Quality Assurance Framework for Mini-grids

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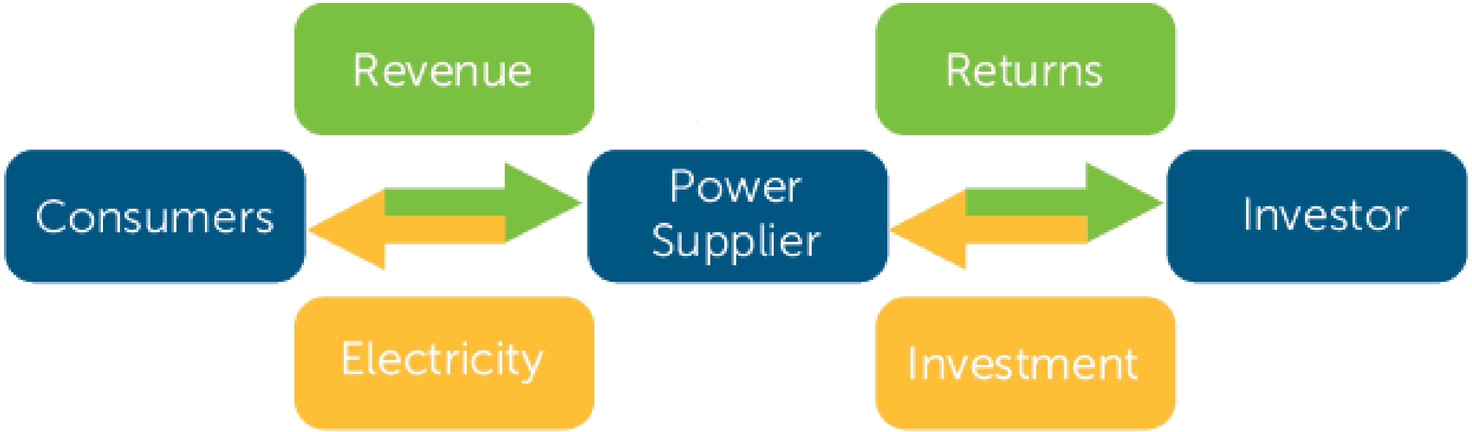
The Utility Model

Business models for commercially viable mini-grids must address the needs of the three key stakeholder groups:

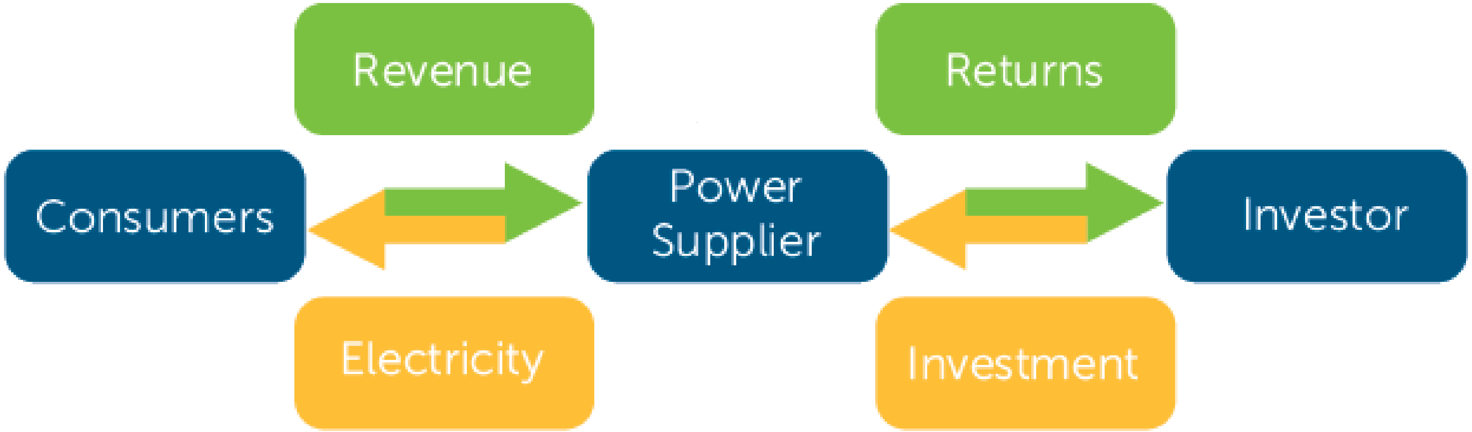
- **Customer:** Need a guarantee of service that they can afford and are willing to pay for
- **Power Suppliers:** Need to be able to guarantee a rate of return to their investors while covering operational costs
- **Investors:** Need to be confident of the risks they are taking



THE MINI-GRID MODEL

Utility model breaks down in the case of rural electrification as a result of three main challenges:

- High cost of power provision to remote customers
- Lack of consistent cash flows from customers
- Poorly understood investment risk profile due to small number and high variability of projects



Mini-grids quality assurance (QA) framework

Purpose: Provide structure and transparency for mini-grids sector, based on successful utility models, while also accounting for the broad range of service levels required to meet the needs of various segments of the off-grid consumer base

Goal: Lay the foundation for successful business models in the mini-grids space

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Mini-grids QA: unlocking investment & scale-up

- **Provide common technical standard for classifying mini-grids** based on well-defined system specifications for different levels of service
- **Strengthen revenue flows by optimizing system design** through system specifications better tailored to different tiers of consumer need and ability to pay
- **Facilitate aggregation and unlock private investment** through a common accountability framework:
  - Provides robust project specific market information that can expand general understanding
  - Allows aggregation of projects, decreasing risk
- **Flexible and adaptable framework:**
  - AC & DC mini-grids; applicable to renewable, fossil-fuel, and hybrid systems; capture basic to "grid-parity" service

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LINKAGES & STAKEHOLDER ENGAGEMENT

- Part of the **Action Plan for the U.S.-India PEACE initiative** (Promoting Energy Access through Clean Energy)
  - Stakeholder workshop held in India – August 26, 2014
- Part of **Power Africa "Beyond the Grid Initiative"**
  - Stakeholder workshop in Tanzania scheduled for February 2015
- Part of **SE4ALL High Impact Opportunity** collaboration on mini-grids

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Introduction to the Proposed QA Framework for Mini-Grids

DEFINITION OF MINI-GRID

Mini-grid concept assumes an aggregation of loads and micro-sources operating as a single system providing electric power and possibly heat. A modern mini-grid may include renewable and fossil fuel-based generation, energy storage facilities, and load control. Mini-grids are scalable, so that additional generation capacity may be added to meet growing loads without compromising the stable operation of the existing mini-grid system.

In this context the Framework is considering smaller systems, generally below 1 MW in size with only distribution level electrical interconnection but more typically would be below 100 kW with no real minimum size.

Note: There are several inconsistent uses of the terms mini-grid and micro-grid, even in international standards.

ELEMENTS OF THE QA FRAMEWORK

1. **Define levels of service** tailored to different tiers of consumers, including appropriate thresholds for:
   - Power quality
   - Power availability
   - Power reliability
2. **Define accountability framework**
   - Clear process for verification of power delivery through trusted information to consumers, funders, and/or regulators
   - Provides defined assessment and reporting protocol for operators

QA framework DOES NOT mandate a standard level of service: "truth in advertising"

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Mental Model – Standards

Two important elements about standards:

1. Replicability/standardization of a product
2. The product is built around the standard

Coordination of Standards for Mini-Grids

Isolated power systems incorporate multiple standards:

1) Power system equipment – Various IEC and National standards exist for most components
2) Mini-grids systems and deployment - 62257 series
3) Distribution system – National standards or WB Guidelines
4) Home wiring – National standards or 62257
5) Quality Assurance Framework **– This Work**

Additional needs:

- Policy on interconnection of isolated grids and the national grid (technical, financial, cost recovery)
- Power system implementer certification

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Elements of the QA framework

1. **Levels of service** tailored to different tiers of consumers, including appropriate thresholds for:
   - Power quality
   - Power availability
   - Power reliability
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   - Clear process for verification of power delivery through trusted information to consumers, funders, and/or regulators
   - Provides defined assessment and reporting protocol for operators

Levels of Service

Levels of Service for Isolated Systems

Power Quality – The power that is provided is of a reasonable or defined quality to safely provide the energy needs of the consumers

- Voltage, frequency, and distortion etc.

Power Availability – Is the power provided in the amount that meets expectations and available with the duration that has been specified

- Hours of service, power and energy levels …

Power Reliability – Is the power provided with enough reliability to meet consumer needs

- System Average Interruption Frequency Index (SAIFI)
- System Average Interruption Duration Index (SAIDI)

POWER QUALITY

Mental Model – Rural Energy Needs

A work truck is a good mental model of “grid parity” power. Does everybody in a rural community need a work truck?

How does this apply to rural and mini-grid energy systems?

What is Power Quality?

- "Any power problem manifested in voltage, current, or frequency deviations that result in failure or mis-operation of customer equipment."
  - *Electrical Power Systems Quality,* Dugan et al 2002

- Power quality is an economic issue
  - Utilities
    - loss of unsatisfied customers
    - Power supply costs
  - Customers
    - equipment mis-operation, equipment damage, additional costs, safety

- Relevant Standards:
  - ANSI C84.1 – Voltage ranges
  - IEEE 1159 – Recommended Practice for Monitoring Electrical Power

Power Quality Issues

- Voltage phase unbalance
- Transients outside of system insulation design
- Short duration voltage variations due to faults lasting <1min
- Long duration voltage variations due to faults lasting >1min
- Voltage waveform Distortion
- Voltage Fluctuations/Flicker
- Frequency Variations

	Base	Standard	High
Voltage Unbalance	<10%	<5%	<2%
Transients	No Protection	Surge Protection	Surge Protection
Short Duration Variations	<5/day	<1/day	<1/week
Long Duration Variations	<10/day	<5/day	<1/day
Waveform Distortion	No restrictions	No restrictions	Noise Limits (?)
Voltage Fluctuations / Flicker	No flicker monitoring	No flicker monitoring	Flicker monitoring
Frequency Variations	48 Hz < f < 52 Hz	49 Hz < f < 51 Hz	49.5 Hz < f < 50.5 Hz

Power Quality in DC Mini-grids

- Conceptually more simple than AC mini-grids with respect to power quality however no real existing standards

- Voltage magnitude is the only real concern
  - No frequency- or phase-related issues
  - Unbalance, harmonics, flicker, and frequency variations are no longer problems
  - Voltage drop will limit the geographical footprint of a DC mini-grid

- Transients similar to AC systems
  - when loads or generation sources are switched on/off or
  - due to lightning

Power Availability

What is Power Availability?

- The amount of energy services being provided to specific customers based on need and other factors

- Availability ties together the parameters that define how much energy service is to be provided to a specific customer based on their ability and willingness to pay for that service. Expected to change over the life of the utility/customer relationship.

- **There are three main criteria driving Power Availability:**
  1. **Power:** Maximum draw in Amps or Watts
  2. **Energy:** Total energy available (kWh) over a defined time period (month, year)
  3. **Time of day service:** For what hours of the day is power available (hours per day)

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CURRENT MODEL: TIERS OF SERVICE

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Peak Available Power (W)	None	>1 W	>20 W	>200 W	>2,000 W	>2,000 W
Consumption (kWh/year)	< 3	3 - 66	67 - 321	322 - 1,319	1,319 - 2,121	> 2,123
Duration of Supply	None	> 4 hrs	> 4 hrs	> 8 hrs	> 16 hrs	> 22 hrs
Evening Supply	n/a	> 2 hrs	> 2 hrs	> 2 hrs	4 hrs	4 hrs
Quality	n/a	low	low	Adequate	Adequate	Adequate
Typical Applications (Cumulative)	None	Radio, Task lighting	General Lighting, fans, TV, light office needs	Air cooling, food processing, and task oriented food preparation	Refrigeration, water heating, pumps, expanded food preparation	Air conditioning, space heating and full food preparation

Multi-Tier Framework for Measuring Household Electricity Access – proposed by Mikul Bhatia and others 2013-2014, however this classification:

- Makes it hard to consistently classify different types of power systems or consumers since they can fall into multiple, or different Tiers.
- Specific to residential customers

1. Peak Available Power (Amps or Watts)

Power Level	Peak Level (W)
Level 1	n/a
Level 2	50
Level 3	100
Level 4	150
Level 5	200
Level 6	500
Level 7	1,000
Level 8	5,000
Level 9	>5,000

- Largely defines what types of devices (energy services) can be used
- Minimum and maximum levels of service for different customers could be specified
- Different rates could be applied to different levels of service

- **India experience**: Attendees mentioned that mini-grids are being used to supply lower per-household customers then demonstrated in the Tier systems, multiple customers only consume 50-100W.

2. Energy available Per Time Period

Energy Level	Energy use (kWh/year)
Level 1	n/a
Level 2	180
Level 3	321
Level 4	550
Level 5	1,319
Level 6	2,121
Level 7	5,000
Level 8	>5,000

- Would typically be tabulated over a period of time (month or year) even if pre-pay meters focused on energy were used
- Minimum and maximum levels of service for different customers could be specified
- Different rates could be applied to different levels of service

- **India experience**: Minimum average loads can stay between 0.5 to 1.5 kWh/day.

3. Time of Day Power Availability

Availability Level	Power Availability
Level 1	No guarantee of availability
Level 2	Variable certainty – X hours a day with Y% certainty
Level 3	Full certainty – generally 100% availability

- Variable certainty allows more flexibility in determining power availability (ex. 16h/day, 90% of the time
- Need to include a provision for time of day use, such as insuring electrical service in the evening, which may be important

POWER RELIABILITY

Power Reliability

- Represents how well the power system provides power during times when power should be provided.
- Unplanned power outages
  - System Average Interruption Frequency Index (SAIFI)
  - System Average Interruption Duration Index (SAIDI)
- Planned power outages
  - Planned System Average Interruption Frequency Index (P-SAIFI)
  - Planned System Average Interruption Duration Index (P-SAIDI)

Power Reliability - Unplanned Outages

Unplanned Outages:

Level of Service	SAIFI-Interruption Frequency	SAIDI-Interruption Duration
Base	< 52 per year	< 876 hours (90% Reliability)
Standard	< 12 per year	< 438 hours (95% Reliability)
High	< 2 per year	< 1.5 hours(99.99% Reliability)

Planned Outages:

Level of Service	P-SAIFI	P-SAIDI
Base	< 12 per year	< 438 hours (95% Reliability)
Standard	< 2 per year	< 1.5 hours(99.99% Reliability)
High	0 per year	< 0.0 hours(100% Reliability)

Note: These values are based on 24h service – final methodology will need to be modified for service that is only provided for part of the day

Providing Different Levels of Service

Multiple ways to provide levels of service:

- **System Standpoint:** The power system is designed to provide all customers a minimum level of service
- **Customer Standpoint:** Where each specific customer can be provided (and pays for) a specific Tier of service and the system provides different Tiers to different customers
- **Hybrid Approach:** Power quality is defined on a system level by the highest (?) required level of service while availability is defined by on Customer basis?

India Experience: Hybrid approach was most applicable.

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Summary of Levels of Service

Power Quality

Three levels to define different degrees of power quality with brackets based on grid parity and safe operation

Power Availability

Building on the Tiers of Service concept, defines different amounts of energy service that is expected by each customer

Power Reliability

Identifies planned and unplanned reliability levels to help ensure that expectations of energy access is met

Applying Levels of Service

CURRENT MODEL: TIERS OF SERVICE

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Peak Available Power (W)	None	>1 W	>20 W	>200 W	>2,000 W	>2,000 W
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Quality	n/a	low	low	Adequate	Adequate	Adequate
Typical Applications (Cumulative)	None	Radio, Task lighting	General Lighting, fans, TV, light office needs	Air cooling, food processing, and task oriented food preparation	Refrigeration, water heating, pumps, expanded food preparation	Air conditioning, space heating and full food preparation

Multi-Tier Framework for Measuring Household Electricity Access – proposed by Mikul Bhatia and others 2013-2014.

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Tiers of Service for Different Plant types

	Bhatia Tiers of Service by Category						
	Peak Power	Consumption	Duration of Supply	Evening Supply	Quality	Typical Application	Bhatia Tier
Part time diesel plant	3 to 4	4 to 5	2	4/5	3/5	3	?
Full time diesel plant	4/5	4 to 5	5+	4/5	3/5	5	5
Renewable only	Varies	3?	2	3	3/5	3	3
Small hybrid system	3 to 4	various	5+	4/5	3/5	5	4
Large renewable-diesel	5+	5	5+	4/5	3/5	5	5

+ indicated likely exceeds Tier 5 value

- Standard power plant topologies fall into different tiers – largely based on configuration, design, and operational mode
- A simple tier classification may not work well due to the range of potential options

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Isla Mechuque, Chiloe, Chile (Diesel Only)

- Island Community in Southern Chile with about 60 homes
- Power provided by a small diesel plant.
- Operated by a local energy cooperative.
- Power provided for a few hours in the evenings.
- Every electrified home pays a flat monthly fee for energy services
- Local businesses are run out of individual homes with no additional fee.
- Several small generators owned by the more wealthy families to provide more energy flexibility.
- Susceptible to fuel price instability: no funds, no fuel, no power.
- Local and regional government provide funding for major equipment problems

Tiers of Service – Part time diesel plant

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Peak Available Power (W)	None	>1 W	>20 W	>200 W	>2,000 W	>2,000 W
Consumption (kWh/year)	< 3	3 - 66	67 - 321	322 - 1,319	1,319 - 2,121	> 2,123
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- The Isla Monchique system and service Tier not easily classified

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Proposed QA Level of Service - Isla Mechuque

QA Framework Parameter	Level of Service
Power Quality	Standard
Min Power Availability	n/a
Max Power Availability	Level 8 (of 9)
Min Energy Availability	n/a
Max Energy Availability	Level 8 (of 8)
Time of Day Power Availability	4h/day with 95% certainty
Unplanned Reliability	Standard
Planned Reliability	Standard

Diesel only power system providing part time power

Power supply is typified by:

- No real control on energy consumption
- Home fusing providing the only power limits
- Flat payment negates minimum level of service values
- Time of day service is limited
- Some planned and unplanned reliability based outages expected

Subax, Xinjiang, China (Hybrid System)

- Small community of 60 homes in a very remote part of Western China.
- Power system consists of wind, PV, diesel generator, and a battery bank.
- System provided through a federal electrification program.
- Operated by the regional government.
- Power provided 24h per day with good reliability.
- Each household has a meter and pays on a usage basis.
- Small businesses pay a different rate.
- No real system in place to cover for major equipment failures

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Proposed QA Level of Service - Subax

QA Framework Parameter	Level of Service
Power Quality	High
Min Power Availability	Level 2
Max Power Availability	Level 5 (of 9)
Min Energy Availability	Level 2
Max Energy Availability	Level 5 (of 8)
Time of Day Power Availability	Level 3 (100% availability)
Unplanned Reliability	Base
Planned Reliability	Standard

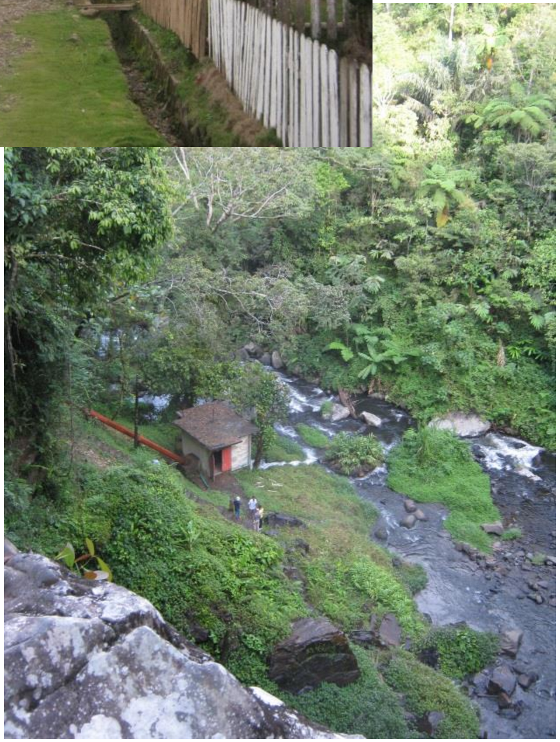
Hybrid power system

Power supply is typified by:

- Basic energy service provided with limits on energy use
- Basic home metering
- Full time power with good, power electronics based power control
- Issues of fuel availability and limited winter access causes high unplanned outages
- Planned reliability is good

Muara Siau, Indonesia (RE Only)

- Remote community in the mountains of Sumatra, Indonesia
- Pico-hydro power system.
- Operated by local power cooperative.
- System provided through donor funded electrification program.
- Power provided 24h per day with good reliability through seasonal fluctuation.
- Each household has several lights and one power plug that operate when power system running (note antenna's).
- All houses are metered, but pay a flat rate with no switches
- Small businesses pay a different rate.



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Proposed QA Level of Service - Muara Siau

QA Framework Parameter	Level of Service
Power Quality	Basic
Min Power Availability	Level 3
Max Power Availability	Level 3 (of 9)
Min Energy Availability	Level 4
Max Energy Availability	Level 4 (of 8)
Time of Day Power Availability	16 h/day with 95% certainty
Unplanned Reliability	Standard
Planned Reliability	Standard

Hydro based renewable only power system

Power supply is typified by:

- Limited power quality control
- Only basic energy appliances allowed but home fusing providing the only power limits
- Flat payment limits minimum energy level
- Time of day service is limited based on operator
- No system backup but hydro provides good unplanned reliability

Accountability framework

Accountability framework

1. **Consumer Accountability** defines, demonstrates, and validates that a specific level of service is being provided to a customer
   - Level of Service verification
   - Service Agreement

2. **Utility Accountability** allows funding or regulatory organizations to understand if the system is safe and providing contracted service
   - Technical reporting
   - Business reporting
   - Reporting template

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Consumer Accountability framework

Level of Service Verification

- Ability to record energy consumption
- Ability to record hours of service at service drops
- Ability to check voltage levels at service drops
- Implementation of periodic, random, and documented voltage surveys to ensure proper quality of service

Service Agreement

- Defines applicable power quality standards in place
- Identifies what type of investigation is warranted based on complaints
- Describes how to address power quality impacts caused by the customer vs. those caused by the power system (utility)

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Utility Accountability framework

Provides a defined and secure methodology for utilities to provide relevant information to regulators and project financiers, essentially the information that will allow a good understanding of the utility business

Information about the performance of the utility

- Technical Reporting: Measurements addressing system performance, energy usage, operational issues
- Business Reporting: Payment collection rates, electrification rates, customer characteristics, service calls and safety concerns, etc.

Reporting Template

Standard document or procedure that provides performance information to the funder/regulator, providing consistency across energy platforms and projects.

Technical Reporting Information

Technical performance information will include (as examples):

- Assessment of power quality
  - Voltage surveys for small systems
  - Expanded power monitoring for larger systems
- Energy production / Energy sales
- Plant Reliability – planned and unplanned outages
- Renewable energy contribution
- System efficiency (kWh/l)
  - Diesel system efficiency
  - Power system efficiency (including renewables)
- Operation and maintenance logging to document system upkeep

Business Reporting Information

Business performance information will include (as examples):

- Percent of renewable energy contribution over a defined time period
- Payment collection rate:
  - % of customers current on payments
  - % of customers that are more than 6 months behind
- Percent of electrification:
  - Number and % of residential customers in community electrified with electrical service that meets power quality requirements
  - Number and % of commercial and governmental customers in community electrified with electrical service that meets power quality requirements
- Number and nature of service calls and complaints
- Safety issues and workplace injuries

Reporting Template

- A defined reporting process and/or document that provides a consistent way to report utility performance
- Implemented to allow:
  - Security and accountability
  - Ease of data collection and processing
- Will result in:
  - Assessment of utility system
  - Trending of service and energy needs
  - Risk assessment of investment and the ability to develop mitigation strategies
  - Ability to look across investments

Summary of Accountability framework

1. **Consumer Accountability**

   Defines the expectations between the consumer and provider (utility) which increases overall confidence but also allows improved energy planning

2. **Utility Accountability**

   Defines a set of information that a utility should provide regarding operational performance, but more importantly puts in place a process that expands the off grid market from a series of one-off or small projects into a pool of mini-utilities, building investor confidence and decreasing risk.




CLOSING

Elements of the QA framework

1. **Levels of service** tailored to different tiers of consumers, including appropriate thresholds for:
   - Power quality
   - Power availability
   - Power reliability
2. **Accountability framework**
   - Clear process for verification of power delivery through trusted information to consumers, funders, and/or regulators
   - Provides defined assessment and reporting protocol for operators

How is The Framework Applied

Funders

- Integrate level of service concepts into community and initial system assessments
- Use Framework concepts as part of system supplier selection process
- Implement long term performance tracking
- Assess long term customer, operation, and payment information

Governments

- Specify a minimum level of service
- Integrate level of service concepts into community and initial system assessments
- Use Framework concepts as part of system supplier selection process
- Implement long term performance tracking
- Collect performance data to ensure compliance

Developers/Suppliers

- Use level of service information to design systems
- Use willingness to pay to identify rate structure that can cover costs
- Collect data to demonstrate operation, service levels, and payment
- Use level of service concepts to consider system expansion needs

Customers

- Know how to determine if their level of service meets that being paid for
- Process to alert regulators or power providers of any concerns

Benefits of the QA Framework

Funders

- Easier to define performance requirements that meet the needs of different consumers
- Standardized process to identify project revenues
- Standardized long term tracking of projects allowing improved sustainability
- Understanding of mini-grid risk profile
- Improved data on rural energy use and needs

Governments

- Easier to define performance requirements that meet the needs of different consumers
- Defined project development process
- Standardized long term tracking of projects allowing improved sustainability
- Improved data on rural energy use and needs

Developers/Suppliers

- Standardized approach to project development process
- Uniformity in mini-grids technology options
- Independent data streams to justify funding
- Reduced risk through standardized data collection and processing

Customers

- Overall higher quality of energy services
- Recourse if service is not meeting expectations
- More people with energy services

Next steps for implementation

- Pilot/demonstration projects: Spring 2015 – 16
- Seeking incorporation of QA framework into appropriate international standards and guidelines
  - Originally proposed as part of **IEC TS 62257 series** "*Recommendations for small renewable energy and hybrid systems for rural electrification*" but was never completed
    - Propose incorporation into updated IEC TS 62257
- Working with governments and donors to encourage adoption of the final framework

THANKS!
PLEASE PROVIDE FEEDBACK

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