Introduction for Practitioners

Real-time Monitoring, Control and Payment Technologies for Mini-grids

Introduction

Mini-grids are expected to contribute more than any other electricity supply arrangement to the provision of electricity access to the 1.1 billion people who are currently living without (SE4All, 2015). Those lacking electricity access are overwhelmingly located in rural areas of sub-Saharan Africa and South Asia, where the International Energy Agency (IEA) estimates that mini-grids will be the best solution for 45% of people, and stand-alone systems for 25% of people. Grid extension is only the most economically viable option for 30% of the rural population (IEA, 2011). Measured by numbers of connections or by millions of dollars, mini-grids are already a globally relevant technology, yet there remain a number of challenges which must be overcome before mini-grid coverage can expand by the degree required to deliver universal electricity access.

The central challenge of increasing the number of sites where mini-grids can be economically viable (or increasing the economic viability of any one mini-grid) is the focus of much research and innovation. One technical area which can have strong positive effects on the drivers of mini-grid profitability – revenues, tariffs and costs – is that of monitoring, control and payment technologies. In recent years, a number of mini-grid and solar home system businesses have flourished thanks to the innovative deployment of these technologies, which allow mini-grid operators and system distributors to reduce costs and increase revenues. Strong monitoring capabilities also give confidence to investors and donors who provide the initial capital that new installations or value chains require.

The advancement in monitoring, control and payment technologies also enhances the customer experience by improving the availability, reliability and quality of supply and increasing convenience and information about usage.

This Technical Brief discusses the factors of mini-grid economic viability – revenue, tariffs and costs - and introduces technologies and approaches for enhancing viability through real-time monitoring, control and payments. It introduces the benefits of integrated monitoring, control and payment systems and provides information about some of the business models that are emerging to capitalise on these benefits.

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Definition and Models for Mini-grids

A mini-grid is an isolated system separate from the main grid network that consists of generation and distribution of electricity to consumers located in the vicinity. Mini-grids typically provide in the region 5-100 kW of power, although can be up to 1,000 kW (1 MW). They can provide useful amounts of power for households, businesses and social institutions.

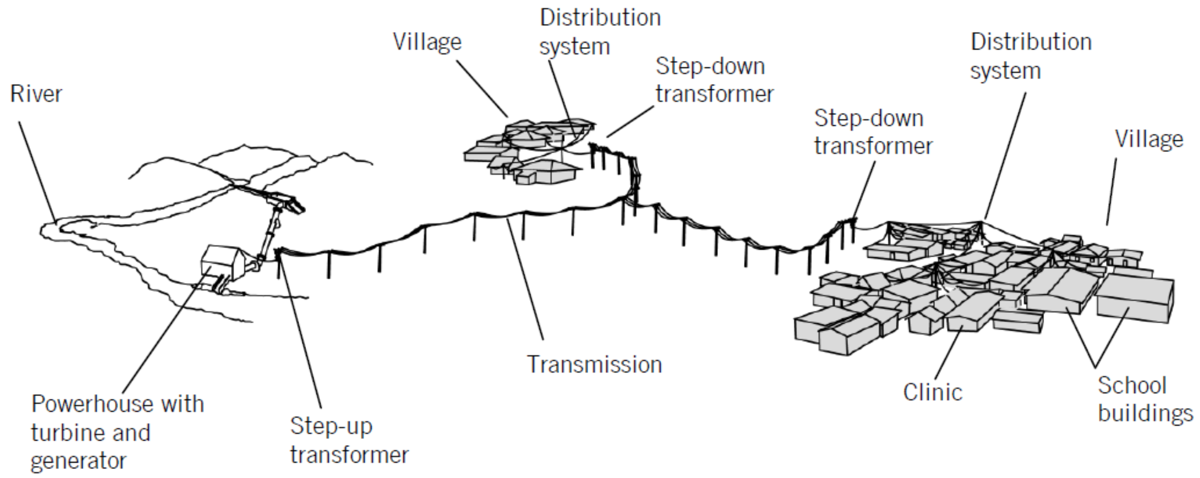

Figure 1: Typical components of a micro-hydro mini-grid system (Practical Action Micro-Grids Technical Brief).

Mini-grids can be powered by a variety of renewable (solar, hydro, wind or biomass) and non-renewable sources, or a combination of both. Many developing countries are endowed with a good renewable energy resource base, solar being most notable due to its widespread suitability. The choice of renewable energy technology should depend on the availability of the resource, but also a range of other technical, financial and economic factors.

In terms of monitoring and control of mini-grids, an important technical distinction is between:

- **Power-limited systems** - such as hydro, biomass or diesel generator powered systems that constantly generate power. Usage is limited by the power supply at any given time.
- **Energy-limited systems** - such as solar or wind powered systems that have varying generation and typically use battery banks for storage. Usage is limited by the energy generated and stored in the batteries.

There are four prominent mini-grid ownership models:

- Private sector
- Utility / government
- Community-led
- Hybrids (e.g. public private partnerships)

Good practice and successful initiatives can be found for each model and a number of international experiences with mini-grids, especially in Africa, are outlined in the Mini-grid Policy Toolkit (EUEI PDF, 2014). The most appropriate approach is context-specific and scale-up and replication of each is important for achieving universal access to electricity (EUEI-PDF, 2015).

Factors of Mini-grid Viability

The tariffs, revenues and costs of a mini-grid are the drivers of profitability. Whilst there are a variety of ownership models with different financial structures, the following schematic is a useful framework for assessing the viability of any mini-grid.

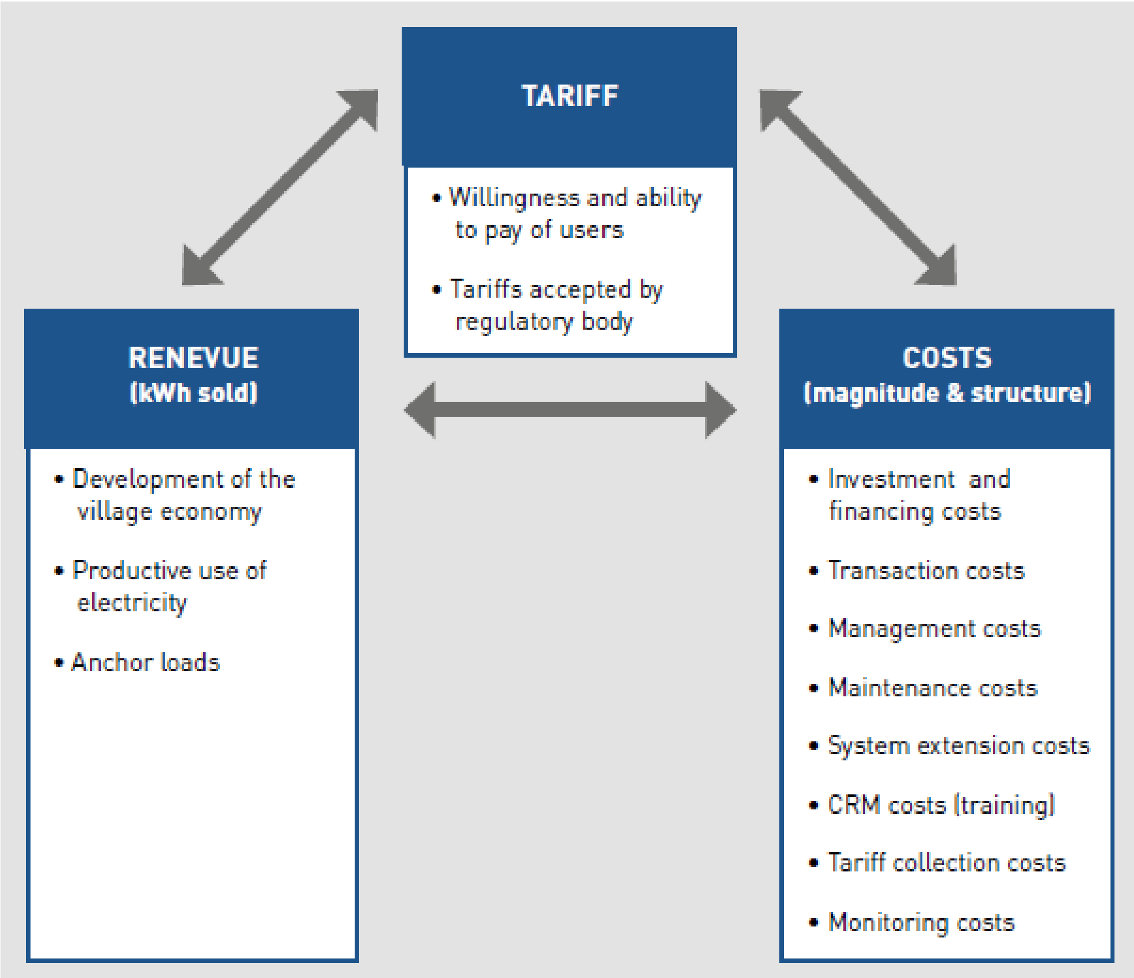

Figure 2 : First sight factors of micro-utility profitability (SBI, 2013)

This section explores the drivers of Revenue, Tariff and Cost, and presents technologies and strategies for enhancing viability.

Revenues

Under most tariff models, a mini-grid operator will see greater profitability if they can sell more electricity from the same generation and distribution equipment, whether by serving more customers or allowing each customer to consume more within the limits set by the equipment. They will also benefit from more effective collection of monies owed.

Utilisation: Maximising Sales, Improving Reliability

Mini-grids typically supply electricity to poor rural households with low power demands. Although consumption tends to increase over time as customers move from lights and phone charging to appliances such as TVs and fridges, the revenue from the average customer remains low in the medium-term. The number of customers also tends to be small, and those customers are fairly homogenous in terms of their power demands: an evening peak between 5 and 9pm is common when many customers use lights, cookers, etc. simultaneously.

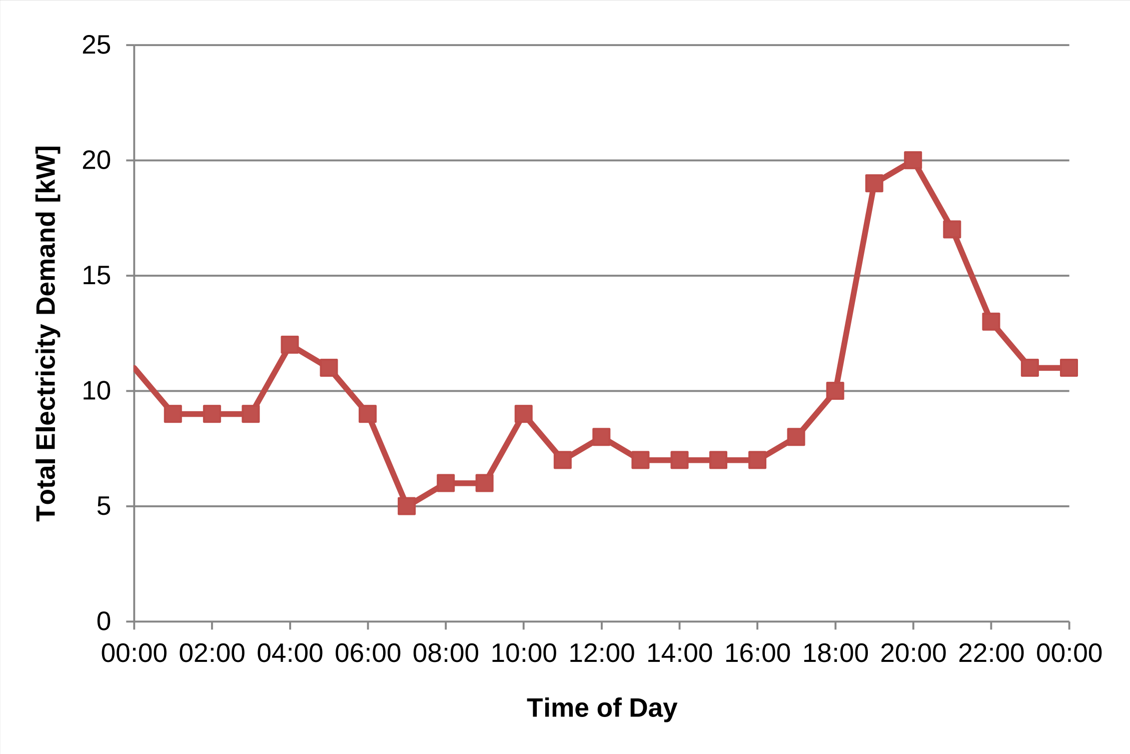

Figure 3: The load profile of a micro-hydro mini-grid in Malawi (Practical Action)

The different energy sources for electricity generation and the different types of system that they feed into encounter different challenges with respect to utilisation (the electricity that is actually used as a proportion of the electricity that could have been used, had there been sufficient demand at all times). A utilisation rate of 30-40% is common for power-limited mini-grids[1] – meaning that operators are not able to sell the majority of the power that could potentially be generated. At other times of day, electricity from power-limited mini-grids goes unused, or the revenue-generating potential of the equipment is only partially harnessed.

Often, well-designed energy-limited systems can achieve higher utilisation rates than equivalent power-limited systems, because the presence of energy storage allows electricity to be consumed some time after it was generated. The power generation no longer needs to instantaneously match the demand, so generators can be smaller and operate more constantly. The designer can match both generation and storage to the forecast demand. In the case of solar mini-grids, the modular nature of photovoltaic and energy storage technologies also allows more panels or batteries to be added as demand grows. However, energy resource variations and intermittency mean that even the most carefully designed system will at times find itself with surplus energy (e.g. during the sunniest or windiest days) if the designer is not to risk supply shortages during times when the resource is weaker. Solar PV mini-grids will typically be under-utilised during the middle of the day at the

[1] In comparison to an Independent Power Provider that sells close to 100% of power generated into the grid, it is easy to see why rural electrification is a less profitable venture. The necessity to construct the distribution system to reach dispersed customers also counts against mini-grid profitability.

sunniest time of year in order to be able to supply enough electricity during the less sunny times.

At the same time, the ability of supply to meet peak demand is very often a limiting factor for the number of customers that may be connected to a mini-grid. This is most true for power-limited systems, but does also apply to energy-limited systems where certain components, including the distribution network, are only able to handle a certain peak amount of power. If demand exceeds supply, the system voltage will drop (dimming lights or damaging appliances) or the system will cut-out and disconnect all the customers. A variety of demand-side management (DSM) strategies and technologies can reduce the peak demand and allow more customers access, and more electricity to be used and benefitted from at non-peak times.

DSM Strategies	DSM Technologies
Efficient appliances and lights	Current limiters
Commercial load scheduling	GridShare
Restricting residential use	Distributed Intelligent Load Controllers
Price incentives	Conventional meters
Community involvement, consumer education, and village committees	Prepaid meters
	Advanced metering systems with centralized communication

Table 1 : List of Demand-side Management Strategies and Technologies (SERC, 2013)

Complementary to reducing the evening power demand peak, increasing demand during the day is essential to increasing the utilisation rates and revenue. This can be done through encouragement of the types of user that will tend to consume during the day, or by influencing or controlling the behaviour of users that would otherwise tend to consume at other times.

For either of these two approaches, it is agricultural, commercial and industrial users that offer the best opportunities for increasing daytime consumption without proportionally worsening the evening peak. A partnership with an anchor load - a high-power customer such as a mobile base station or industrial user – can provide a strong revenue stream. In many villages however no such anchor load is present, and promoting small-scale productive users such as agro-processers, carpenters, welders, bakeries, etc. may be necessary. Irrigation pumping can offer excellent opportunities for demand-smoothing, because the exact time of water application is rarely critical. If the irrigation system includes elevated water storage, pumping can be done at any time of day without impact on the irrigation user.

It is recognised that increased productive use does not always happen automatically as a result of gaining access to electricity. Entrepreneurs and businesses are not always able to capitalise on the availability without additional support (PPEO, 2012).

A manual for practitioners seeking to promote productive uses of electricity has been developed (www.produse.org). It outlines the following steps to encouraging economic activity:

- Economic and livelihood analysis

- Skill and business training
- Access to finance

Monitoring of mini-grid power generation and consumption can enable mini-grid operators to make decisions that will increase utilisation and improve reliability: whether or not to connect new customers, to promote increased or decreased consumption at certain times of day, or to add new generation or energy storage. Under the EPSRC ESCoBox project, researchers at De Montfort University have developed a spreadsheet decision support tool that provides mini-grid operators with information and analysis that can help them to optimise these factors (tool available to download at http://www.dmu.ac.uk/research/research-faculties-and-institutes/institute-of-energy-and-sustainable-development/research-projects/escobox.aspx). When monitoring data is transmitted to the decision-maker in real-time, load control decisions or demand-side management actions can be taken on an hour-by-hour or even minute-by-minute basis, and can involve pre-programmed automated responses. Control actions can include the switching on and off of individual customers or sub-sections of the network as part of a load-shedding regime.

Box 1: Time-Control of Productive Electricity Use

To make better use of periods of energy surplus (typically mid-day periods for energy-limited systems like PV-battery mini-grids, and overnight for power-limited systems like micro-hydro mini-grids), power can be made available to users, or even individual machines and appliances, over controlled and limited time periods. This can be done in 4 ways:

1. **Human user control** – the user can be relied upon to only turn on the appliance during the pre-agreed period. This method requires a very high level of trust and/or discipline among mini-grid customers and operators, but has been proven to be effective in some contexts and is known to be fairly widely used in Nepal.

2. **Isolated "fixed" controller** – a clockwork or electronic timer programmed with an agreed fixed time window is hard-wired into the power supply to a particular appliance. This timer unit can be in a locked box so that the risk of tampering is removed. This simple and low cost solution is widely used for irrigation pumps in India and Bangladesh. To change the time window for each and every user of a mini-grid is a time-consuming and expensive exercise, so the time window is for the most part fixed.

3. **Local central control** – a switch is installed on the user's side of the meter, or on the power supply to an individual appliance, that is remotely controlled by the operator via a central control system located nearby. The communication from central controller to switch may be via a physical data connection or radio frequency signals that enable or disconnect the power according to the time period. This system can easily change the time windows for individuals or groups all at once.

No product is known to be commercially available at present (2016) that provides this function. The hardware development work stream of the ESCoBox project seeks to address this gap.

4. **Cloud-connected controller** – a control unit is hard-wired into the power supply, equipped with a mobile (GSM) data network connection that transfers data to and from a central system that can be located anywhere with connectivity. This controller “in the Cloud” offers similar functionality to the local central control system of option 3, but can also be integrated with smart monitoring and payment systems. Several products are available on the market to do this, but have the disadvantage that every time-controlled appliance must have its own metered supply and payment account. Cloud-connected systems can be expensive to install and operate, especially if they must be installed in parallel with non-time-controlled supplies for lower power appliances. Good mobile network coverage is a prerequisite that may be challenging in some remote areas. Even where good coverage exists, the mobile network provider may not offer a service other than general mobile phone communications packages, which may not be appropriately designed and priced for Machine to Machine communication applications.

Revenue Collection and Metering

Revenue collection is a challenge for many mini-grids. Payment meters have historically been considered poor value-for-money given the low energy usage and revenues per customer. The technical and management requirements of the meter system have also proved prohibitive for the village setting. In these cases, an individual from the community is responsible for visiting each customer on a regular basis to collect payments. This leads to low collection rates as the collector may favour certain individuals, and be reluctant to cut off offending customers. Poor financial management and record keeping of such informal systems is also a risk. Without a meter, a simple time- or capacity-based tariff is necessary (described in more detail in the “Tariffs” section).

It is common to use a load limiter in systems with no meter[2]. This low-cost device switches off the connection to the customer when the load exceeds a certain power limit, but allows unlimited energy consumption within the power limit set. This reduces each individual’s contribution to peak demand (therefore allowing more customers to be supplied), but also limits power usage at non-peak times, thus reducing consumption and revenue for the operator. The mini-grid developer can through design ensure that the aggregate of loads does not exceed the available power and thus mitigate power quality issues or outages.

Figure 5: Electricity load limiter by Shenzhen Sailwider Electronics Co., Ltd. The limiter automatically gives an alarm or cuts off the power supply when the electrical power consumption is higher than a pre-set value.

[2] Most meters also have basic load limiting functionality.

Revenue collection method	Description	Advantages	Disadvantages
Manual collection	An individual from the community is responsible for visiting each customer on a regular basis to collect payments. Flat-rate or per-device tariffs can be used.	- No cost for hardware and maintenance. - Low-tech for easy management of system.	- Low revenue collection rates. - High risk of financial mismanagement. - Only allows simple tariffs. - If used with load limiter it restricts usage and lowers revenue.
Post-payment meters	The meters provide cumulative energy consumption readings (in kWh). Billing is forecast based on previous consumption and checked by customers. Verification visits are necessary for the operator. Time-of-day tariffs are possible by using two meters to record usage within different time windows.	- Improved revenue collection rates. - Allows consumption-based tariff.	- Billing is inaccurate. - Operator defers income. - Requires operator to take meter reading. - Medium cost of hardware. - Limited tariff options.
Pre-payment meters	Customers buy units and load onto meter; the meter acts as a bank and deducts according to the assigned tariff. On reaching a threshold value a warning is issued, and upon reaching zero the service disconnects. 'Emergency' units are usually available. Units can be obtained through vendors, scratch cards or mobile money platforms.	- Operator receives income up-front. - No meter reading required by operator. - Improved revenue collection rates. - Allows consumption-based tariff. - Flexible payment options.	- Higher cost of hardware and maintenance. - Inconvenience for customer to regularly purchase units.
Smart pre-payment meters	Smart meters have consumer-oriented features such as consumption records (in kWh, currency or CO_2), forecast amount of time units will last, real-time remote monitoring from other device (e.g. mobile), etc. Smart meters often transmit data to operator at regular intervals.	- More consumer-oriented features. - Promotes efficient electricity usage. - Improved customer monitoring for operator. - Can integrate with mini-grid monitoring and control system.	- Higher cost of hardware and maintenance.

Table 2: Revenue collection methods and technologies

Some pre-payment metering systems offer further functions to influence or control consumer behaviour in order to better balance generation and demand and to "smooth" the mini-grid's load profile over the course of a day or several days. For example, a solar mini-grid in Nepal visited by partners of the ESCoBox project uses pre-paid meters that switch off power when one of two limits is reached: when the pre-purchased energy credits have run out and when a daily total electricity consumption limit is reached.

Some post-payment metering systems also incorporate a “disconnect” function that allows the operator to remotely switch off a customer’s electricity supply in the event of repeated non-payment or misuse.

Tariffs

Clearly, the tariff type and structure have a direct bearing on revenue and utilisation of the electricity supply. The tariff structure needs to consider the customers’ willingness and ability to pay and the requirements of the regulatory agency. In many countries, regulation dictates that mini-grid tariffs should have parity with the grid tariff, but in other locations the mini-grid operator is free to set a tariff that is reflective of costs / system viability. In the case of private sector markets, the tariff structure should also aim to attract private parties to invest in mini-grids. The tariff structure is a strong determinant of the metering and payment system.

Tariff type	Description	Meter required (Y/N)
Flat-rate	A set fee per month irrespective of usage.	N
Capacity-based	Tariff is calculated based on maximum power limit. If the limit is exceeded the customer is disconnected.	N. But needs a load limiter matched to tariff level[3].
Device-based	Tariff is calculated based on number of lights / appliances in use. The operator needs to assess and verify the number of devices in use.	N
Consumption-based	Customers are charged based upon energy consumption.	Y
Service-based	Customers of electricity services – e.g. pumped water for irrigation, milled maize, TV viewing, etc. are charged by the business according to level of services utilised.	Y
Supply-type	A higher rate is charged for a three-phase supply (for high power and industrial users) than a single-phase supply.	Y. Three-phase meters are distinct from single-phase.
User-type	Customers are classified according to type such as domestic, business and social (e.g. school or clinic), with different tariffs charged to each.	Y

[3] For safety, all connections no matter what the tariff type require a current-limiting device but the rating of this will be much higher and not related to the tariff level paid for by the customer.

Consumption-based tariff structures	Description	Meter required (Y/N)
Linear	Customers are charged based only upon energy consumption.	Y
Block tariff or Lifeline / Social tariff	Customers are classified based on electricity consumption; as consumption increases beyond certain thresholds (e.g. 100kWh/month) the price per kWh increases. Two or more blocks may be defined. The lifeline / social tariff is a low price for low energy consumers.	Y
Time of day	A higher rate is charged during peak hours to incentivise customers to reduce consumption at these times.	Y. Sometimes two meters are used to measure consumption during certain time windows.
Dynamic/real-time pricing	The electricity price for a particular time slot (e.g. one hour, one day) is determined centrally and communicated to customers via smart meter displays or other means like SMS.	Y. Smart meter required.

Table 3: Tariff types, descriptions and associated meter types

Tariffs must be accepted by all parties before being put in place. Experience shows that tariffs accepted by the national regulatory authority might not be accepted by mini-grid users. Engaging communities in the tariff-setting process through structures such as village power committees can be a factor for successful long-term cooperation, mutual trust and, as a consequence, rapidly increasing electricity consumption as well as early breakeven. This engagement will require explaining tariff calculations and allowing community groups to contribute to the design and fixing of connection fees, basic service fees and per kWh prices. Especially critical situations can arise when tariffs have to be increased due to e.g. currency depreciation or rising fuel prices (SBI, 2013), and at these times good community engagement can greatly increase the prospects for a smooth and sustainable transition.

Costs

The often-remote locations of mini-grids are a significant factor in reducing their financial viability; quite simply the staff time and expenses associated with frequent visits to isolated locations can render a mini-grid financially unsustainable. For many mini-grids with rudimentary technologies, site visits are regularly required for:

- Monitoring of system performance
- Technical maintenance and repair
- Payment calculation and collection
- Customer relationship management

Modern communications technologies allow the mini-grid operator to monitor key indicators of supply and demand remotely, providing access to information that drastically reduces the need to physically visit the mini-grid, and thus significantly reduces operational costs.

Figure 5: Real-time performance monitoring of a SteamaCo micro-grid in Kenya on their Dashboard.

With access to the internet, the operator can have real time monitoring (RTM) (instantaneous or at convenient intervals) information on:

- Power generation
- System frequency and voltage (for power-limited systems)
- Battery voltage and energy storage (for energy-limited systems)
- System failures
- Power demand (for each individual customer and/or aggregated demand)
- Revenue collection
- Customer credit volume (i.e. amount banked in pre-pay units)

Data is uploaded to the cloud by the Global System for Mobile Communications (GSM) network. Clearly, good mobile network coverage is a necessity. The cost of GSM hardware and ongoing service costs are also a consideration. Frequent reports allow a performance history to be built up and indicate significant recent trends that may alert the mini-grid operator of the necessity to undertake maintenance, or expand the system, for example.

Remote control systems can provide further cost reductions, enabling the mini-grid operator to disconnect and reconnect individual customers or sub-sections of the network in order to perform scheduled maintenance, emergency repairs or precautionary shutdowns when threatened by natural disasters.

However, it should be recognised that too much remote management may be detrimental to the mini-grid's sustainability. Through taking away control and responsibility from local governance structures and individual users, the result can be a degradation of consumers' willingness to act for the collective good.

Box 2: Real-time Monitoring, Control and Payment for Standalone Electricity Systems

Smart meters with real-time or near-real-time monitoring are also being incorporated into pay-as-you-go solar home system technologies. The smart meter has been proven to significantly increase repayment rates and reduce default. Detailed long-term battery data has also allowed solar home system (SHS) providers to refine their system design based on real user experience.

The real-time systems share much functionality with smart meters used on mini-grid connections to provide monitoring, control and payment functions. However, the smaller scale and typically lower cost of standalone systems relative to mini-grid connections mean that complex systems cannot necessarily be supported, and near-real-time systems are also widely used. These involve the use of encryption codes that a customer obtains and enters into a keypad to unlock the device for a set period or amount of energy consumption. The encryption code is obtained by sending a code (usually from a scratch card) by SMS to a server that in turn returns the code to unlock the device. The main challenge for this system is ensuring the efficient distribution and stock management of scratch cards (GSMA, 2013). Strong and reliable network coverage is also a necessity.

Integrated Monitoring, Control and Payment Systems

As introduced in the previous sections, dedicated technologies are being used to improve mini-grid viability by providing visibility of operational performance (monitoring), adjusting system components to balance or optimise generation and consumption (control) and enabling the use of smarter tariff structures or more effective revenue collection (payment). These improvements can increase a mini-grid's revenues, or reduce its costs, or both – allowing the operator to set a tariff structure that is affordable to the most number of potential users while fulfilling the operator's requirements for cost recovery or profitability. The enabling of pre-payment for electricity or the ability to remotely disconnect customers who are defaulting on payments are important features that reduce the risk for investors.

Traditionally, the functions of monitoring, control and payment collection were provided separately by different devices and systems (including human systems). However, in recent years products and services have become available that provide monitoring, control and payment collection functions in one package. These technologies offer the opportunity for seamless integration between mini-grid status monitoring and price-signal-based demand side management (time-of-day tariffs or real-time electricity pricing), although the cost and complexity of such approaches may not be appropriate at smaller mini-grid scales. The potential for all of these functions to be provided to an operator who is remote from the mini-grid location can also be a game-changing benefit, although this is potentially accompanied by disadvantages stemming from the removal of local control and responsibility. The most successful approaches may be those that strike a balance between local and remote control in order to preserve the user engagement and local governance support that is often needed for mini-grid sustainability.

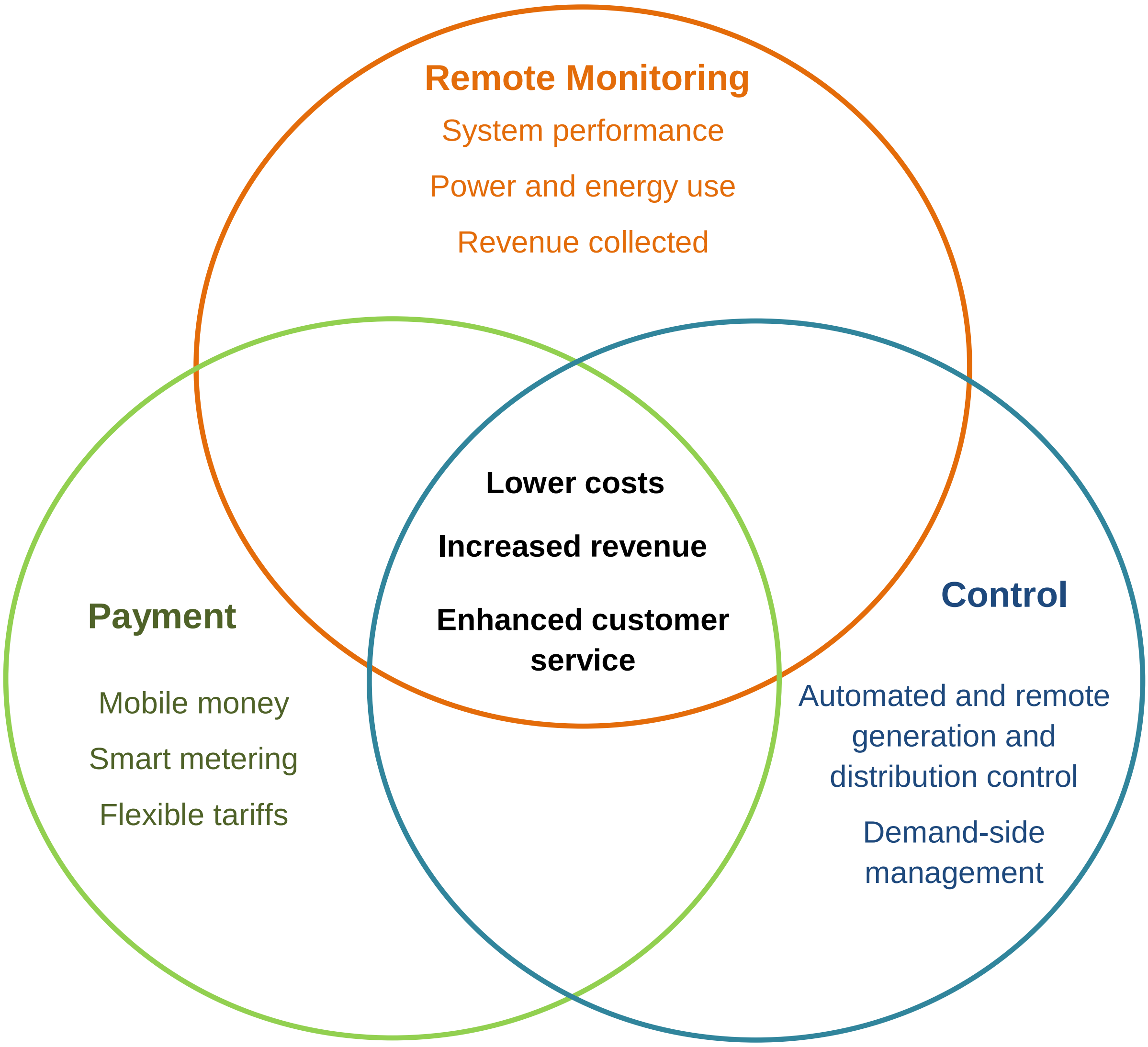

Figure 6: The viability 'sweet spot' at the confluence of Real-time Monitoring, Control and Payment Technology

Many integrated systems are also able to communicate with mini-grid customers through SMS to deliver diverse services: enabling payments using a mobile money platform, delivering automated communications (warning of unit consumption, outages, tariff changes, etc.), and permitting customer monitoring of their own accounts. The low-cost, low-risk, flexible revenue collection enabled by mobile money platforms is an enormous benefit. These technologies are easily adopted in countries with high uptake of mobile money platforms such as Kenya and Tanzania. However, in countries where mobile money penetration is low and usage expensive the difficulty of implementing remote monitoring technology is a significant barrier to project developers.

Some mini-grid supply companies have developed bespoke metering technology to fit seamlessly with their system, often incorporating monitoring, control and payment functions. There are also devoted technology companies that are producing smart meters targeted at the rural electrification market. **SparkMeter** is one example:

SPARKMETER

	Conventional Meters	Prepaid Meters	SparkMeter	AMI / Smart Meters
Pre-payment	✔	✔	✔	✔
Post-payment billing			✔	
Time-of-use tariffs		✔	✔	✔
Custom tariffs			✔	✔
Static load limits		✔	✔	✔
Custom demand management			✔	✔
Remote connect/disconnect			✔	✔
Remote monitoring			✔	✔
Loss detection			✔	✔
Cloud hosting			✔	✔
Locally autonomous	✔	✔	✔	✔
Amperage rating	100A	5 – 100A	5 – 120A	100 - 200A

Figure 7: SparkMeter Product Comparison (from product brochure)

AMI = Advanced Metering Infrastructure

Innovative Monitoring, Control and Payment Business Models

A number of mini-grid and solar home system businesses have developed and deployed business models that take advantage of innovative monitoring, control and payment technologies. These technologies allow mini-grid operators to reduce costs and increase revenues. Strong monitoring and control gives confidence to investors and donors seeking assurance of long-term technical and economic viability. This technological advancement also enhances the customer experience by improving the availability, reliability and quality of supply and increasing convenience and information about usage. Increased electricity access has strong links with social and economic development in rural communities.

The new pro-poor energy service business models that have emerged from this innovation include (IDS, 2013):

1 Mini-grid supply companies
2 Pay-as-you-go solar home systems
3 Fee-for-service solar home systems

SteamaCo is an example of a mini-grid supply company enabled by innovative remote monitoring, control and payment technology. SteamaCo operate more than 30 micro-grids, supplying electricity to about 1,000 homes in total. These installations are mainly in Kenya, and their number is growing rapidly with the assistance of commercial and donor financing.

The basic SteamaCo micro grid consists of a 6 kWp solar PV array, battery storage and distribution grid to 16 houses. The modular design can be increased in increments of 16 houses.

SteamaCo developed their own bitHarvester technology that provides real time monitoring of system performance, usage and revenues. The bitHarvester includes a 'THINK' unit and 'CONNECT' unit for full functionality. It relies on a GSM signal.

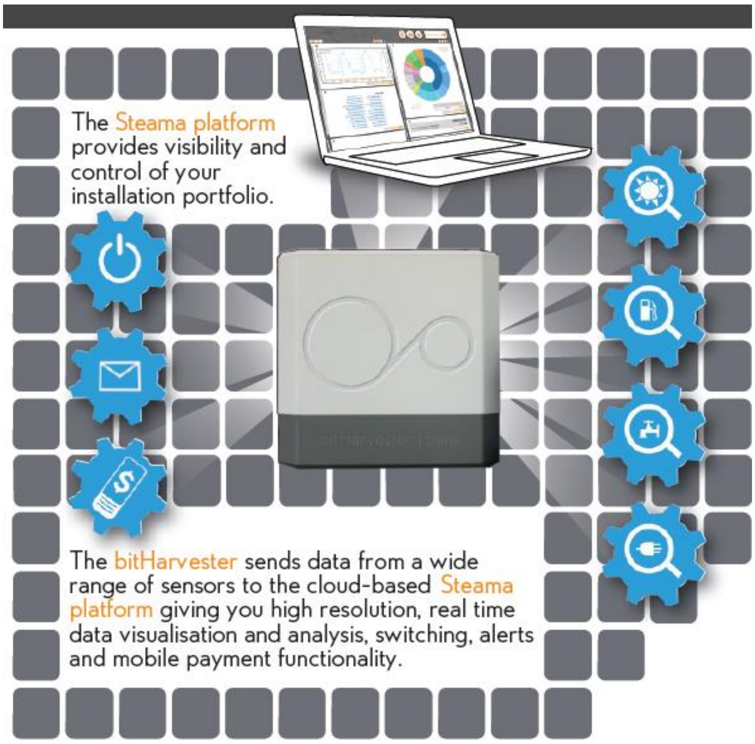

Figure 8: Illustrative diagram of Steama platform and bitHarvester functions

The standard SteamaCo micro-grid is a hub and spoke design, with each individual customer connected via their own line from the central battery bank to closely manage the smart control technology. However, flexible placement of the CONNECT unit allows for different arrangements if required.

SteamaCo's original business model involved the production, sale and installation of individual renewable energy systems. The company moved to installing micro-grids because more people could be reached by selling units of electricity rather than hardware. It was this experience that showed the value of remote management of metering, control and payments. The focus of the business is now the development and sale of the technologies that enable this. SteamaCo sells its hardware to micro-grid developers and leases the software on a monthly basis (Ashden Awards, 2015).

Figure 9: Solar PV power station using SteamaCo technology. Credit: SteamaCo

Independent micro-grid owners that deploy bitHarvesters can expect to pay around $1500-2000 for the hardware, and then a monthly fee of around $100 for the Dashboard software that gives access to the real time data.

The bitHarvester is also deployed in industrial applications to monitor and control the operation of machines, fuel pumps, air conditioning, etc. This is a second dimension of the SteamaCo business portfolio.

SteamaCo is an Ashden Award winner - a case study and video information is available on their site.

Inventory of suppliers of real-time monitoring technologies for pro-poor electricity access

Adapted from: ESCoBox research literature and *Real time monitoring technologies for pro-poor access to electricity* (IDS, 2013).

Mini-grid developers/operators supplying monitoring/control/payment technologies

Name of company	Monitoring, control and payment technology	Generation technology	Energy services	Business model	Geographic scope
Devergy	Pay-as-you-use meters with remote trouble monitoring.	Solar mini-grids	Power provision for low and medium-power appliances: lights, TV, radio, refrigerators.	Grid installation is covered by Devergy, however a small connection fee is paid by the customers. Customers enable their power supplies using codes punched into a metering box mounted in every home. Codes are bought via scratch-cards or sending an SMS requesting a credit code to the Devergy payment system.	Africa, though currently mainly operating in Tanzania
Inensus	The Load Management and Accounting Unit (LAU) with pre-paid smart cards.	Solar- or wind- diesel hybrid mini-grids	Provision of power to rural households and businesses.	Public-private partnership ownership model. Electricity is distributed through a mini-grid which is controlled by the LAU and to which users are connected for free. The electricity is sold to consumer households and community service facilities through Inensus Agents who sell electricity blocks. A block illustrates a load limit and energy limit.	West Africa
Gram Power	Prepaid smart meter. The meters together form a remotely manageable communication network that eliminates power theft and payment defaults, optimises supply and demand of power, allows wireless payments and provides grid performance data to Gram Power.	Solar, biomass, wind and hybrid technology microgrids	Power provision to telecom towers and to rural households for fans, lights, TVs, mobile phones and other small appliances.	Telecom towers pay a fixed monthly instalment according to the purchase agreement whereas households and enterprises use a prepaid purchase model. The local entrepreneur purchases bulk energy credit from Gram Power at a wholesale price. These energy credits, deposited in the seller's Energy Wallet, can be transferred to consumers' meters once they make the prepayment.	India

Husk Power	Self-developed pre-paid smart meters. Also a user of other firms' technologies, for example the SparkMeter.	30–50 kilowatt (kW) rice husk gasification power plants serving local mini-grids	Basic household electricity connections supply two 15-watt compact fluorescent lights and mobile phone charging. Increased capacity can be purchased.	Household subscribers pay a basic rate of $2.20 per month, which includes 40W of electricity for 6–8 hours every evening, enough to power two 15W compact fluorescent lamp (CFL) bulbs and recharge a cell phone. Business subscribers tend to use more electricity, between 60–75W, paying an average of $4 - 4.50 per month. Subscribers can pay more, at $1.10 for each additional 15W connection, if they have appliances requiring greater wattage. HPS' service compares favourably to the cost of alternatives such as candles, kerosene lamps, and LED lanterns. Local employees collect payments once a month.	India

Specialised metering technology providers

Name of company/ product	Monitoring, control and payment technology	Generation technology	Energy services	Business model	Geographic scope
Lumeter	Off-grid electricity meter that allows prepayments through mobile phones. Cloud accounting software transmits data on payments and time of usage to renewable energy providers. The meter can be integrated with lights or batteries provided by other suppliers.	n/a	Provide smart metering systems to mini-grid developers.	Meters have a payment mechanism similar to a pre-paid cell phone system, where customers can use their cell phone's text message service (SMS) to buy electricity credit.	Zambia and Peru

SparkMeter	Metering systems that allow both pre and post-payment, either for energy consumed or a flat-rate tariff. Technology allows real-time monitoring and control on microgrids. The system consists of four hardware components, a cloud-based operator interface, and a mobile money or cash-based pre-payment system.	n/a	Provide smart metering systems to microgrid developers.	Each micro-grid utility puts Spark Meter's flexible tariff system and load management to use in ways that are most beneficial to their business models, whether time-of-use or monthly fixed tariffs.	Haiti
Powerhive	Honeycomb m-PowerOS™ cloud-based software platform and mobile money pre-payment.	Solar mini-grids	**Indirect**: offers technologies and services to partners implementing mini-grids.	Powerhive partners with energy providers, project developers and local entrepreneurs that take the role of ESCOs, providing energy services to final customers	Kenya
SteamaCo	BitHarvester smart meters monitor and control mini-grid equipment and industrial hardware and relay information to SteamaCo's cloud software Steama.	n/a	**Indirect**: offers equipment/products and services to partners implementing mini-grids.	SteamaCo's business focus is the development and sale of technologies that enable remote metering, control and payments. SteamaCo sells its hardware to micro-grid developers and leases access to the interface (Dashboard) software on a monthly basis.	Kenya

Monitoring/control/payment technologies for Solar Home Systems

Name of company/ product	Monitoring, control and payment technology	Generation technology	Energy services	Business model	Geographic scope
Angaza Design	Angaza Energy Hub receives customer payments through different mobile money systems across multiple countries, securely and automatically communicating with customers' Angaza solar systems.	SoLite3 pico-Solar Home System, 3Wp	8 hours of lighting in normal or 4 hours in high mode, and mobile phone charging.	Small up-front payment and then pay-as-you go solar energy.	Tanzania, Kenya and Zambia
Azuri	The Indigo system provides real time information on top-ups: frequency and period of time covered. This links to a metering device integrated in the SHS that blocks the system when the period covered by the top-up ends.	SHS 3 – 80Wp	Basic system provides 8 hours of lighting (normal mode) or 4 hours (bright mode) for two rooms and mobile charging. As the consumer upgrades, the system can power appliances of increasing power consumption.	Small up-front payment, then pay-as-you-go using scratch cards and SMS service. After around 18 months the customer will have paid off the investment and can either own the system or upgrade to a larger system, through Indigo's energy escalator.	East Africa
BBOXX	BBOXX technology allows remote controlling and trouble alerts. Monitors customer energy use with high-resolution voltage, current and temperature data.	SHS	Designs, manufactures, distributes and finances innovative solar systems. Appliances include battery and phone charging systems, LED lights, LED TV, portable radios.	Sell solar home systems on credit spread over a long period. The instalments are matched to the current energy costs to make the offer attractive to clients.	Africa, Australia, Papua New Guinea, Peru, Colombia
EcoNet Solar	A power control module links the home power station to the mobile phone network to allow mobile payments and blocking of the unit when the credit runs out.	SHS	4 lights and mobile charging.	Prepayment through mobile phones.	South Africa

M-KOPA	A GSM communications module is attached to the product, to update credit purchased through mobile payments.	SHS	3 bright lights and mobile charging.	Initial deposit followed by periodic payments on a pay as you go basis, for up to one year. After completing payments, customers own the product outright.	Kenya
Mobisol	A Mobisol controller transmits real time information to Mobisol head office. Payments are made through mobile phone using the platform M-PESA. The remote monitoring technology transmits consumption and technical data. Potential maintenance problems are swiftly identified and the system can be locked automatically in case of overdue repayment.	SHS 20W, 60W, 120W and 200W.	Smallest system: light for 2 rooms and charging for 4 mobile phones. Largest system: multiple lights, laptop, TV, refrigerator, 10 mobile phones charged simultaneously. Enough energy to run a business.	Pay-as-you-go through mobile banking and microfinance, with a 36-month instalment plan.	Kenya and Tanzania.
Off-grid Electric	Pre-paid systems, with data link allowing software to track the systems.	SHS	Solar systems, LED lights radios and TVs	Financing for appliances like radios and TVs to customers. Payment collection via mobile money, allowing customers control over how and when they pay for services.	Tanzania
SIMbaLink	The SIMbaLink data monitoring system is a module with a GSM connection to the charge controller in a SHS, which logs data about the battery and sends it wirelessly to the product provider. Also has the function to lock or unlock the system according to credit availability.	n/a	**Indirect**: offers equipment/products and services to SHS providers.	SimbaLink's customers are SHS providers who are thus enabled to sell their products on a pay-as-you-go basis.	East Africa: Uganda, Kenya, Tanzania

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