GREEN MINI-GRID HELP DESK

Solar Mini-Grid Policy 2.0

Stepping up support to Solar Mini-Grid PPPs through the next phase of operational risk mitigating policy

Report prepared by Nico Peterschmidt
February 2019

INENSUS ENERGY4IMPACT ACCELERATING ACCESS TO ENERGY SUSTAINABLE ENERGY FUND FOR AFRICA SUSTAINABLE ENERGY FOR ALL AFRICA HUB AFRICAN DEVELOPMENT BANK GROUP

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Aslan Eqbal	INENSUS

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LIST OF ACRONYMS

AfDB	African Development Bank
CAPEX	Capital expenditure
CRM	Customer Relationship Management
DFID	Department for International Development
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GMG	Green Mini-Grid
IDCOL	Infrastructure Development Company Limited
IRR	Internal Rate of Return
LCOE	Levelized cost of electricity
O&M	Operations and Maintenance
OPEX	Operational expenditure, Operational expenditure
SE4All	Sustainable Energy for All
SEFA	Sustainable Energy Fund for Africa
TOU	Time of Use

1 INTRODUCTION

Understanding solar mini-grid risks for effective policy actions

The emergence of solar mini-grid public private partnerships as a quick and affordable solution to support rural electrification have raised stakeholder expectations. The proposition appears reasonable: the private sector invests in mini-grid infrastructure in return for attractive financial terms and/or concessions from public sector entities. The challenge with this approach however, is that while mini-grids are considered "High Impact Business Opportunities" by donor organizations and governments, the private sector is not yet convinced. And it is understandable why they are not. To date, there is no proven successful and scalable model for a private sector solar mini-grid rollout. As a result, there is no accompanying evidence of reasonable long-term returns. Given the risk such investors must assume when operating in the sector, their interest is limited and capital for the sector is rare.

There are two options to help alleviate this concern: increase profits or reduce risk. The first option leads to higher electricity customer tariffs, while the second option potentially reduces tariffs in the long run. Understandably, policymakers are focused on the second option.

In recent years, several African countries, including Kenya, Nigeria, Rwanda, Sierra Leone, Tanzania, Uganda, Zambia and others, have adjusted, or are adjusting their policy frameworks to attract more private companies into their national mini-grid sectors. The more the countries have taken the mini-grid specific risk portfolio into consideration in their respective policy framework design, the more successful they have been in attracting private sector interest and capital.

Up until this point, policy adjustments have focused on the need for solar mini-grid specific tariff setting and compensation mechanisms in the event of main-grid connection to the mini-grid, as well as the need for streamlined administrative processes around the mini-grid business. In order to bring the discussion to the next level, the following Mini-Grid Policy 2.0 has been developed to highlight additional solar mini-grid specific policy requirements.

The following policy paper introduces solar mini-grid specific operational risks and their interlinkages with licencing terms, tariff regulation and grant funding programs for solar mini-grid roll-outs. It suggests policy mechanics to overcome these risks, while steering free of market forces, and without simply diverting the risk to the public sector. The author further introduces a potential way of leveraging the private sector's unique ability to raise capital, reach markets quickly, and continuously improve upon the customer experience in bringing reliable and affordable electricity to more unelectrified rural towns and villages.

There are some prerequisites for success specifically related to the electricity tariff applicable in mini-grids. This paper assumes that mini-grid electricity customers are willing to pay tariffs which are cheaper than any alternative energy supply available locally, yet still considerably more expensive than any uniform main-grid tariff. By accepting this higher tariff in the short to medium terms, mini-grid customers benefit from reliable electricity immediately, while simultaneously supporting main-grid extension to their community by helping to confirm and build local electricity demand.

2 OPERATIONAL RISKS

The three dimensions of mini-grid operational management risk

Mini-grid operational risks are essentially three dimensional, consisting of: electricity demand risk; load pattern risk; and overspending and technical underperformance risk. Regulators typically calculate the tariff to be charged to mini-grid electricity customers using a financial model which assumes a certain demand and load pattern, as well as the cost and technical performance of the system. If any of the three dimensions is not as projected, the Internal Rate of Return (IRR) decreases, and may result in a negative value. To help mitigate this risk, private sector mini-grid operators take measures to stabilize the financial performance of their businesses.

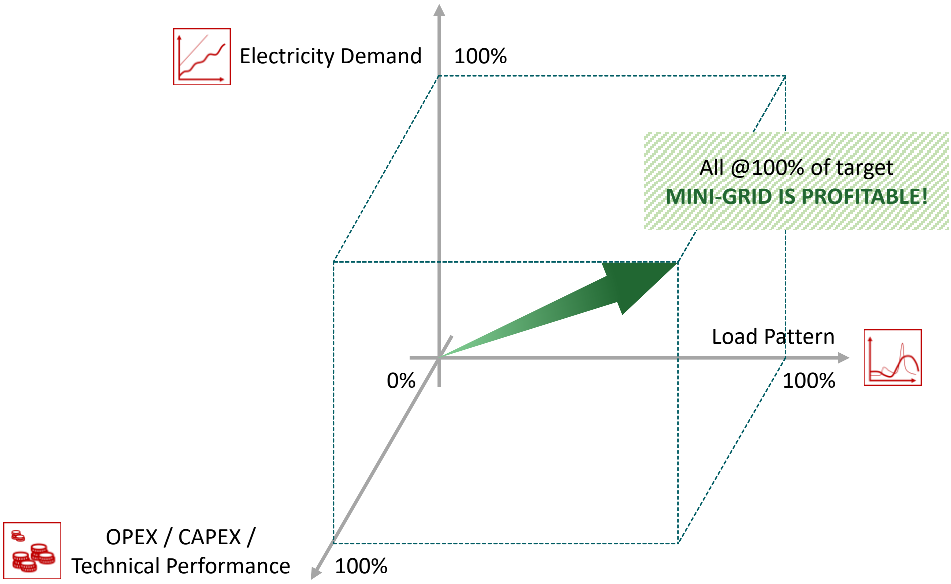
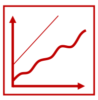


***Figure 1:** The three dimensions of mini-grid operational management risk*

All three operational risks will be described below together with their respective risk mitigation strategies. The most effective policy and funding programs are likely to be those that are designed to accommodate these mitigation strategies. Suggestions on designing the necessary conducive frameworks are described at the end of this paper.

2.1 Electricity demand risk



The electricity demand (also referred to as "volume") is the largest risk for mini-grid investors. Electricity demand development in mini-grids over time is typically linear[1] with relatively small deviations unless influenced by strong unforeseen circumstances such as drought, recession etc. Figure 2 shows examples from the Infrastructure Development Company Limited (IDCOL) mini-grid funding program in Bangladesh. Solar equipment provider, ENERSA in Senegal records similar characteristics. The diagram demonstrates the often-limited accuracy of the estimated upfront demand. The three displayed scenarios reached the demand for which they were designed

[1] Please note that as demand development is linear, it cannot be expressed as a percentage of growth per year as it would reveal exponential growth. Although the sector has yet to collectively agree upon a way to express demand growth, one option could be to simply calculate the difference in annual energy consumption between the most current and previous years for which such data has been recorded [kWh/customer/year].

after 1.9, 2.6, or 3.1 years, respectively. Although the spread may be substantially greater in non-illustrated scenarios, the same method for demand assessment has been used at all sites.

Experience has proved that it is impossible to accurately project future electricity demand of a mini-grid site prior to electrification. Future demand depends on a range of factors that cannot be easily surveyed upfront given the constraints may change at any point in time.

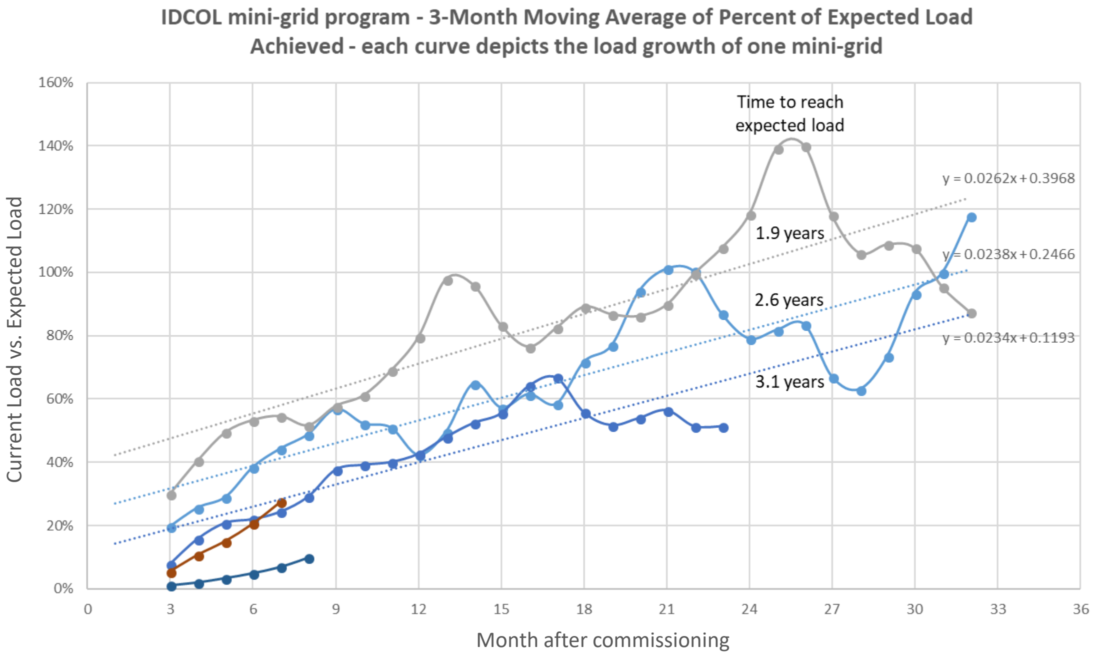


Figure 2: *Electricity demand/load development in mini-grids under the IDCOL mini-grid funding program in Bangladesh 2017. Demand growth is linear. Although the demand survey was conducted uniformly in all communities before electrification, demand starts at different levels and increases at various speeds. Given that systems were designed according to the demand projection, some mini-grids demonstrate profitability after some years (as displayed), while others may never be profitable under the current generation system sizing and financing schedule. Data: IDCOL; Diagram: Anil Cabraal*

Some of the factors affecting such demand growth include the:

1. Success of the mini-grid operator in building a trusting relationship with the community as a foundation for local investment into productive use of electricity;
2. Locally available microfinance for the establishment of micro-business;
3. Creativity and education level of local businesspersons in making use of the new opportunities arising from electricity access;
4. Availability of off-takers for locally manufactured goods or locally harvested and processed crops in markets inside and outside the community, and related logistics costs (access to markets);
5. Availability of providers of electric machines and appliances, as well as repair-shops in the community;
6. Success of electricity customers in mobilizing family members working in cities or abroad to send money to increase the local standard of living;
7. Degree to which additional income generated, thanks to the new income making activities mentioned above, is converted into electricity expenditure (This is mainly subject to the degree of individual household risk-aversion: high-risk aversion, more savings; less risk-aversion, immediate consumption); and
8. Availability of public funds to cover electricity expenses incurred by government institutions.

Figures 3 through 5 provide a simplified illustration of the varying demand (volume) development over time within different mini-grid structures (solar battery only, hybrid solar and diesel or bio-generators and the introduction of fixed charges) and their influence on profitability.

The diagrams depict cost and revenue (in currency values) over the amount of electricity sold (in kWh per year) in a mini-grid. Where the cost and revenue curves intercept, the mini-grid operator breaks even. The green area shows the quantity of electricity sales that lead to profitable system operations. Different technologies and business models have different cost and revenue curves and accordingly, distinct green areas of profitable operation. High fixed costs (e.g. through high CAPEX) result in a curve that starts at a high y-axis interception. High variable costs (e.g. high percentage of generation from diesel) result in a steep cost-curve. The vertical line marks the maximum technical generation potential of the assets installed.

The diagrams help explain where volume risk can be mitigated by system designs and implementation strategies in photovoltaic (PV) systems above approximately 50 kW of installed battery inverter power. The legal/regulatory framework and mini-grid funding programs must avoid hindering the application of these mitigation instruments. If designed properly, a mini-grid funding program can even support these implementation strategies and therefore contribute considerably to the sustainability of mini-grid electricity supply.

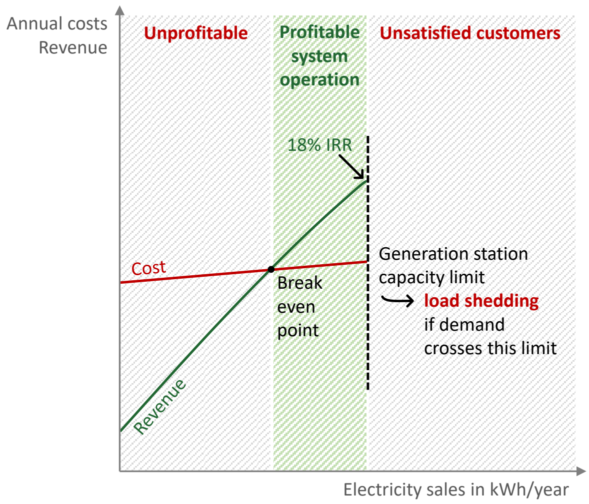


Figure 3: *Volume risk in mini-grid solar battery only systems. The demand slot for profitable system operation is small*

Solar only system. In solar battery only systems (see Figure 3), the system is designed for a certain demand. The internal rate of return (IRR) is determined exactly for that demand (and related load curve). As solar battery only systems require high capital expenditure (CAPEX) and low operational expenditure (OPEX), the cost curve has a high y-axis interception, is flat, and thus the slot of profitable system operation is slim. If the actual demand falls below even a fraction of projected demand, the system cannot operate profitably. At the same time, if demand is slightly higher than projected, load shedding or load limitation applies, and customers become unsatisfied that in spite of paying high tariffs, they still do not receive the level of service they deserve. Such dissatisfaction often leads customers to stop consuming mini-grid electricity. Both cases lead to unprofitable mini-grid operations and consequent bankruptcy of the mini-grid operator resulting in discontinuation of the service.

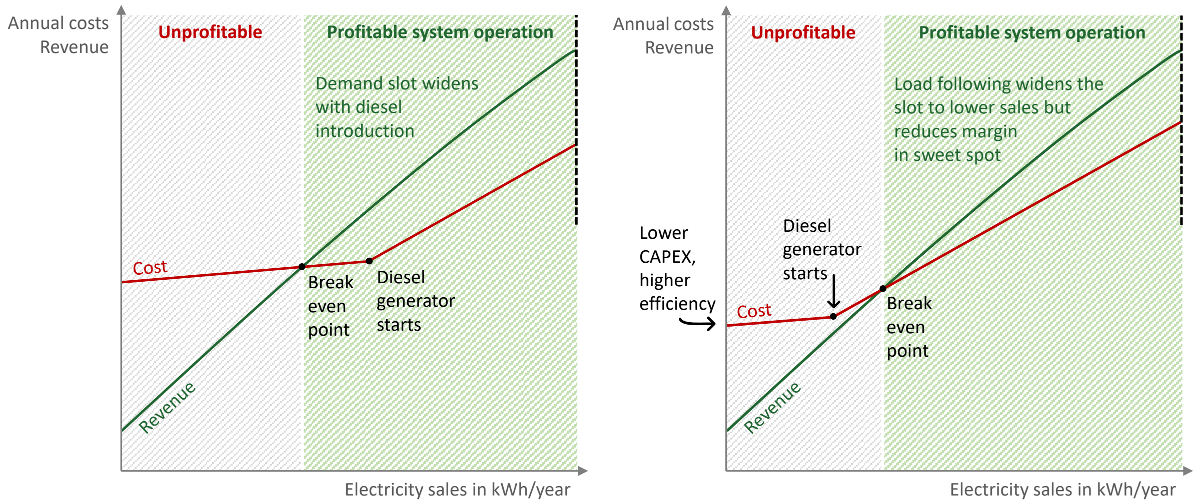


Figure 4: *Volume risk in hybrid solar diesel or biodiesel generators and Cycle Charge (left) vs. Load Following design (right)*

Hybrid solar system. As shown in Figure 4, the integration of a diesel or biodiesel generator into a hybrid solar mini-grid system increases the generation capacity of the system to the right. The diesel or biodiesel generator kicks in when the energy capacity of the solar-battery system is depleted. Such system requires low fixed, but high variable costs. A lower solar fraction expands the green area to the left. Such hybrid system can be designed as either a “Load Following” or “Cycle Charge” system.

When a diesel generator is required to run for long hours, a “Load Following” system is preferred. Under this system, a diesel generator controller is in charge of the overall system and informs the battery inverters when to charge the batteries and when to direct power into the distribution network. The generator primarily produces electricity as required by the load (hence the name, ‘load following’). Typically, the battery is solar charged in load following systems.

In “Cycle Charge” systems, the generator runs at optimum efficiency with high power output and charges the batteries with any power that cannot be absorbed by the load. The battery inverter performs the main controlling features of the generation system. It also starts and stops the diesel generator. Batteries are usually larger, have a higher energy throughput and thus produce more losses. Cycle charging is most appropriate for systems with a high solar fraction or in systems with specific load patterns.

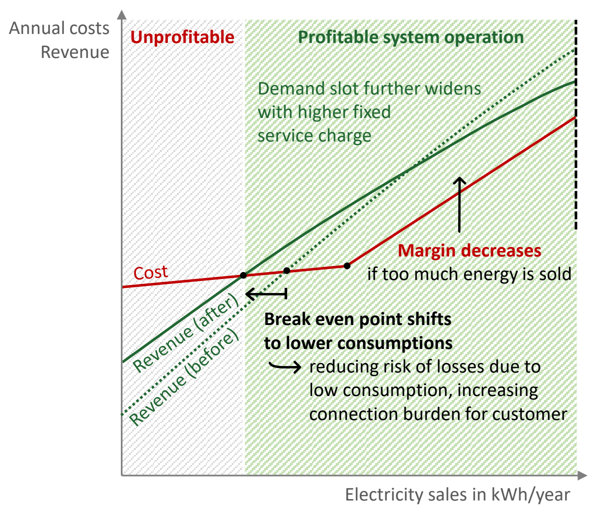


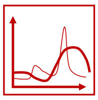
Figure 5: *Reduction of volume risk through the introduction of fixed component-based tariffs*

Fixed component-based tariffs system. Another option to expand the green area further to the left is changing the revenue curve by applying tariffs to fixed components. This positions the revenue curve higher on the y-axis and flattens it. Fixed tariffs may appear as a monthly or weekly service charge; access rate, or meter rent that is independent of the number of kWhs consumed by the customer. The effect of fixed component-based tariffs on the revenue curve is depicted in Figure 5. Although such tariffs are not welcomed by customers in many African countries due to abuse of this type of tariff in the past, some mini-grid operators have established relationships with their customers under which this risk mitigation instrument of fixed component-based tariffs is applied successfully.

Staged implementation. Last but not the least, a staged implementation of renewable generation assets may help avoid the issue of overdesigning from the very beginning. Under such system, only half perceived demand would be filled in the short-term and the remaining half as soon as demand has increased. In the meantime, demand is observed and any exceeding the initially installed renewable capacity is covered by diesel or biodiesel generators until a trajectory of demand development becomes visible. A Load Following approach may be considered in this phase. According to Figure 2 and experience from other projects, after one or two years of operation, the demand trajectory can be projected with relatively high accuracy. If daily and annual load patterns allow, this is the point in time in which the renewable fraction of a mini-grid can be increased (70 or even 80 percent) to levels that allow for a Cycle Charge approach or a mixed Load Following/Cycle Charge approach with a potentially lower levelized cost of electricity (LCOE).

The staged implementation approach requires a modular system design which can increase its generation and distribution capacity over time without significant opportunity cost and may even decrease its capacity when necessary.

2.2 Load pattern risk



The second largest risk for a mini-grid investor is the load pattern risk. This risk can be explained as follows: Solar PV generates electricity during the daytime, supplies power to customers and charges any surplus into batteries. Batteries have one of the highest portions of capital expenditures. Battery size is selected to optimize financial performance. Size is therefore usually determined based upon a certain percentage of the electricity expected to be generated by the solar PV system. In a larger battery-based system, the depreciation of battery CAPEX over its lifetime and the conversion losses during battery cycling (including converter losses) increase the levelized cost of electricity (LCOE).

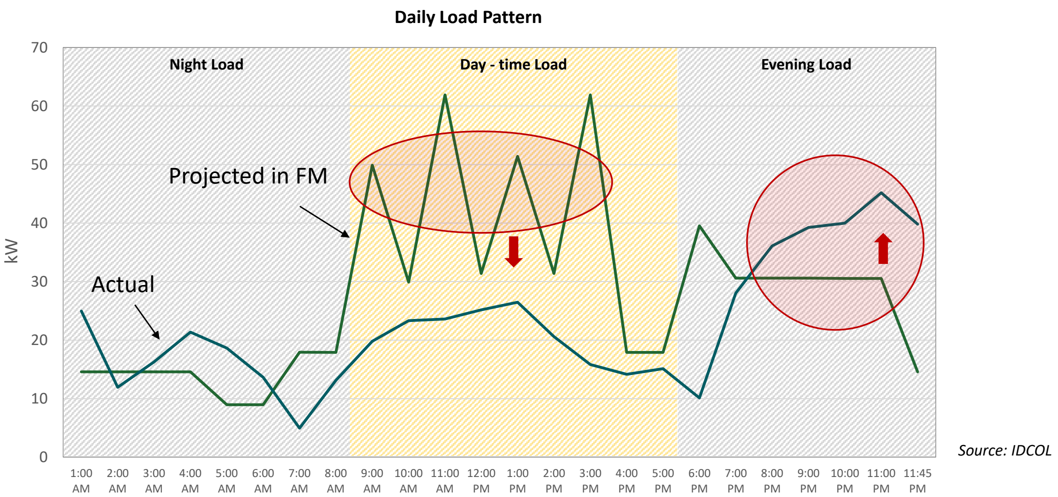


Figure 6: *Comparison of projected vs. actual load patterns*

In a solar battery hybrid diesel mini-grid system, when there is more night time load and less daytime load than expected during the system design phase, electricity that could potentially be generated by PV during the day is lost when the battery is full. At night, small batteries will be discharged to their lowest state of charge quickly, subsequently requiring the diesel generator to kick in. In the end, there is excess electricity from PV that cannot be used during the day and additional diesel fuel consumed at night. All of this increases operational costs significantly and reduces the mini-grid's profitability.

Figure 6 displays a typical case of a discrepancy between the projected load pattern and the actual load pattern. Mini-grid developers frequently over-estimate the daytime load and under-estimate the evening peak and other night-time loads. When the battery is charged, above 80 percent its state of charge, lead-acid batteries reduce their charging current and thus also the power that can be charged into the battery as shown in Figure 7. This results in a loss of energy that could potentially be generated by solar PV if the battery capacity or the load was available at that time. Figure 7 displays the energy lost due to limited battery capacity.

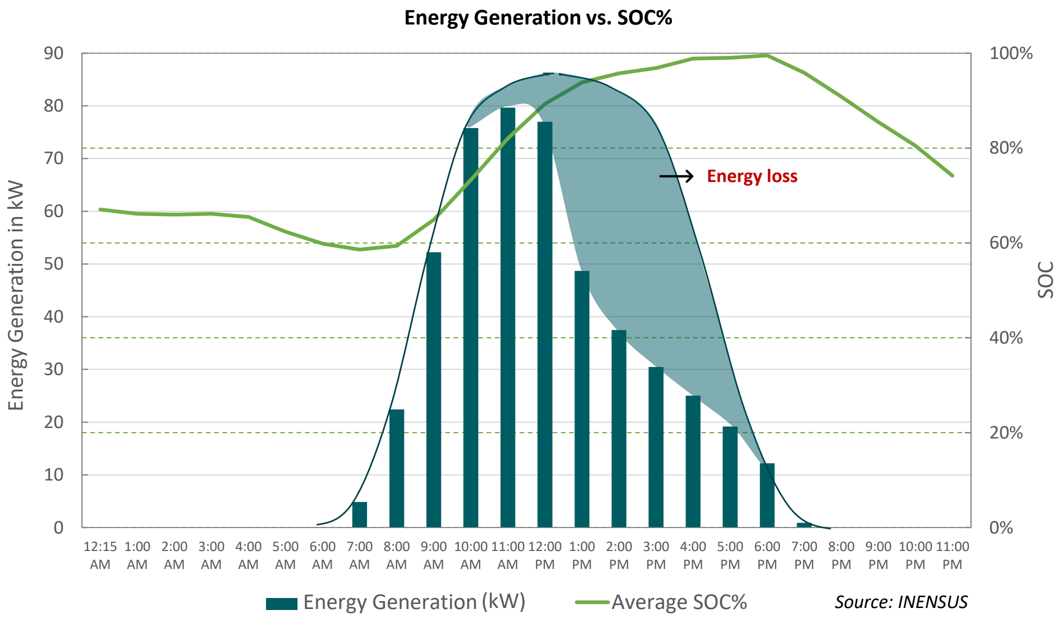


***Figure 7:** Excess electricity of a solar battery system*

Risk mitigation strategies for load pattern risk are threefold:

1. Demand management through the application of Time of Use Tariffs (TOU) may shift electricity consumption to daytime by having a higher night-time electricity tariff and a lower daytime electricity tariff;
2. Load management through switching so-called deferrable loads to increase daytime consumption (i.e. water pumps filling fish ponds or rice paddies during the day, but with careful attention to load managed irrigation given the economic feasibility and challenges of affordable non daytime crop watering); and
3. Adjustment of system design through additional battery capacity, for example. This causes additional capital expenditure increasing tariffs for the customer.

2.3 Overspending and technical underperformance risk

Overspending can happen through increased capital or operational expenditures. While increased capital expenditures can be avoided by state-of-the-art project management approaches, reduction of operational expenditures requires automation options and information technologies that just arrived on the market or are still under development. Not many mini-grid operators are familiar with these new kinds of software tools. Table 1 below lists traditional Operations and Maintenance (O&M) management procedures and compares them to the latest most cost-efficient methodologies. The same software and data communication tools also help in controlling all processes including maintenance, which reduces the risk of technical underperformance.

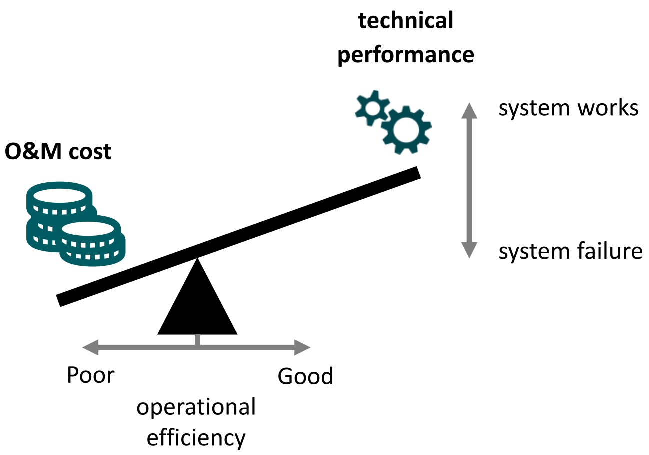


Figure 8: *Operational efficiency determines how much money is required to keep the mini-grid power supply system running reliably*

Operational expenditure overspending and technical underperformance are interlinked by operational efficiency. The higher the efficiency, the lower the operational expenditures required to keep the system running in a reliable manner. Information technology can reduce effort and cost for many O&M processes. Remote data access and monitoring, automated system operation and data evaluation, automatic alarm systems, mobile money payments, etc. help to keep operational expenditures down with limited additional capital expenditures.

Table 1: Mini-Grid O&M processes and cost reduction through the application of efficient IT solutions

Processes	Traditional method	Cost reduction potential
	Tasks on the ground	
Cash collection and transfer	Manual meter reading and issuing bills. Manual collection. Cash transfer by carrying cash during travels. More advanced: Smart card or keypad prepayment meters with offline vending machines.	Receipt of mobile money triggers a (cloud) server to fully automatically generate a token for balance recharging that is automatically transferred to the meter via internet directly or via SMS to the customer's mobile phone (STS meters). Any transaction is stored in a database on a server.
Customer service	Customer meets company representative at its local office, takes her/him to her/his connection to explain any issues.	Customer Relationship Management (CRM) through call centres answering most customer queries and ticketing systems informing local staff about any on-site actions required.
O&M of generation assets	Plant manager operates diesel generator manually. Periodic site visits with manual recordings and preventive maintenance work. System failures reported by customers after system shut-down.	Operation of diesel generator through auto-start/stop. Remote monitoring of technology.
Synergies between business streams	Pure electricity supply business.	Combination of electricity supply with so-called KeyMaker activities[2] that use electricity and the same management resources to process and export local goods increasing the revenue stream.
Security of generation assets	24/7 guarding through security company or local watchmen.	Security through CCTV, glass-fibre remote alarm systems and local part-time watchmen for theft protection.
	Head management tasks	
Accounting of revenue	Manual ledgers transported to the head office periodically to copy data into accounting system.	Cloud-based mobile-money revenue data collection via remote data communication. Automatic import of revenue data from the (cloud-)server to the accounting software.
Reporting to authorities and donors	Collection of data as needed and compiling of reports on a case by case basis.	Automatic forwarding of data from the cloud to platforms like Odyssey that are used by donors for reporting purposes.
Staff management and performance monitoring	Limited supervision of on-site staff due to geographic distance. Performance monitoring based on customer satisfaction surveys.	Payment of on-site staff per service ticket resolved. Feedback from the customers through call-centres.

[2] A KeyMaker activity is a way to increase the profitability of the mini-grid business. The utilization of synergies between the mini-grid business and trade of locally produced goods leads to significantly increased revenues at just slightly increased operational cost. In contrast to the traditional promotion of productive use of electricity, in the KeyMaker model, the mini-grid operator is the trader of the locally produced goods.

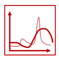
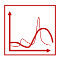
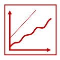
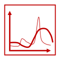
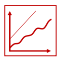
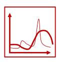
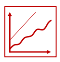
3 BUILDING BLOCKS OF THE SOLAR MINI-GRID POLICY 2.0

Structuring mini-grid policy to overcome operational risks

Understanding the risk portfolio of solar mini-grid operators enables policymakers to make informed policy decisions to better attract private mini-grid investors and potentially reduce solar mini-grid tariffs through the implementation of a conducive policy framework. The relevant policy areas addressing the operational risks of solar mini-grids include the mini-grid tariff and licence regulation, as well as the design of solar mini-grid funding programs as depicted in Figure 9.

3.1 Well designed tariff and licence regulation

The below table introduces policy measures in tariff and licence regulations with their related operational risk mitigating effects.

Policy measure	Risk addressed
Allow Time of User (TOU) tariffs to enable solar mini-grid operators to shift electricity consumption from night to daytime using price incentives.	
Allow and support **Load Management** approaches in solar mini-grids. This can increase daytime load when excess electricity from solar generation is available.	
Keep **mini-grid tariffs flexible at all times**. The regulator should be available to adjust the tariff at any time if the demand or load pattern does not develop as expected or if the cost structure projected cannot be met.	  
Describe the tariff calculation methodology not only in words in the regulation, but **prepare a tariff calculation tool** that applies to all mini-grid operators of a certain size and fix the usage of this tool in the licence. For smaller mini-grids for which the operator can negotiate tariffs with the customers freely, this tool may become the fall-back option in case of any conflict. This way, tariffs are harmonized across the country and investors can trust in the tariff stability.	  
The regulator should **enforce efficiency** in mini-grid operational costs by requiring the mini-grid operator to use the latest proven efficiency measures and software tools. Tariff calculations should assume the application of state-of-the-art operational measures and tools.	
Enable time-wise **unlimited mini-grid operation duration** by, for example, not limiting licensing periods or making licence extension automatic. In case of underperforming demand growth, equity investors especially are usually ready to wait for a longer period of time to realize their Return on Equity. If, for example, the licence duration is limited or even a time-limited concession model or (build, own, operate, transfer) BOOT model has been deployed, waiting for longer may not be a viable option. The natural end of the mini-grid operation time is the arrival of the main-grid which triggers the wellknown exit options.	

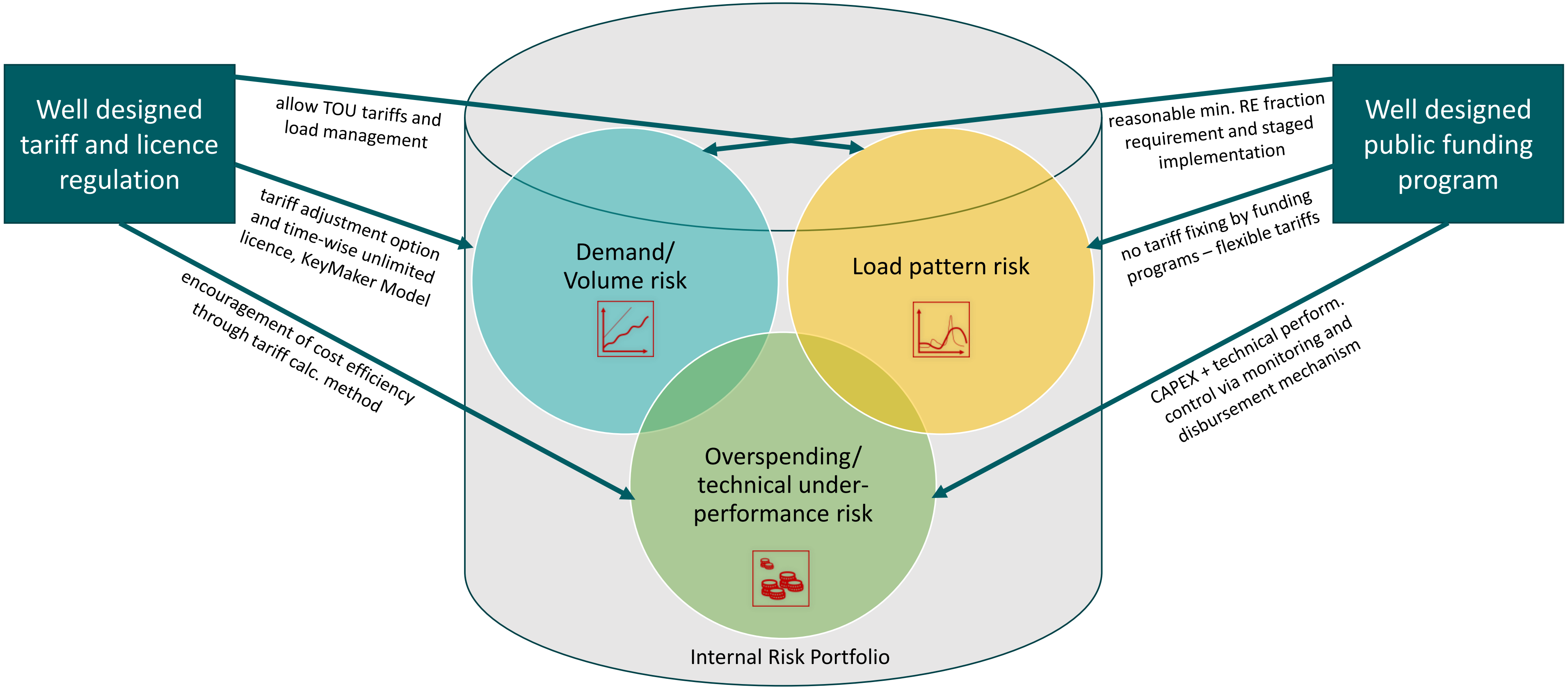


Figure 9: *Government actions supporting risk mitigation in the mini-grid businesses*

3.2 Well designed public funding programs

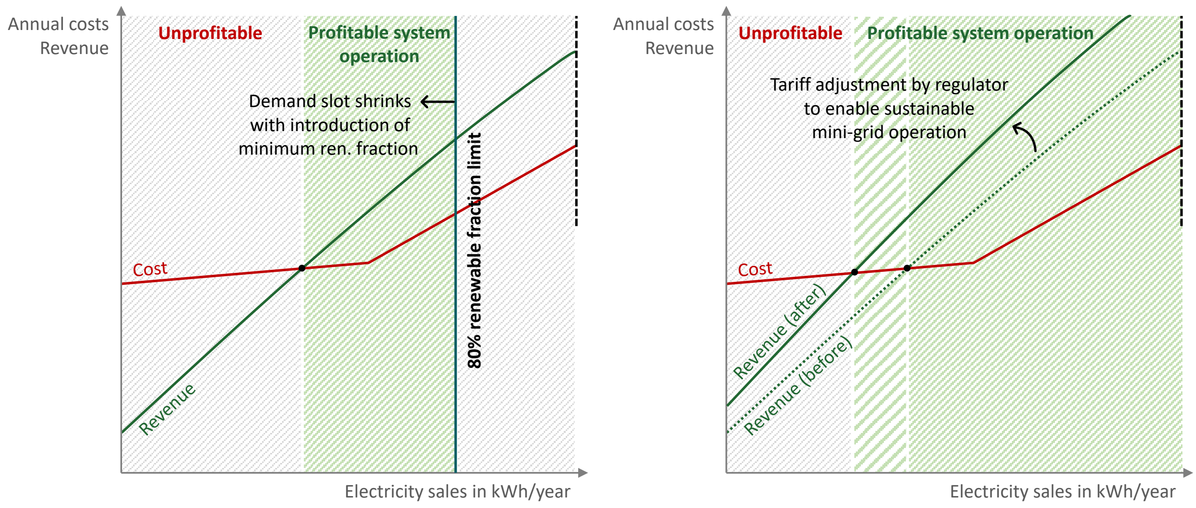
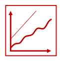
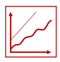
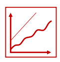
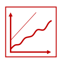
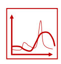


Figure 10: *The effect of artificial limitations of renewable fractions (left) and tariff regulation (right) by funding programs on the sustainability of a PV-hybrid mini-grid*

The following policy measures should be considered in solar mini-grid grant funding programs to mitigate operational risks.

Policy measure	Risk addressed
If a **minimum solar fraction requirement** in a mini-grid cannot be avoided in a mini-grid, select one that is **as low as reasonably possible**. The market and competitiveness of solar energy and battery technology in combination with tariff regulation will determine the renewable fraction leading to minimum tariffs automatically.	
Allocating **subsidies** to reduce **connection costs for the electricity customer** may speed up the demand update and thus reduce the volume risk.	
Design the mini-grid implementation time under a grant funding program to **allow** for a **staged implementation** under which the mini-grid operator starts with a lower power capacity and solar fraction and increases the power capacity and solar fraction of the system as soon as the demand growth trajectory can be projected with adequate security.	
As the regulator must have the opportunity to adjust mini-grid tariffs flexibly at any time, **avoid fixing tariffs** for a long time **through grant funding programs** (e.g. by auctions on tariffs). Instead, auctions/tenders can be performed on lowest grant or lowest weighted average cost of capital which is used for tariff calculation but leaves room for adjustments by the regulator.	 
The grant fund manager may collaborate with the regulator to **ensure** application of **state-of-the-art efficiency measures** and tools in all mini-grids. The enforcement can be increased through the grant manager's monitoring and disbursement mechanisms. Monitoring of performance standards helps to keep the service quality up while driving operational cost down.	

Encourage so called **KeyMaker Models** increasing and diversifying the mini-grid operator's revenue stream. Under KeyMaker Models, mini-grid operators use the reliable local electricity supply and mini-grid management capacities to also process and market natural resources available around the mini-grid. These capacities (logistics, financing, management, controlling, accounting, electricity) of the mini-grid operator are usually what is missing in the local community to market their resources successfully. Grant funding programs could, for example, reward the cooperation of a mini-grid company with a certain industrial processing company creating jobs in rural areas. The synergies of the two business streams may not only accelerate electricity demand uptake and stabilize the mini-grid business through a diversification of income sources, but also allow more control over the load pattern and provide cost reduction potential through shared staff capacities and logistics costs.