GREEN MINI-GRID
HELP DESK

Module 9

Mini-grid Performance Monitoring

April 2020

ENERGY4IMPACT
ACCELERATING ACCESS TO ENERGY

INENSUS

SUSTAINABLE ENERGY FUND FOR AFRICA

Module Overview

Introduction to the Module

- Learning objectives
- Module Requirements
- Agenda

Topic 1	**Topic 2**	**Topic 3**	**Topic 4**	**Topic 5**
Introduction	Data Collection	Analysis	Performance Indicators	Reporting for Mini-grids

End of Module

- Module recap
- Further reading

Objectives & Requirements

Learning Objectives

- Learn about the process of mini-grid performance monitoring.
- Understand the type of data to collect and the different collection methods.
- Learn about the analysis tools available to developers, including the Mini-grid Quality Assurance Framework.
- Learn about the three most important areas for mini-grid reporting and the key performance indicators within them.

Module Requirements

- This module is targeted at mini-grid developers and operators at all stages of development.
- They are expected to have a basic understanding of rural, off-grid energy markets and community dynamics in developing countries.
- No prior knowledge of performance monitoring is required.

Agenda

1. Introduction
   - Definition
   - Benefits of Performance Monitoring
   - Process overview
2. Data Collection
   - Data collection overview
   - Data classes
   - Automated vs. manual data collection
   - Data collection tools
3. Analysis
   - Data analysis tools
   - Quality Assurance Framework (QAF)
   - QAF Service Levels
   - Analysis of socio-economic data
4. Performance indicators
   - Commercial & financial
   - Customer & utility accountability
   - Technical
5. Reporting for Mini-grids

Definition

Performance monitoring is the process of tracking technical, business, and social metrics for a mini-grid, and providing this information to all stakeholders to be measured against relevant performance agreements, standards, or specifications.

Benefits of Performance Monitoring

Developers

- Improve demand forecasting for existing and future micro-grids.
- Better understand energy needs and growth opportunities.
- Build trust with customers and evaluating customer satisfaction.
- Maintain customer service levels.
- Optimise operations by reducing O&M costs, improving revenue collection, and reducing system losses.
- Improve troubleshooting of technical system issues and failures.
- Monitor and mitigate against safety concerns.

Regulators & Policy Makers

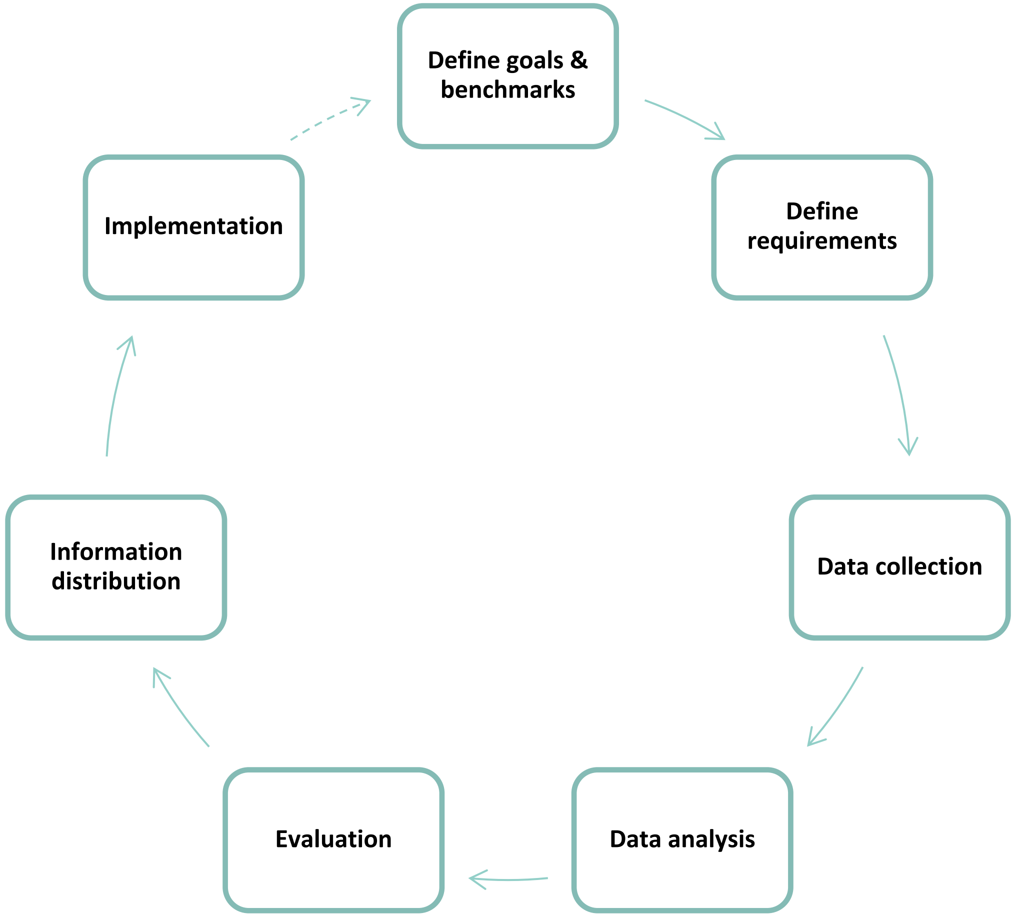
- Assess better the short and long-term energy needs of a community or region.
- Standardise system performance and services across installations and ensure regulatory compliance.
- Learn about impacts of regulation and if any modifications to the regulatory structure are necessary.

Investors & Donors

- Report and document business models, financial sustainability, and returns.
- Measure socio-economic impacts of mini-grids on the local community.
- Better understand risks and risk mitigation opportunities.

Process Overview

- **Define goals & benchmarks**: Define goals and target benchmarks that the project is seeking to achieve.
- **Define requirements**: Identify the data required to evaluate these benchmarks, and the method used to collect the data. Different goals will require different measurements or methodologies.
- **Data collection**: Use automated or manual methods as defined in the previous stage. Timely and accurate collection of data is critical to performance monitoring. Quality and relevant data is vital for data analysis.
- **Data analysis**: Verify and analyse the raw data to determine potential improvements to the mini-grid. Developing data analysis tools at an early stage in a project enables efficient and immediate analysis throughout the project. Analysis tools should be automated as much as possible and include an initial quality control to identify flaws or errors in the data.
- **Evaluation & distribution**: Evaluate potential improvements to determine if they are viable for the mini-grid's environment and resources. Communicate results of the evaluation to stakeholders for their approval.
- **Implementation & verification**: Implement corrective actions or system improvements that are necessary *and* cost effective. The actual impact of these improvements must be evaluated against the original benchmarks by a continued process of data collection and analysis.



Data Collection Overview

Methodology

- Type of Data
- Collection Method
  - Automated data recording instruments such as energy management systems, inverters, or smart meters.
  - Manual / hand-held devices.
- Frequency of collection (hourly, daily, monthly, quarterly, semi-annually, annually)

Resources

- Some developers require a lot of time and resources to manage data collection, but with well-designed collection infrastructure (e.g. smart meters) the burden can be reduced.
- Decide which measurement system to use during the development phase of the project so that the appropriate technology can be costed, procured, and installed.

Impact

- Collect data to measure two types of impact: economic and social.
- Measuring the social impact of a project is more difficult, but developers, investors and regulators will often all want to understand this.
- There are no industry standard frameworks or indicators for social impact for developers to use.

Data Classes

There are 3 "classes" of data:

Remote Monitoring Data

Smart meter and plant-side data collected monthly containing:

- Energy consumption data: if possible on hourly basis
- Energy payment data: number of customer payments and amounts
- Power quality (AC / DC): voltage stability, ripples & switching noise, transients, faults / day
- Power reliability: SAIFI, SAIDI (see notes)

Socio-Economic Data

Customer feedback:

- Customer complaints and satisfaction.
- Surveys on demographic, household, and income information, which is conducted by enumerators on the ground via mobile surveying applications.

Commercial & Financial Data

Commercial & financial data monitoring performance of the business:

- Financial information on past and projected CAPEX and OPEX costs (cost of connection, cost of power, payroll, etc.).
- Information on projected revenues and consumption (number of customers, of new connections, of unconnected customers). Information on tariff structure.
- Information on mini-grid sizing (total losses).

It is important to capture all these classes because they give a different perspective on mini-grid performance.

Sources: Quality Assurance Framework for Mini-Grids, NREL, U.S. Department of Energy, Nov 2016
Mini-Grids Performance Monitoring work done by E4I & NREL as part of the Power Africa Beyond the Grid programme

Automated vs. Manual Data Collection

	Automated	Manual
Pros	• Continuous recording of data with high flexibility of recording rate • Less labour intensive and time consuming • Generally more accurate • Can collect data at any level depending on equipment used (e.g. at the customer, feeder, or plant level)	• Low up-front and maintenance costs • Allows for flexibility in the data collection process and parameters recorded over time • Qualitative data can be collected
Cons	• High up-front cost • Expensive to maintain and replace • Requires a high level of technical skills to install and maintain • Focus typically on quantitative data • Can require a robust mobile network to transmit data	• Time consuming • Labour intensive • Requires data entry • Can be inaccurate due to human error in data collection and entry

Data Collection Tools

Automated

- **Smart meter**
  - Data about electricity supplied to each connection.
- **Inverter data**
  - Generation data: voltage, energy, power, battery charging / discharging and the amount of energy evacuated.
- **Energy management systems**
  - Same capabilities as an inverter, with some more advanced features: remote control of components of the mini-grid and demand prediction algorithms.
- **Automated SMS feedback surveys**
  - Surveys to gauge customer satisfaction in areas of the mini-grid service.

Manual

- **Qualitative / subjective data collection gathered from:**
  - Face-to-face surveys
  - Phone Interviews
  - Other customer feedback and staff

Data Analysis Tools

- There are currently no standard data analysis tools for the mini-grid industry, but several companies are working on components of this.
  - These companies include Spark Meter, Odyssey Energy, and a spin-off from Rafiki Power based on their Asset Management and Monitoring Platform (AMMP) technology.
- There are generic customer relationship management (CRM) tools which can be adapted to a developer's needs. These can incorporate payment systems (such as the Angaza Technologies platform) and SMS aggregators for bulk-sending of SMS messages.
- Analysis is often done on an adhoc basis. Developers need support, training and tools to create standards aligned with reporting requirements.

Quality Assurance Framework (QAF)

A mini-grid's **technical performance** can be measured using NREL's Mini-grid QAF.

The QAF evaluates performance against the service level of power supplied. **Level of service** measured by

- **Quality of power**: Voltage imbalances, transients, frequency variations, DC ripple, etc.
- **Availability of power**: Maximum power draw, amount of energy available and duration of daily service.
- **Reliability of power**: how consistently the power system provides power (SAIFI & SAIDI).

QAF service levels are based on international standards and typical power requirements of different electrical devices. These levels range between:

- **High** (highest number): parity with the grid.
- **Basic** (level 1): safety-based minimum.

Source: Baring-Gould, I. et al 2016 & Booth, S. et al 2019

QAF Service Levels

Here is an example showing the service level definitions for peak available power, which is a measure of power **availability**.

Power Level	Peak Level (W)
Level 1	>3
Level 2	>50
Level 3	>200
Level 4	>800
Level 5	>2,000
Level 6	>5,000

For more information on electricity service levels for quality, availability and reliability, please see Chapter 3 of Baring-Gould, I. et. al. (2016).

Analysis of Socio-economic Data

To assess the impact of testing and changes to a mini-grid's business model, standard statistical study designs and analyses should be used. This will enable the developer to understand the effect of new strategies ("treatments") on the mini-grid customers, without hidden biases skewing the results.

Study designs:

1. Randomised control trial
   - Control and treatment groups are assigned randomly. While this is the gold standard for study design, it can sometimes be impractical / unethical to randomly assign treatments to a population.
2. Encouragement design
   - Randomises likeliness of taking up treatment if randomisation of treatment access is not possible.
3. Natural experiment
   - Individuals are exposed to treatment based on natural conditions and not randomisation.

Useful analysis techniques:

1. Propensity Score Matching (PSM)
   - Used to match members of a treatment group with a suitable control group member. PSM matches treatment samples to the control samples with the closest propensity score I.e estimated probability that the sample has received a treatment.
2. Difference in Difference
   - Studies the differential effect of a treatment between a treatment and a control group.

Performance Indicators

Most performance monitoring happens during the **operation and maintenance** phase of a project.

O&M performance monitoring can be split into **three main functional areas**:

- Commercial and financial monitoring
- Customer and utility accountability and demand monitoring
- Power quality, reliability, and availability monitoring (QAF - technical)

Commercial & Financial Indicators (1)

Key indicators: **Customer numbers**

Indicator	Units
Number of customers	# (number)
New connections	# / month
Potential unconnected customers	#
Expired connections	#
Metered customers	#
Monthly payment collections (number of customers who payed / total number of customers)	%
Total electrification (number of customers / total population in reach)	%

Commercial & Financial Indicators (2)

Key indicators: **Revenues & Costs**

Indicator	Units
Revenue	USD[1] / month
Other revenues (e.g. from other services offered by the project, connection fees, wiring fees, etc.)[2]	USD / month
Administrative and/or distribution cost per connection	USD / connection
Cost of power generation, distribution and administration (disaggregated)	USD / kWh
Total cost of power	USD / kWh
Total fuel costs (differentiating fuel costs and fuel transportation costs)	USD / month; USD / litre

[1] When using currencies, any currency can be used. It is advisable, however, to use one that is stable so that trends are not hidden by currency fluctuations.

[2] Revenue data should be disaggregated by service level and sector.

Commercial & Financial Indicators (3)

Key indicators: **Power efficiency & contractual**

Indicator	Units
Fuel efficiency (to assess fuel loss and generator operational efficiency)	gallons / kWh
Total losses (kWh generated / kWh sold)	%
Number and type of suppliers or contractors	#
Performance of suppliers or contractors	description
Payroll (disaggregated by team)	USD
Team responsibilities	description

Customer & Utility Accountability Indicators (1)

Key indicators: **Performance, complaints and safety**

Indicator	Units
Performance of the project against the customer service level agreement	description
Annual electricity production	kWh
Renewable energy contribution (renewable kWh / total kWh)	%
Duration of daily service	hours / day
Number of complaints	#
Number of consumer safety incidents	# / month
Number of health and safety incidents (including near misses)	# / month
H&S report (identifying the incident or near miss, the staff / team involved, the root cause of the incident, and the corrective action taken)	report

Customer & Utility Accountability Indicators (2)

Key indicators: **Connections & community**

Indicator	Units
Power consumption (disaggregated by customer, service level, and type)	kWh / month
Number of new connections	# / month
Number of disconnections	# / month
Reasons for connection or disconnection	description
Number and type of outreach activities	#
Percentage of the community connected	%
Increases in the community's participation in local industry value chains	%, by value chain

Customer & Utility Accountability Indicators (3)

Key indicators: **Services, appliances and other**

Indicator	Units
Increases in the number of products and services available in the local community	# & types
Sample appliance ownership by customer	# & appliance
Customer satisfaction with various aspects of mini-grid service	Satisfaction score (1-5), with reasons
Training methodologies	description
Customer training on energy usage	# trained

Technical Indicators (1)

Key indicators: **Power quality and voltage**

Indicator	Units
Average power	kW
Maximum power	kW
Average power factor	kW / kVA
Energy generated	kWh
Amount of fuel used	Litre
Voltage imbalance	%
Transients	#
Voltage variations	# / day
Frequency variation	Avg. deviation (Hz) / time
DC ripple	%

Key indicators: **Reliability**

Indicator	Units
Planned power outages	#
Unplanned power outages	#
Length of power outage	hours & minutes
Average hours in a day that power is available	hours / day
SAIFI* (planned & unplanned)	Total number of customer interruptions / total number of customers
SAIDI** (planned & unplanned)	Total minutes of customer interruptions / total number of customers

*SAIFI - System Average Interruption Frequency Index
**SAIDI - System Average Interruption Duration Index

Technical Indicators (2)

Key indicators: **Battery performance**

Indicator	Units
Battery voltage	Volt
Current in & out	Ampere
Battery (charge) efficiency	%. Ratio of charge that can be extracted from a battery, compared to the amount that has gone in during charging
Battery temperature	Degrees
Cycle count	Unit

Key indicators: **Event recording**

For each key event (e.g. power outage / voltage variation / etc.) record:

Indicator	Units
Type of event	predefined category
Cause of event	predefined category
Outcome of event	predefined category
Date & time	date & time
Duration of event	time

Reporting for Mini-Grids

It is important for mini-grids to periodically report on their performance – often this is required by donors or investors.

Business Reporting: (usually quarterly)

Operational performance, financial performance, and growth potential:

- Total revenues
- Number of customers, customer by level of service, by sector
- Payment collection
- Revenues from other services
- Electrification rate
- Operating costs

Technical Reporting: (usually monthly)

Power quality and reliability, energy production and consumption, generation sources, and system efficiencies, KPIs:

- Annual electricity production and sales
- System losses
- Renewable energy contribution
- Number of outages
- O&M events
- Power quality events

Module recap

- Performance monitoring is important for all stakeholders: the mini-grid operator, their customers, regulators & policy makers, and investors & donors.
- Performance monitoring is a continuous process. Strategies are implemented, their impact is analysed, then strategies are updated, and the process starts again.
- Developers can collect data on the ground e.g socio-economic data or remotely e.g on consumption and payments.
- There are no industry standard data analysis tools, but some companies are offering platforms for such work.
- Developers report on 3 main areas of performance: customer demand/utility accountability; commercial/financial; and technical performance.
- Technical reporting can be done using the Quality Assurance Framework (QAF) which measures services levels based on quality, availability and reliability of power supply.

Further Reading

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