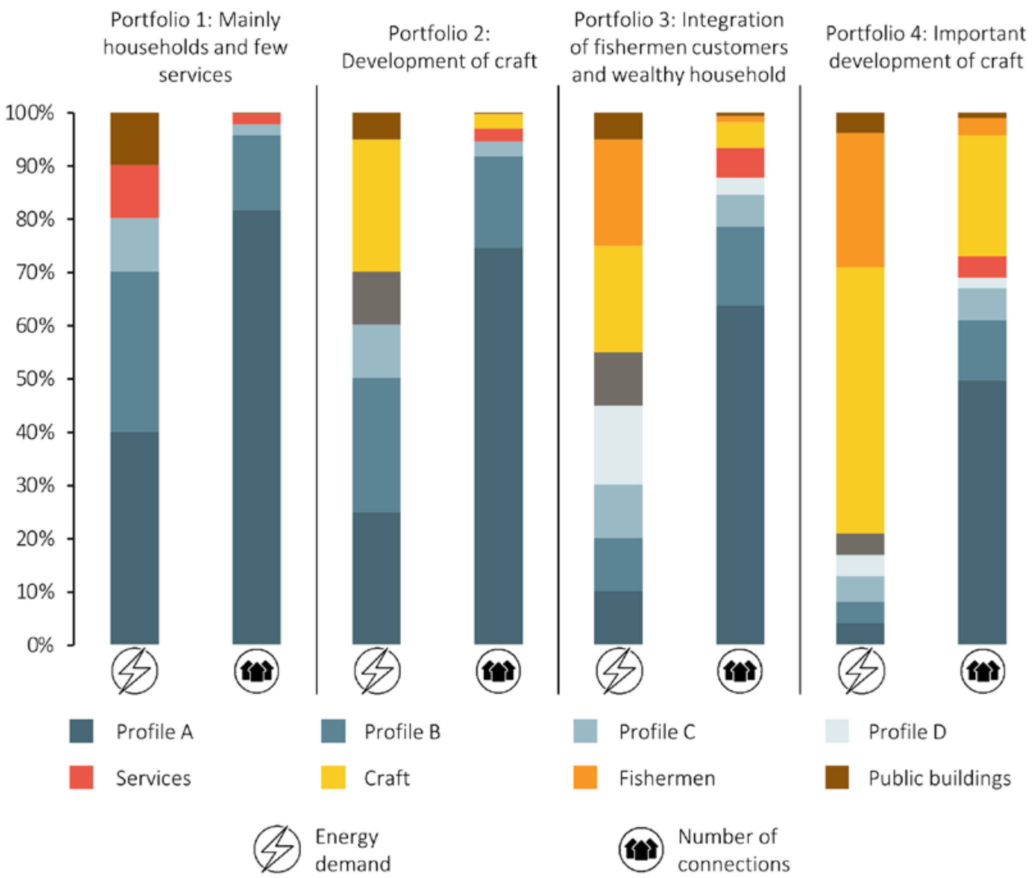


Table 1

Asset utilization rates for different customer portfolio balances

	Portfolio 1: Mainly households and few services	Portfolio 2: Development of craft	Portfolio 3: Integration of fishermen customers and wealthy households	Portfolio 4: Important development of craft
Asset utilization rate	48 %	57 %	61 %	78 %

The different utilization rates between the portfolios shows how the inclusion of productive users helps balance

the consumption and obtain better overlap between demand and generation:

- **Portfolio 1 –** Mainly composed of households, the mismatch between demand and generation is high resulting in low utilization rate.
- **Portfolio 2 –** The inclusion of craft users with significant consumption during the day ensures better matching between the demand and generation curves.
- **Portfolio 3 –** Fishermen with refrigeration needs have constant consumption throughout the day, and wealthier households tend to also have consumption more equally spread throughout the day compared to Profile A and B.
- **Portfolio 4 –** By significantly increasing the number of craft customers, the project developer increases consumption throughout the day and therefore the utilization rate.

Seasonality can be a risk or opportunity depending on the timing of consumption and production seasonality

Seasonality also has an important effect on the characteristics of a microgrid and its associated risks as it can affect both electricity consumption and generation.

The effect on electricity generation is directly linked to sun exposure. Generation is reduced during the rainy season and reaches its maximum during the dry season. To generate sufficient electricity to meet demand, the maximum number of customers should be constrained by the reduced generation level during cloudy days (leading to underutilization of the microgrid during sunny days)[12]. For example, with a standard 100 kWp microgrid (see Appendix 3 - Table), generation is expected to be 545 kWh on a cloudy day but 695 kWh on a sunny day.

Also, electricity usage fluctuates widely due to several factors such as holidays and seasons Bib.5.

12 In the base case, the maximal number of customers is constrained by the least sunny days. It is possible for the microgrid operator to put in place some incentives to reduce consumption during cloudy days. This way more customers can be connected taking advantage of increased production during sunny days and being able to manage a reduced demand during cloudy days.

Seasonal economic activities, especially those related to agriculture and fishing, significantly reduce their energy demand during their low season. The impact of seasonality on demand depends on the crop types (maize harvested during two seasons while cassava and irrigated rice harvested all year long) and processing patterns (crops processed directly after harvesting or stored and processed on a longer period depending on demand). Project developers should limit their exposure to customers that are directly tied to seasonality.

Household consumption is less sensitive to seasonality. However, seasons can still affect the households' disposable income and thus their ability to pay for electricity. Temperature (for fan or AC) and daylight (for artificial lighting) also impact the electricity consumption of households and small shops.

If seasonality for generation matches seasonality for consumption, i.e. if electricity demand is higher during the sunny season, then seasonality can be an opportunity to earn more profit as the extra generation will be consumed by the increased activities. On the contrary, if electricity demand is higher during the rainy season and lower during the sunny months, it greatly limits the utilization rate of the microgrid. The potential impacts of seasonality must be assessed on the actual activities and solar yield of each site.

Minimizing risks while maximizing grid utilization throughout the year can be achieved through a balanced portfolio of households and business customers

The target customer portfolio should be balanced between different characteristics. Table compares each of the hypothetical customer portfolios served by a system having fixed assumed specifications (other than the number of customer connections which varies per portfolio)[13].

- Portfolio 1 is largely under-optimized and should not be targeted (see Figure 13). Indeed, the focus on household customers leads to two negative effects. First, these customers consume electricity mainly in the evening, leading to underutilization of the electricity generated due to limited storage capacity. Second, this portfolio requires a significant investment in distribution (lines and meters) for customers with limited consumption.
- Portfolio 4 shows the importance of developing productive uses to better utilize the electricity generated. It also reveals two potential limits of this focus on productive uses. First, the limited number of households connected[15] would likely cause problems concerning the acceptance of the project by the local population and authorities. In addition, the importance of craft, which uses high-power appliances, has a higher risk of unpredicted peaks, which can result in power outages and battery damages. This aspect can be managed through diversification of the business customer portfolio and dedicated demand management strategies to ensure that the consumption of these business customers is well distributed throughout the day and the year. This portfolio is also very ambitious regarding the number of business customers connected, which can be limited by the economic development of the village.
- Portfolios 2 and 3 are more balanced and realistic. The importance of productive users linked to agriculture for Portfolio 2 and fishing for Portfolio 3 highlights the need to accurately understand these users and estimate their electricity demand and consumption patterns (daily and seasonal). A balance should be found between connecting a sufficient number of household customers to reach the energy access objective of the project and focusing on business customers to reduce aggregate connection costs due to higher average consumption per customer. In some cases, low

13 A 100 kWp microgrid with 350 kWh storage was modeled and the amount of electricity that can be supplied, according to the different portfolio load curves, was evaluated (see Appendix 3 - Utilization rates) for modeling hypotheses and detailed analysis).

15 For a given asset, at maximal grid utilization, increasing the share of productive user customers means reducing the number of household customers

consumption households (profile A) may be served more efficiently with smaller solutions such as solar home systems in the first years while they climb the energy ladder. These households represent potential new customers for the microgrid later on as they increase their electricity consumption.

The main limitation of this analysis is the static evaluation of the long-term optimization once the micro-grid reaches its maximum capacity. In practice, this evolution is dynamic and the micro-grid saturation will be reached only after years. The customer portfolio can evolve greatly during this dynamic process. The purpose of this analysis is to demonstrate the importance of targeting productive users and why sites with strong economic activities should be targeted Bib.5.

As described above, some customer portfolios improve demand predictability and regularity, as well as the amount of energy consumed. Cash flows generated by the microgrid depend first on the volume of energy consumed, and second on electricity prices. These prices should ensure the project's financial viability and can be used to limit the impact of demand variations, but they must also be accepted by the local population.

Table 2

Portfolio qualification

Customer portfolio	Portfolio 1: Mainly households and few services	Portfolio 2: Development of craft	Portfolio 3: Integration of fishermen customers and wealthy households	Portfolio 4: Important development of craft
Amount of energy sold (kWh/d) and utilization rate	260 (48%)	310 (57%)	335 (61%)	425 (78%)
Risk with seasonality	Constant consumption	Matching of generation and demand seasonality to be studied		
Number of household customers served14 (incl. BoP customers)	2,450 (2,000)	1,900 (1,500)	900 (650)	450 (350)
Risk of unpredicted peak demand	Low	Medium	Medium	High
Number of connections	2,481	2,030	1,024	668

14 For a given asset, at maximal grid utilization, increasing the share of productive user customers means reducing the number of household customers

3

Price structure can be used to hedge the risk of unsteady cash flows

Pricing is a complicated topic for project developers as price level and structure pursue four potentially conflicting objectives:

- **Comply with customer willingness** to pay and be socially accepted;
- **Incentivize higher consumption and consumption** during the right periods to maximize asset utilization;
- **Cover the costs** (CAPEX and OPEX) of the project owner to ensure financial viability;
- **Comply with the pricing** regulations[16].

Electricity prices should reflect customer willingness to pay and be accepted by the community

Proper pricing strategy is a way to reach targeted revenues at the highest confidence level. They can be designed so that customers pay in accordance with their disposable income and willingness to pay. Customers' willingness to pay depends on the service provided (phone charging, lighting, TV, etc.). For instance, prior to grid connection, customers were reported to pay an equivalent of $40/kWh for phone charging[17]. Vulcan Impact Investing Bib.5 highlighted that rural customers were willing and able to pay for electricity at prices as high as USD $4.00 / kWh (unsubsidized). Customer willingness to pay declines as energy consumption increases for "comfort appliances" (TV, fridge).

Electricity prices must remain socially (and politically) acceptable. Microgrids operate as legal or de facto monopolies, meaning that the microgrid operators are price makers. Consequently, if prices seem too high to the regulatory bodies, it could be challenged and regulated to prevent citizens from paying too much for their electricity. After commissioning, project developers could be forced to adopt prices that do not cover their cost of service and capital, putting the project at risk.

The price-elasticity of energy demand measures how responsive household electricity consumption is to changes in the electricity price Bib.10 & 11. It shows how much the project developer can change prices without impacting demand. Studies showed that price-elasticity of energy demand is almost non-existent in Tanzania off-grid areas Bib.10, contrary to what was shown at country level. That is, based on the limited evidence available[18], low volume consumers are not likely to change their electricity consumption due to a price increase (or decrease) in the short run. This means that price variations such as season or time-of- use dependent prices may not be as effective as expected in the broader Tanzanian context.

16 Regulation is not considered here as depending on the country context.
17 Interview
18 Only one paper studied price-elasticity of Tanzania off-grid area
19 In Pay-as-you-go solutions for microgrids, customers prepay via mobile money for energy packages of a defined number of units. They can then use those units whenever they want, usually with an Energy Day Allowance (EDA) limiting the number of units to be consumed in a single day.

Existing service models show that it is difficult to balance steady cash flows and customer satisfaction

Microgrid developers work with various service models Bib.12, such as:

- **Capacity and/or daily quantity limited model –** The customer has access to a set amount of power (kW) via a flat-rate or subscription fee. A load limiter ensures that the customer does not exceed the set maximum power and a smart meter ensures that the customer does not exceed the energy-day- allowance (EDA)
- **Consumption based model –** The customer pays per unit of energy consumed (kWh) (requires a metering device). Customer charges can be adapted (decrease in kWh as consumption grows, price increase during peak hours, etc.)
- **Price per device –** The customer pays per number and type of devices
- **Energy as a service –** Energy is sold as a service based on the number of hours of charging, number of printouts / copies, lumen-hours, etc.

In East Africa, all interviewed project developers used capacity-based or consumption-based models, mostly in the form of a monthly flat fee or pay-as-you-go[19]. In these projects, all customers prepaid for energy. Therefore, only the pros/cons and induced risks of these models were analyzed in Table.

At this stage, it is unclear which service model is most advantageous. The next section will study which price structure makes cash flows most resilient to demand variations.

Table 3

Pros and cons, and induced risks of selected price structures

Service model	Capacity-based price (flat fee)	Per kWh price		
		Fixed whatever the consumption	Decreasing with volume consumed	Increasing with volume consumed
Pros	Easy customer education Easy to bill Very predictable cash flows, linked with number of connections	Easy customer education	Consistent with customer willingness to pay	Cross-subsidies among customers: easy and affordable for low income consumers (easier to reach bottom of pyramid)
Cons	Customers are not satisfied if they consume less than their EDA Difficult demand prediction	Customers can stop consuming without prior notice	Project developer underlined that margins shrink as revenues grow Bib.5	Need significant customer education to gain acceptance of wealthier and larger customers
Incentives and induced risks	Limited incentive for energy efficiency Could discourage productive use as customers do not pay for exactly what they are consuming	High volatility risk, difficult to apply for households consuming less energy (would need to charge high price per kWh to achieve equivalent revenues)	Incentivizes energy efficiency Encourages productive uses	Could discourage productive use and more demand growth in the long term

A monthly flat fee combined with a limited unit price is the most effective price structure to limit cash flow variations and ensure customer satisfaction

To assess which one of the above-mentioned price structure makes cash flows most resilient to variation in demand, project cash flows under four scenarios were compared to cash flows in the reference scenario.

The selected reference portfolio is "Portfolio 2: Development of craft" (as described in Figure 10), used to simulate cash flows of a 100 kW microgrid project Initial investments (CAPEX) and operational costs (OPEX) are considered fixed, as if the project has already been commissioned and the project developer must choose between various service models.

Cash flows generated by the reference portfolio and the associated Project Net Present Value[21] (NPV) are calculated for five different price structures. A further description of those price structures is available in Appendix 5 - Price structures used. Price levels were defined so that the reference scenario's NPV is the same for all five price structures:

- **Price structure 1 –** A monthly flat fee
- **Price structure 2 –** kWh price is fixed independent of the volume of electricity consumed
- **Price structure 3 –** kWh price decreases with consumption
- **Price structure 4 –** kWh price increases with consumption
- **Price structure 5 –** Combined monthly flat fee and fixed per kWh price

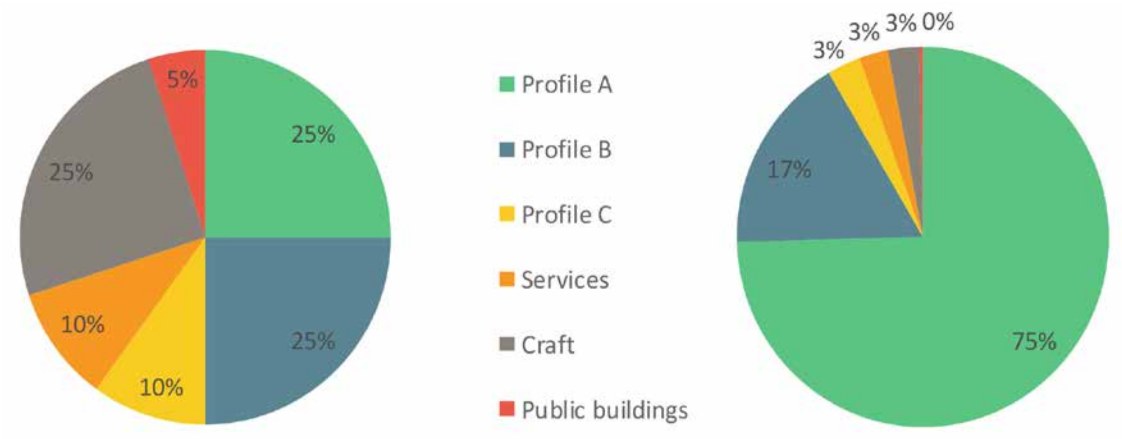
Upfront costs paid by customers to be connected is defined as USD 15[22], based on existing upfront costs communicated by project developers. More information is available in Appendix 1 - Connection costs.

The robustness of the service model is then evaluated by examining the effect of a 30% reduction in demand on cash flows and project NPV. This reduction in demand was simulated with four variations on the reference scenario:

Energy consumed: 310 kWh/day
Number of connections: 2030 [20]

Figure 10

Left – Distribution of energy consumed per customer type
Right – Distribution of number of connections per customer type



20 As not all customers are connected on day 1, the simulations take into account demand growth rates of 16% for the first 5 years and 2.5% afterwards until the portfolio reaches its final size. Portfolio composition in terms of the share of total electricity demand and the share of the number of connections for each customer profile remains the same during the project entire life (e.g. profile A continuously represents 75% of connections and 25% of energy consumed).

21 Net present value (NPV) is a method of determining the current value of all future cash flows generated by a project after accounting for the initial capital investment.

- **Variation 1 :** Only 30% of the number of expected productive users are connected (leading to 81 fewer connections and a 30% decrease in demand). This corresponds to risk D3 (low adoption from productive users) shown in Chapter 1
- **Variation 2 :** The number of connections remains the same (2,030 connections) but with the proportions of portfolio 1 (households A represent 82% of connections and 40% of total energy consumed)[23]. This corresponds to risks D2 (low demand from households) and D3 (low adoption from productive users)
- **Variation 3 :** The number of connections stays the same, but each customer type consumes on average 30% less than expected (demand reduction is uniformly split among customers). This corresponds to risks D2 (low demand from households) and D4 (low demand from productive users)
- **Variation 4 :** 60% fewer than expected households are connected (i.e. 880 connections instead of 2,030). This corresponds to risk D1 (low adoption from households)

From interviews conducted, variations 1 and 2 are the most likely to occur. They reflect a mismatch between the forecasted and real consumption, either due to fewer productive users (variation 1) or a lower average household demand (variation 2). Variation 4 is the least likely to occur, as project developers report that residential customers have a strong desire to be connected to their microgrids.

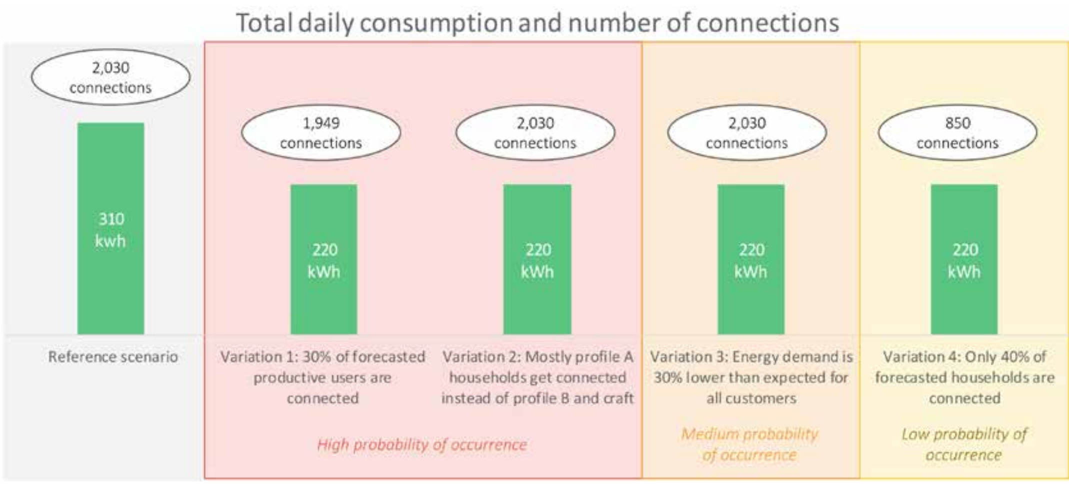
Total consumption, number of customers and probability of each variation are summarized in **Figure 11**.

For each variation and for each price structure, cash flows were modeled and the associated NPV was calculated. For each variation, the NPV reduction compared to the reference variation is shown in **Figure 12**.

The monthly flat fee service model (price structure 1) is the most robust as it is not linked to energy consumption but only to the number of connections. This is consistent with earlier studies that highlight that the fixed monthly fee is usually the

Figure 11

Overall energy consumption, associated number of customer and probability of each variation

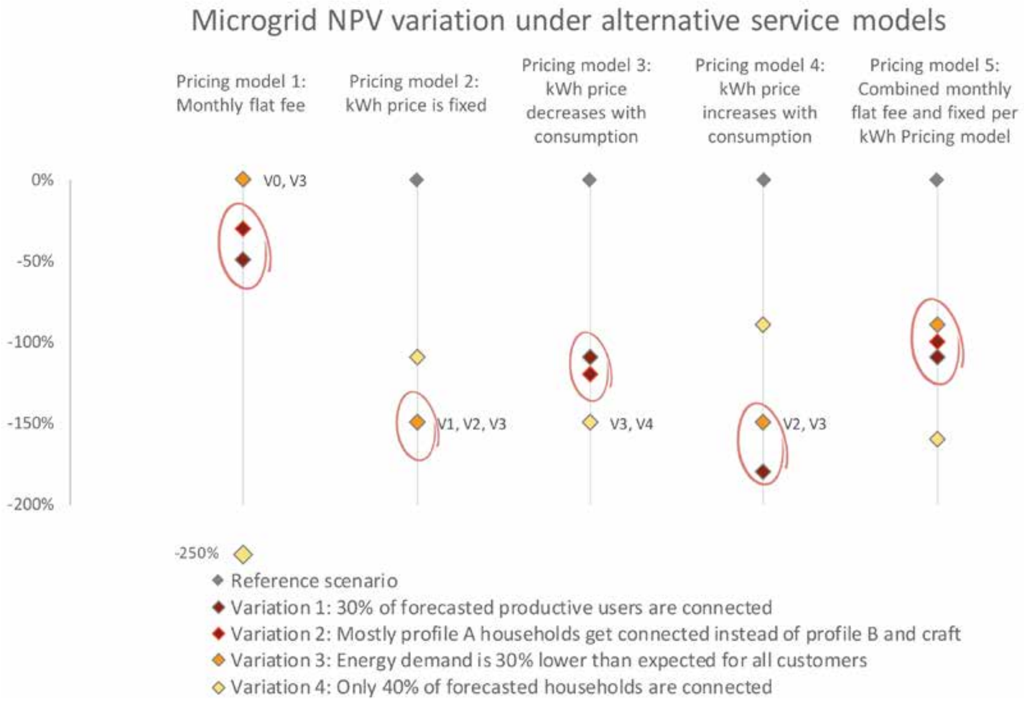


22 This does not cover all the costs linked with the connection of a new customer (meter, wiring, etc.). It is assumed that project developers integrate this full cost to their service model.

23 Instead of some productive users and higher energy demand households (profile B) as planned, mostly profile A household with very limited consumption get connected

Figure 12

Microgrid NPV variation under various service models



most suitable to the cost structure of microgrids, which consists mainly of fixed costs Bib.13. However, monthly flat fees leave customers unsatisfied as they do not offer the flexibility customers need to modulate their demand.

Per kWh pricing (price structures 2, 3 and 4) result in significant cash flow variations, even though they enable customers to pay only for the electricity they consume. The most resilient per kWh price structure is a price that decreases with the amount of energy consumed (price structure 3): households pay more per kWh, thus hedging the risk of demand reduction caused by productive users and making cash flows less sensitive to productive users' demand.

As shown in the NPV variation of the fixed per kWh price (price structure 2), cash flows are more impacted by a reduction in demand without reduction in number of connections (- 150%, variation 1,2,3), than by a 60% reduction in household customers (V4, - 110%). This is explained by the cost reduction induced by the lower number of connections (around 900 instead of 2,000, see Figure 11). This reinforces the need for project developers to recruit "good customers."

Subsidizing households by making productive users pay more for their electricity (price structure 4) is very sensitive to the consumption of productive users. Unless the project developer has secured an agreement with productive users for the quantity of energy they will consume, this price structure should not be adopted.

A combination of a monthly flat fee and unit price (price structure 5) appears to be the most suitable service model to both ensure customer satisfaction and limit the impact of energy demand reduction on revenues. While this price structure shows the same sensitivity to reduced demand by productive users (V1, - 110%), it is less sensitive to the other variations (2 and 3) in which demand is reduced.

This analysis has two main limitations: only four variations of demand reduction were modeled. Many more could occur and lead to different results. This analysis could be reproduced for a specific project by adapting the most likely demand variations for that project. Also, each price structure can be defined to make a microgrid project financially viable. The social acceptability of each price structure has not been considered here as the purpose of the analysis was to study cash flows variations.

APPENDIX 1
Operational risks

Demand risks

Low adoption of micro-grid from household customer

Risk definition: this risk corresponds to the potential overestimation of the number of customers that will be connected compared to actual results, as it is difficult to estimate the potential adoption of a new service such as electricity. The associated revenues are therefore reduced.

Probability: low, as potential customers are very interested in being connected, but they do wait for early adopters' feedback to be confident in the benefits provided by the microgrid.

Impact: serious, as revenues can be significantly reduced but lower than the impact of connecting a "bad" customer consuming very low energy for which expenses are engaged (wiring, meter).

Mitigation strategy: Realistic evaluation of potential customers as well as pre-construction promotion effort enable to ensure good matching between planned and actual customer number.

Getting "good customers" (high ability to pay, high consumption) and getting "many customers" tend to be competing forces and due to the important connection cost, the former should be prioritized in the first months of operations. Operators should not connect as many customers as possible without making sure they are able to pay for the service.

Table 4

Low consumption from household customers risk evaluation

	Probability	Impact
Before risk mitigation strategy	*Low*	*Serious*
After mitigation strategy	*Very low*	*Serious*

Demand risks

Low demand from household customers

Risk definition: it is commonly seen that "customers tend to overestimate how much electricity they need" resulting in an actual consumption that is lower than expected [2]. The fact that households will "climb the energy ladder" progressively should be expected, with limited consumption in the first months/years (light, mobile charging).

Probability: high, as seen in numerous cases of microgrid development, especially during the first months/years of operations

Impact: critical, as the connection cost engaged is unbalanced with the limited revenues generated.

Mitigation strategy: connecting customers with sufficient demand from the start through realistic evaluation of willingness to pay; focusing commercial efforts on these customers and accelerating the transition toward higher demand for other customers. Partnerships with local shops and MFI can support the acquisition of medium consumption appliances (TV, fridge, fan). Indeed, the ability to get appliances is the main barrier to increased electricity consumption before ability to pay **Bib.5**.

Diversification of the customer portfolio, including productive users, is a way to reduce the impact of a reduced demanded from household.

Table 5

Low consumption from household customers risk evaluation

	Probability	Impact
Before risk mitigation strategy	*High*	*Critical*
After mitigation strategy	*Low*	*Serious*

Demand risks

Low adoption from productive users

Risk definition: for productive users, the adoption of electrical appliances can be uncertain due to limited equipment information (price, benefits) and limited investment capacity.

Probability: high, as seen in numerous cases of microgrid development, especially for the mechanization of manual tasks and the development of new activities (see Figure 3)

Impact: critical, as productive users are expected to represent a significant share of the consumption (e.g. 40% for Portfolio 2), enable to reach higher utilization rate (see 2.1.2) and display high consumption for a single connection (limited cost for high revenues)[24].

Mitigation strategy: address the two bottlenecks for adoption by productive users: lack of capital and lack of information. It is crucial that the project developer (or her partners) provide productive users with the relevant information regarding electrical equipment (potential costs, economic balance, advantages of electrical equipment) to ensure that this aspect is not a limitation. The project owner should also facilitate access to capital for productive users so that they can invest in new equipment.

These two strategies should be implemented as early as possible, ideally several months before the project starts so that productive users are prepared and can switch to electricity soon after the microgrid development. Diversification of the customer portfolio, serving not only on productive users but also on households, is a way to reduce the impact of a reduced demanded from household.

Table 6

Low adoption from productive users risk evaluation

	Probability	Impact
Before risk mitigation strategy	*High*	*Critical*
After mitigation strategy	*Low*	*Serious*

24 Except if located far from the microgrid area, resulting in higher distribution costs

Demand risks

Low demand from productive users

Risk definition: it is unlikely that productive users will reduce their consumption intentionally (considering the potential benefits from electricity) but some external factors (meteorological, economic) can affect their consumption. A severe drought for example can reduce milling (and electricity consumption) but should not be a long-term problem. On a long-term basis, the slowdown of an economic activity, for example due to the decreasing availability of a resource (fish, wood, etc.) can lead to decreased electricity consumption and is difficult to control and avoid.

Probability: low, as there is no reason for productive users to limit their consumption (high initial investment, productivity gains or reduced expenses in diesel) unless a clear external factor that affects economic activity is identified as likely to happen.

Impact: critical, as productive users are expected to represent a significant share of the consumption (e.g. 40% for Portfolio 2), enable to reach higher utilization rate (see 2.1.2) and display high consumption for a single connection (limited cost for high revenues)[25].

Mitigation strategy: diversification of the productive users' portfolio reduces project sensitivity to any specific sector. Potential impact factors (evolution of agricultural activity, reduction of one resources) should also be assessed before project development to evaluate the long-term risks

Table 7

Low consumption from productive users risk evaluation

	Probability	Impact
Before risk mitigation strategy	*Very low*	*Critical*
After mitigation strategy	*Very low*	*Moderate*

25 Except if located far from the microgrid area, resulting in higher distribution costs

Revenue collection risks

Customer payment delay and default

Risk definition: revenue collection has been often highlighted as one of the main issues in microgrid operations as it can require a significant workforce and potentially lead to customer default **Bib.4**.

Probability: medium for delayed payment and low for customer default when the price was set in accordance with the ability to pay of customers.

Impact: moderate for delayed payment as microgrids are long-term assets but high for default customer.

Mitigation strategy: Implementation of pay-as-you-go with mobile money solutions solves revenue collection issue as the consumption credits are prepaid[26].

Table 8

Customer delayed payment or default risk evaluation

	Probability	**Impact**
Before risk mitigation strategy	*Delayed : medium* *Default : low*	*Delayed : moderate* *Default : serious*
After mitigation strategy	*Delayed or default : very low*	*Delayed or default : low*

Revenue collection risks

Electricity theft

Risk definition: electricity theft can occur in a rural microgrid through a direct link to distribution lines. In addition to unpaid electricity, risks include safety issues related to uncontrolled wiring, damages to the distribution lines, uncontrolled consumption leading to battery damage, etc.

Probability: very low, as the limited scale of the microgrid makes it easy to control (compared to national grid)

Impact: serious, as the theft causes revenue loss and puts the inhabitants and the asset at risk.

Mitigation strategy: electricity theft can be avoided by community engagement through clear explanations of the price structure (to limit disagreement with the price) and of electricity theft impact on the community. If electricity theft still occurs, it can be detected, either visually or through data monitoring, and acted on.

Table 9

Electricity theft risk evaluation

	Probability	Impact
Before risk mitigation strategy	*Very low*	*Serious*
After mitigation strategy	*Very low*	*Serious*

System risks

The cost of equipment damage is either directly borne by the project owner or covered by an insurance mechanism. In either case, it is a cost for the project owner and proper mitigation strategies can either reduce the direct cost of these risks (by reducing the probability of occurrence or the impact) or reduce the insurance fee thanks to lower perceived risk.

Solar panels

Risk definition: there are few reasons for degradation of solar panel during normal operations (25 to 30 years lifetime) but they are subject to damage by external events (storms, vandalism). Poor upkeep and cleaning procedures can also lead to faster degradation.

Probability: low, as the occurrence of events damaging the unit (storms, vandalism) is limited.

Impact: serious, as solar panels account for around 20% of the initial investment Bib.7. However, it is still expected that the cost of solar panel will continue to decrease in the coming decade, lowering the potential replacement costs.

Mitigation strategy: a limited solution (design with avoidance of potential threat such as trees and rocks) can be implemented to mitigate impact of meteorological events. Vandalism can be limited by community engagement (inclusion in price setting, hiring of local staff). In terms of upkeeping, detailed procedures should be implemented to ensure maximal lifetime of the panels. Data analysis can support the detection of potential degradation of the equipment and could be used to establish predictive maintenance programs to limit the associated costs.

Table 10
Solar panel failure risk evaluation

	Probability	Impact
Before risk mitigation strategy	*Very low*	*Serious*
After mitigation strategy	*Very low*	*Moderate*

System risks

Batteries

Risk definition: of all microgrid components, batteries are the most susceptible to ageing (around 2-6 years lifetime for lead acid batteries Bib.14), especially under poor operation and misuse. There are two main causes of battery degradation: discharge is too deep due to mismatch between demand and production (bad design of the microgrid compared to demand, for example consumption at night higher than expected) and high peak demand leading to overly rapid discharge (caused by simultaneous use of high power appliances, for example). This phenomenon can be limited by the system controller but then also limits the electricity delivered to customers. Depending on the technology, climate can also have an impact on batteries' lifetime, with higher temperatures leading to shorter lifetime.

Probability: high, as batteries are highly stressed during microgrid operations, especially if consumption at night is significant.

Impact: serious, as the lifetime can be significantly shortened by misuse leading to frequent and costly replacement (accounting for 40% of the global maintenance cost with normal operations) Bib.2.

Mitigation strategy: energy management systems (EMS) are designed to control electricity supply and avoid damages to the storage system. However, when the demand is too high and the system is at risk, the EMS will limit the energy supply and therefore not satisfy all of the energy demand, which can lead to customer dissatisfaction. This dissatisfaction can be mitigated by creating incentives to displace night consumption during more favorable time (e.g. lower price for productive users at midday). Customers that are willing to limit their consumption for a certain period can also receive a discounted price for this flexibility. The effect of such incentives on the demand profile is limited for household customers (demand at specific time, low consumption and low price elasticity) but can be more influential on some productive users (significant consumption).

Remote monitoring of the battery indicators is also critical for management and replacement. Battery technology should be selected based on the customer portfolio and the context of the microgrid (climate, accessibility). Battery choice should consider not only initial costs but also the maintenance costs, the lifetime, and the availability of the technologies locally.

Table 11

Batteries failure risk evaluation

	Probability	Impact
Before risk mitigation strategy	*High*	*Serious*
After mitigation strategy	*Low*	*Serious*

System risks

Distribution system

Risk definition: the distribution line system can be damaged due to external events, leading to replacement costs and more importantly, interruption of service that can reduce customer satisfaction and demand (customers switch back to other energy sources, fewer new customers) especially those requiring a secured supply of electricity (e.g. refrigerator for dispensary or fishermen, telecom tower, etc.).

Probability: medium due to the large footprint of the distribution system[27]

Impact: low for the replacement cost (direct effect) which is expected to be limited as only a part of the network might be affected; serious for the customer dissatisfaction (indirect effect) as it affects the long-term demand for electricity.

Mitigation strategy: preventive maintenance, monitoring, and rapid intervention can limit customer dissatisfaction.

Table 12

Distribution system failure risk evaluation

	Probability	Impact
Before risk mitigation strategy	*Medium*	*Replacement cost (direct): Low* *Customer dissatisfaction (indirect): Serious*
After mitigation strategy	*Medium*	*Replacement cost (direct): Low* *Customer dissatisfaction (indirect): Low*

27 The less dense a microgrid is, the more this risk increases

APPENDIX 2
Electricity access tier segmentation

Table 13

Indicative Calculation of Annual Electricity Consumption, by tier Bib.8

Appliances	Watt equivalent per init	Hours per day	Minimum annual consumption in kWh				
			Tier 1	*Tier 2*	*Tier 3*	*Tier 4*	*Tier 5*
Task lighting	1/2	4/8	1,5	2,9	2,9	5,8	5,8
Phone charging	2	2/4	1,5	2,9	2,9	2,9	2,9
Radio	2/4	2.4	1,5	5,8	5,8	5,8	5,8
General lighting	12	4/8/12		17,5	17,5	35,0	52,5
Air circulation	20/40	4/6/12/18		29,2	87,6	175,2	262,8
Television	20/40	2		14,6	29,2	29,2	29,2
Food processing	200	0,5			36,5	36,5	36,5
Washing machine	500	1			182,5	182,5	182,5
Refrigerator	300	6				657,0	657,0
Iron	1,100	0,3				120,5	120,5
Air conditioner	1,500	3					1,642,5
Total			4,5	73		1,250	3,000

Table 14

Definition of household customers profiles

	Households – Level of energy consumption			
Appliances	A	B	C	D
Phone charger				
Light - CFL or tube light				
Radio				
Television - LCD				
Ceiling fan				
Computer				
Food processing (blender, etc.)				
Fridge				
Corresponding daily consumption (Wh)	50	225	500	1,500
Corresponding yearly consumption (kWh)	18	82	183	550

APPENDIX 3
Utilization rates

Approach to modeling various portfolio loads

To simulate microgrid behavior across different customer portfolios, a model was used to achieve the best match between generation, storage, and demand. The EscoBox tool was developed by De Montfort and Cranfield universities to enable the optimization and the good design of microgrids **Bib.15**.

The logic of this simulation is to fix the design characteristics of the microgrid and see how it behaves with different customer portfolios[28]. Based on existing microgrids in Sub-Saharan Africa, the chosen microgrid parameters are presented in Table :

Table 15

Microgrid model characteristics

- PV installed capacity: 100 kWp
- Inverter capacity: 100 kW

- Battery type: lead-acid[29]
- Total storage capacity: 350 kWh
- Cycle efficiency: 0.8
- Maximal use of batteries[30]: no degradation of battery life

- No genset[31]

- Latitude: 5°S
- Weather: cloud, some sun
- Equivalent to 2,000 kWh/y per installed kWp

28 This is a theoretical simulation to identify each portfolio's maximum asset utilization. In the context of project development, it can be considered that the portfolio (number of customers and balance between customer types) is a fixed parameter and that the project developer optimizes the design to fit with this demand (reversed logic compared to this simulation).

29 As the typical battery used for microgrid projects in Africa, lead-acid batteries were selected for the standard scenario.

The limiting parameter in this model is the storage capacity. Depending on the overlap between the generation and consumption curves, the amount of energy generated that can be transferred to the customers is limited due to the use of batteries. Two phenomena lead to lower electricity supply when consumption does not match generation:

- The battery cycle efficiency is limited, meaning that for one unit of electricity generated and stored, only a certain percentage of this unit is delivered to customers. In this model, it is assumed that the efficiency of the lead-acid batteries is 80%. Thus, for every 100 kWh generated and stored, only 80 kWh is supplied to customers.
- The total energy stored is limited by the storage capacity. If the maximum storage capacity is reached during the day due to limited consumption, the extra electricity is wasted. For instance, if there are 100 kWh to be stored but the storage capacity is 50 kWh, only 50 kWh can be supplied to customers.

In this simulation, consumption is constrained by the normal operating conditions of the storage system, defined by the EscoBox tool (equivalent charge fraction at the beginning and end of the day, defined maximum depth of discharge, defined maximum discharge current).

The utilization rate, or the total satisfied energy demand (in kWh), was used to optimize the use of the microgrid:

$$\textit{Utilization rate}\ (\%) = \frac{\textit{Energy consummed by customers}\ (\frac{kWh}{d})}{\textit{Energy generated by the PV unit}\ (\frac{kWh}{d})}$$

In this optimization, for each portfolio, the electricity consumption is maximized up to the limit set by the maximum operating conditions of the batteries[32]. When this limit is reached, the corresponding number of customers reflects the maximum number of customers that can be served without misuse of the asset. The maximum utilization rate is then deduced from the portfolio consumption and the total electricity generated.

Saturation of microgrid capacity is not likely to occur in the first months/years of operation due to the progressive adoption of the microgrid and development of usages. However, this analysis aims to evaluate how the customer portfolio utilizes the microgrid when long-term demand is reached This analysis therefore provides a vision of the typical portfolio after a few years of operation and therefore a strategy for customer acquisition, rather than a view of the potential portfolio in the first years of the project.

30 Based on the deepness of discharge and battery use, ageing and lifetime of the battery are calculated. The logic of these calculations is detailed in EscoBox documentation **Bib.15**

31 The genset is considered only as a back-up in this case and is therefore not included in the optimization simulation

32 The simulation does not consider potential load shedding/demand response mechanisms.

Utilization rates of portfolios modeled

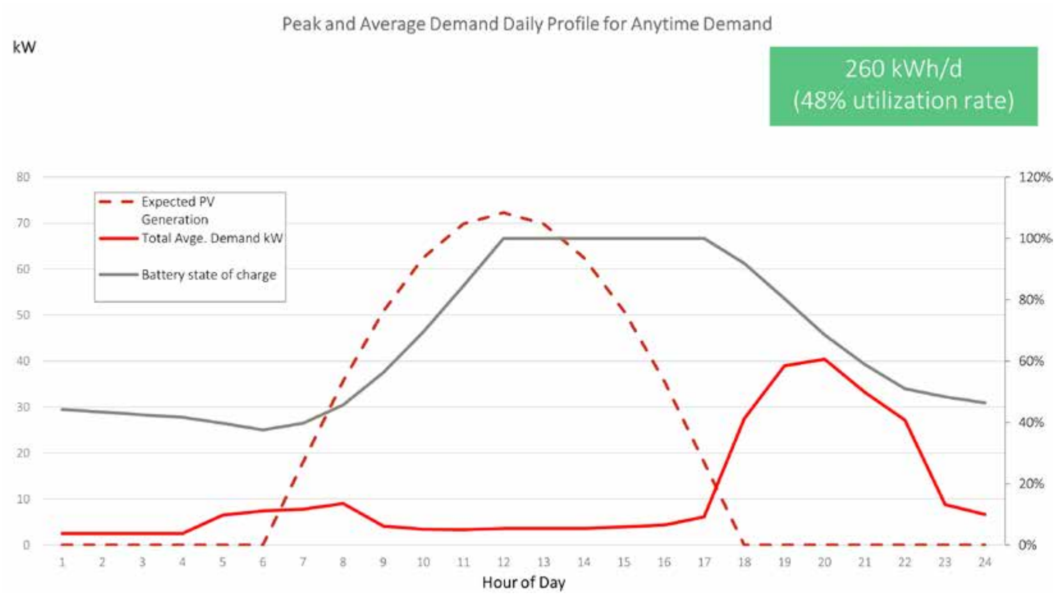
The aim of customer portfolio optimization is to achieve the best overlap between electricity demand and actual generation, thus maximizing asset utilization and limiting storage. As presented above, household customers consume more electricity in the evening compared the electricity generated during the day. Including business customers in the portfolio enables better matching between demand and generation. This matching leads to better utilization of the microgrid, i.e. higher consumption with the same asset. Utilization rates of the four customer portfolios presented in **Figure 9** were calculated :

Portfolio 1 : Mainly Household and few services

The first portfolio represents the current trend of many microgrids dominated by household customers with a few services (small shops, hairdressers). The simulation of electricity generation and demand is displayed in **Figure 13**.

Figure 13

Portfolio 1 – Mainly households and few services – demand simulation



Due to very limited consumption during the day, the maximum storage capacity is reached quickly, leading to a significant waste of the electricity generated. Combined with the effect of battery efficiency, this portfolio has a utilization rate of 48%.

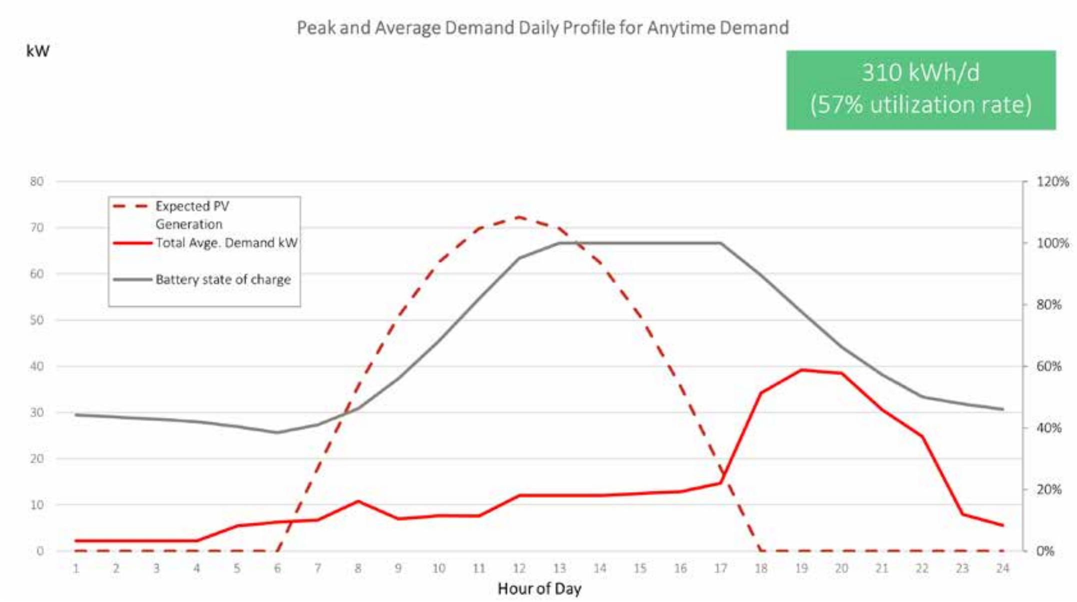
Utilization rates of portfolios modeled

Portfolio 2 : Development of craft

The second portfolio includes craft users and more higher consumption households (profile B). This portfolio corresponds to the potential evolution of Portfolio 1 after a few months/years of operation. Craftsmen become important customers and some households acquire more appliances leading to increased consumption. Millers are expected to be the first productive users with high consumption to switch to electricity. With this development, a more significant use of electricity during the day enables better grid utilization, reaching a 57% utilization rate (19% increase in electricity supplied).

Figure 14

Portfolio 2 – Development of craft – demand simulation



As this portfolio has many non-diversified productive uses, seasonal demand changes pose the largest risk to microgrid utilization. Indeed, the millers may have cyclic consumption (depending on the agricultural activities, see 2.2) in which consumption is high during the harvest season and directly after, but limited during off-season or affected by climate effects like droughts. However, if consumption seasonality matches generation seasonality, then the seasonality effect can be an opportunity to optimize energy demand throughout the year (low consumption during low generation periods/high consumption during high generation periods). This seasonality effect should be evaluated for each site before microgrid development.

Utilization rates of portfolios modeled

Portfolio 3 : Integration of fishermen and wealthier households

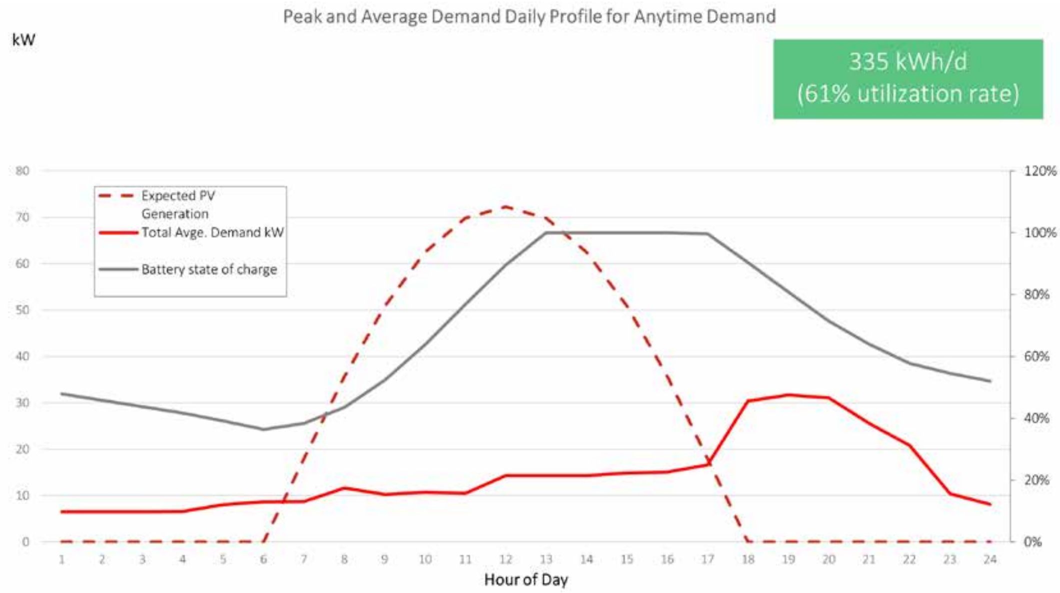
In some geographies, fishing is one of the most important activities, representing a key opportunity for refrigeration and freezing for fish conservation. As these appliances have a stable electricity demand throughout the day, they can help balance overall energy demand. Compared to agricultural activities that are strongly dependent on seasons, fishing activities can be considered stable throughout the year (except reduced activities during rainy seasons).

In this portfolio, these fishing activities were combined with a wealthier household customer segment (with higher and more stable electricity consumption).

This more balanced portfolio reaches a 61% utilization rate.

Figure 15

Portfolio 3 – Integration of fishermen and wealthier households – demand simulation



Some regions have a significant amount of night fishing and thus the associated use of light. This profile can be an opportunity for charging during peak electricity generation to achieve a better utilization rate. This effect has not been included in the simulation (only use of refrigeration is included) as a specific study would be required to evaluate this effect Bib.16.

Utilization rates of portfolios modeled

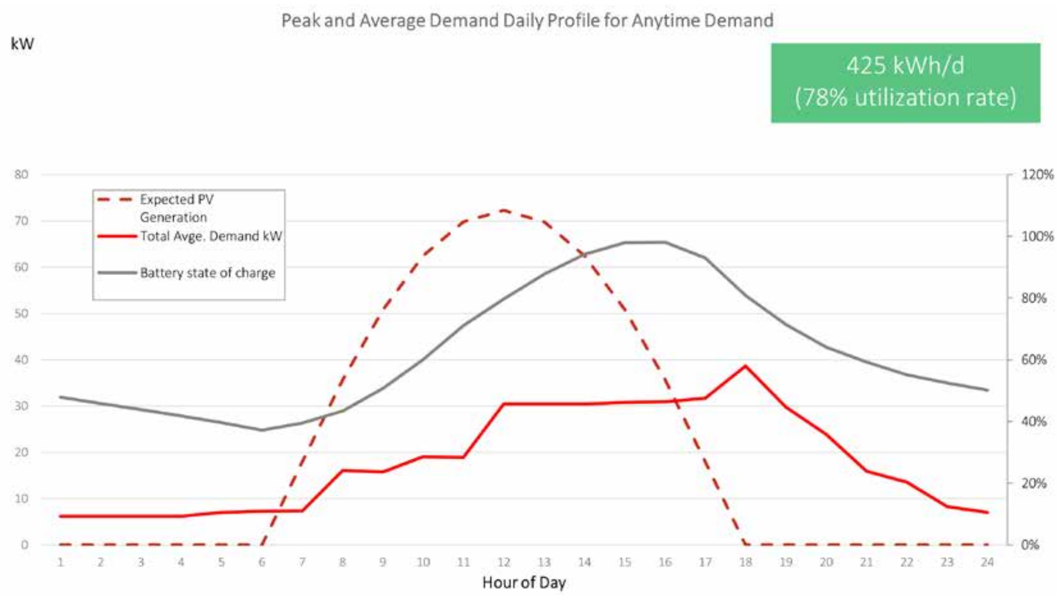
Portfolio 4 : Important development of craft

For Portfolios 1 to 3, consumption still peaks in the evening. To achieve better overlap between demand and generation, a strong focus should be put on craft users as their consumption is mainly during daytime.

A high utilization rate of 78% can be reached with 50% of electricity consumed by craft users.

Figure 16

Portfolio 4 – Important development of craft – demand simulation



This portfolio is highly hypothetical and requires significant development of craft activities. It is presented here to demonstrate the benefits of productive uses, especially craft activities.

With such a portfolio, unpredicted peak demand becomes important. Craft appliances are generally high power (milling machines, welding machines, etc.) and used for a limited duration. If too many of these appliances are used at the same time, power outages can occur (with a risk in terms of customer satisfaction) and batteries can be damaged due to rapid discharge.

APPENDIX 4
Connection Costs

Interviewed project developers reported that microgrid connections should not be free of charge for the customers. The amount paid for the connection should reflect customer's ability to pay rather than the total cost of connection (wiring, meter, etc.). Indeed, having the customers pay for an upfront cost is a good measure of customer reliability [33] and a relevant way to recruit "good customers", e.g. customers who will grow their consumption over time.

Thus, the upfront costs to the customer should be high enough to test her ability to pay but low enough to engage customers without barriers to entry. Upfront costs could be based on the targeted Average Revenue Per User. For instance, if the target ARPU of the microgrid in the first year of operation is about USD 5 (as in Vulcan Impact Investing projects **Bib.5**), the upfront cost to the customer should be between USD 15 to 25 (Tsh 36,000 to 60,000), to be paid in 3 to 5 installments. In this way, project developers can have a good sense of the customer's ability to pay her electricity bills every month.

33 Interview

APPENDIX 5
Price structures used

Price structures used in the analysis, based on literature and actual data from microgrid projects, are shown in the table below. They were adapted so that NPV in the reference scenario is the same for all price structures.

Table 16
Price structures used in the analysis

Power (kW) and EDA (Energy day allowance) (Wh/day)		Price structure 1 Monthly flat fee	Price structure 2 kWh price is the same whatever the volume of electricity consumed Bib.5	Price structure 3 kWh price decreases with consumption Bib.5	Price structure 4 kWh price increases with consumption	Price structure 5 Combined monthly flat fix and per kWh price	
						Monthly flat fee[34]	Per kWh
kW	*Wh/ day*	*USD/month*	*USD /kWh*	*USD /kWh*	*USD /kWh*	*USD / month*	*USD / kWh*
0.5	275	5	2.54	4	1.8	3.2	1
0.5	550	9	2.54	3.5	1.8	5.8	1
0.5	1,100	16	2.54	2.54	1.8	10.5	1
1	1,650	23	2.54	2.54	2.54	15.5	1
1	2,200	30	2.54	1.8	2.54	20.4	1
1,5	2,750	38	2.54	1.8	3.5	25.4	1
1,5	3,300	45	2.54	1.8	4	30.3	1

34 70% of monthly fee in Price structure 1

APPENDIX 6

List of interviewed people

Compagny	Person interviewed	Position
Benoolend	*Bubacar Diallo*	*CEO & co-founder*
Devergy	*Fabio De Pascale*	*CEO*
ENSOL	*Alicia Rutajumbukilwa*	*Sales & administrator*
Power :On	*Tristan Kochoyan*	*CEO & co-founder*
Powergen	*Tobias Dekkers*	*Commercial Development*
Rafiki Power	*Joanis Holzigel*	*General Manager*
SparkMeter	*Daniel Schnitzer*	*CEO*

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