TECHNICAL ASSISTANCE TO THE ETHIOPIAN ELECTRIC AUTHORITY (EEA) ON OFF-GRID REGULATORY FRAMEWORKS

TASK 3B: OFF-GRID TECHNICAL STANDARDS AND GREEN MINI-GRID FEASIBILITY STUDY GUIDELINES

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TASK 3B: OFF-GRID TECHNICAL STANDARDS AND GREEN MINI-GRID FEASIBILITY STUDY GUIDELINES (FINAL REPORT)

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Acronyms & Abbreviations

AC	Alternating Current
AtP	Ability to Pay
CAPEX	Capital Expenditure
CES	Collective Electrification System
DC	Direct Current
DFS	Detailed Feasibility Study
DSM	Demand Side Management
DoD	Depth of Discharge
EDA	Energy Daily Allowance
EEA	Ethiopian Energy Authority
EEU	Ethiopian Electric Utility
ESMAP	Energy Sector Management Assistance Program
GMG	Green Mini-grid
GPS	Global Positioning System
HH	Household
HRSL	High Resolution Settlement Layer
IEC	International Electrochemical Commission
IEEE	Institute of Electrical and Electronics Engineers
IES	Individual Electrification System
IEV	International Electrotechnical Vocabulary
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
KPI	Key Performance Indicator
kVA	Kilo Volt-Amps
LED	Light-emitting diode
LV	Low Voltage
MG	Mini-grid
MGRL	Main Grid Readiness Level
MTF	Multi-Tier Framework
MV	Medium Voltage
NARUC	National Association of Regulatory Utility Commissioners
NASA	National Aeronautics and Space Administration

NEP	National Electrification Program
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
PAYGO	Pay As You GO
PQ	Power Quality
PR	Performance Ratio
PSH	Peak Sun Hours
PUE	Productive Uses of Electricity
PV	Photovoltaics
OPEX	Operational Expenditure
OSM	Open Streets Maps
O&M	Operation and Maintenance
QAF	Quality Assurance Framework
RMC	Remote Monitoring and Control
SHS	Solar Home System
SLD	Single Line Diagram
TTA	Trama TecnoAmbiental
THD	Total Harmonic Distortion
TS	Technical Specification
USAID	United States Agency for International Development
WtP	Willingness to Pay

PART I: OFF-GRID TECHNICAL STANDARDS

Introduction

Intended audience

This document is written for the Ethiopian Energy Authority (EEA) and off-grid project implementers (both public and private) in Ethiopia, as a framework and recommendations for technical regulation.

As per the recent off-grid developments in Ethiopia and the rural electrification goals for 2030 set forth in the National Electrification Program 2.0 (NEP 2.0), EEA, NARUC and the consultants have identified off-grid technical standards as an important missing piece for off-grid market development, monitoring, and evaluation.

Approach

This document provides a series of recommendations for the minimum power quality, power service availability, and operational standards in a **demand-driven approach**, or in other words, for **off-grid electricity tiers as per the end-user's requirements** for both direct current (DC) and alternating current (AC) Green Mini-Grids (GMG), and more in general for off-grid assets (such as autonomous renewable energy plants). This document **categorizes the service level provided to the end-user, from least to most technically demanding**.

The ESMAP Multi-tier Framework[1] for measuring energy access categorization has been used and adapted in this document for capacity categorization and proposed values, while the International Electrochemical Commission (IEC) Technical Specification (TS) 62257-2[2] and the Quality Assurance Framework[3] have been used to propose categorizations and values of power quality and power reliability (the values have been adapted to be suitable for the Ethiopian context). The concept behind these tiered service levels is to **recognize the need for this categorization**—as opposed to regulating on a kWh basis only—motivated by the cost implications and the different energy needs of the tiers and the end-user's requirements of many rural customers.

Additionally, this document should be circulated among key stakeholders (including renewable and electrical engineer associations, relevant project developers and off-grid associations, donors, and financiers) for comments and feedback to **foster a participatory approach.**

Mini-grid definition

The term mini-grid (also referred to as a rural micro-grid or MG) refers to a small-scale distribution network (LV or MV) supplied by one or more power generation plants. It is usually conceived to operate as an isolated system with clearly defined physical and electrical boundaries, however it can be interconnected to other electricity grids such as the national grid. A mini-grid is comprised of the following elements:

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[1] Energy Sector Management Assistance Program (ESMAP), *Multi-Tier Framework for Measuring Energy Access*. https://www.esmap.org/node/55526
[2] IEC TS 62257 Series, *"Recommendations for Small Renewable Energy and Hybrid Systems for Rural Electrification"*.
[3] National Renewable Energy Laboratory, *Quality Assurance Framework for Mini-grids*, 2016. https://www.nrel.gov/docs/fy17osti/67374.pdf

- Electricity generation (power plant, including storage and distributed generation);
- Electricity distribution (distribution network);
- Electricity connection points (the physical and electrical boundaries);
- Electricity metering (metering systems, usually at the connection points); and
- Electricity consumers (may also be co-located with generators, e.g., solar homes, rooftop generation, etc.). Internal wiring and appliances may be included or not depending on the scope of work undertaken by the operator.

Table 1: Other mini-grid definitions

Source	**Definition**
IEC Technical Specification 62257-1	A **micro-grid** (or **mini-grid**) is a grid that transfers a capacity level of less than 100 kVA and powered by a micro-power plant
Definition of IES and CES by IEC Technical Specification 62257-1	**Individual Electrification Systems** (IES) supplies electricity to one consumption point (usually with a single energy resource point) and a **Collective Electrification System** (CES) supplies electricity to multiple consumption points (using a single or multiple energy resource points).

What is a Green Mini-grid?

A Green Mini-grid (GMG) is a mini-grid which mainly uses local renewable resources (such as solar, wind, biomass, or hydro) to generate power and does not depend on fossil fuels to serve client electricity needs. The cost-effectiveness of GMG versus conventional fuel-based mini-grids depends on the local energy resources, fuel prices, financial incentives, and the utilization rate of the power generation.

Solar photovoltaics (PV) tend to be the least expensive option and the most often chosen technology in remote areas for power generation. This is the result of the following factors:

- Ubiquitous resource
- Low installation capital expenditure (CAPEX)
- Quick installation pace
- Simplicity (no moving parts, proven technology)
- Robust operations and maintenance (O&M)

Rated Peak Load definition

This document uses the term "rated peak load" throughout as a reference for categorization of off-grid assets. The peak load in Kilovolt-Amps (kVA) is the maximum value of a load, real or planned, that occurs in a given period of time (e.g. a day, month, or year) not as an instantaneous value but as an average of the minimum resolution time (i.e. 10 minutes or 1 hour typically).[4] The rated peak load could be equal to the maximum value of the load over a period of time (peak load) or a safety factor could be applied (i.e., 10% or 15%) for the purposes of rating the peak load.

Rated Peak Load = Maximum Load x Safety Factor

Technical regulations currently applicable in Ethiopia

- Council of Ministers Energy Regulation No. 447/2019
- Draft Mini Grid Directive NO…./2020 (Version 3, Aug 2020)[5]

[4] *For more information consult the IEV Electropedia reference 601-01-16.*

[5] As of September 2020, EEA's final draft mini-grid directive has been approved by their Board. The draft is currently awaiting approval from the Attorney General and incorporates previous inputs from the following documents reviewed

Technical standards

The proposed technical standards can be sub-divided into 4 main categories:

- Power quality
- Power availability
- Power reliability
- Operational requirements

Balancing innovation and regulation

When regulating a market, the balance between regulating enough to protect customers and investors while not hindering innovation through over-regulation is sensitive. Off-grid assets have experienced a high degree of innovation at different steps of the value chain (finance, logistics, meters, storage, power electronics). More information about renewable mini-grids innovation can be found in the IRENA Innovation Outlook Renewable Mini-grids 2016 report.[6]

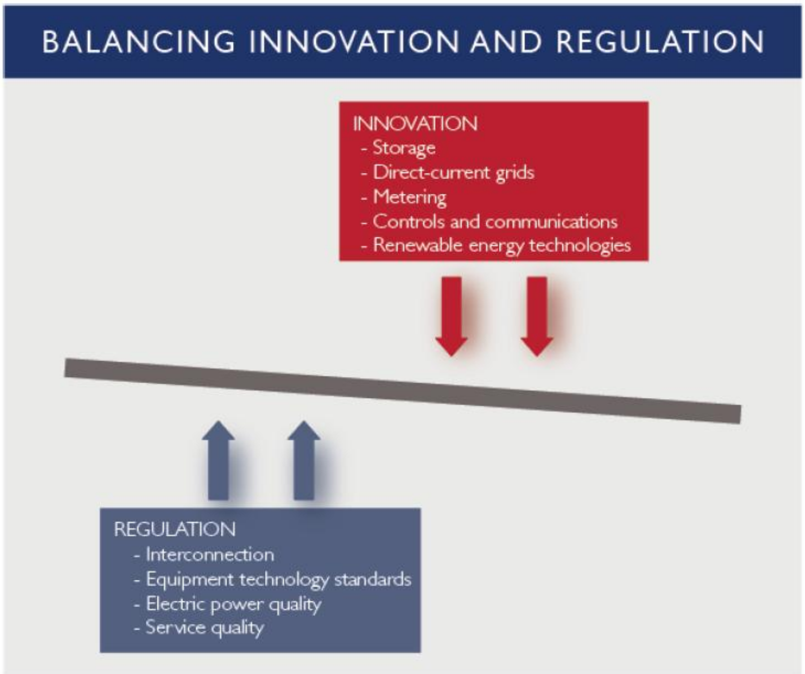

Figure 1: Balancing Regulation and Innovation, Practical Guide to Regulatory Treatment of Mini-grids (USAID, NARUC, 2017)

Certain appliances have become more efficient with regards to electricity consumption in recent years thanks to innovation. This is particularly true for DC lighting bulbs (LED), entertainment appliances such as televisions that can be powered through 12/24V DC input or 100-240V AC input, and refrigerators (Figure 2~~Figure 2~~). Moreover, other appliances like motors (e.g., for milling) are currently being tested in DC or renewable-energy powered mini-grids in countries like Nigeria and Tanzania.[7] Ultimately, innovation drives cost down.

earlier in development of this Implementation Plan: Directive for the Issuance of Licenses for the Electricity Supply Industry (Off-Grid Only), Tariff Guidelines and Methodology for Off-Grid Systems, Quality of Service Standards, and Design Standards for Rural Electrification.

[6]International Renewable Energy Agency, *Innovation Outlook: Renewable Mini-Grids,* 2016. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_Innovation_Outlook_Minigrids_2016.pdf

[7]Dougherty, Jane, *Milling on Mini-Grids: How Africa's Largest Crop Could Go Diesel Free*, April 16, 2020. https://nextbillion.net/milling-on-mini-grids-africa-maize/

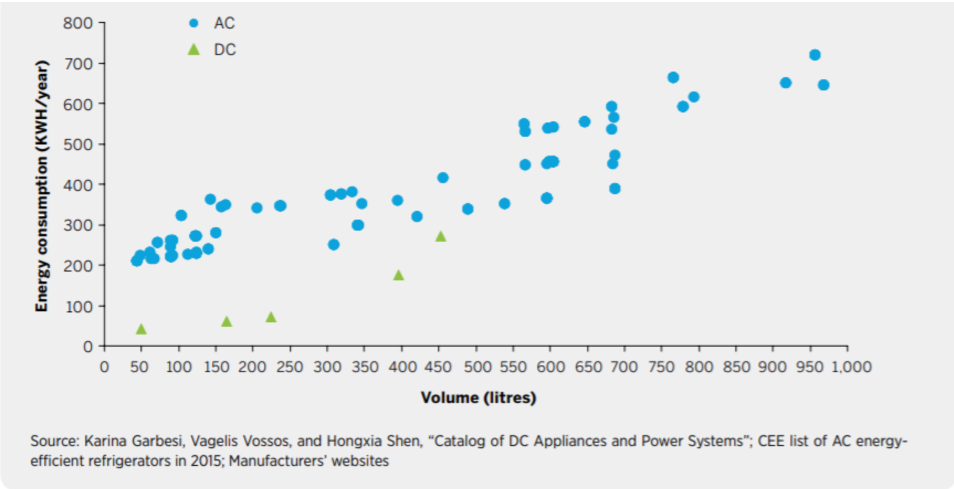

Figure 2: Comparison of annual energy consumption of AC vs. DC refrigerators; "The State of the off-grid appliance Market" report (GLOBAL LEAP, 2020)

The above figure shows a comparison between the consumption in kWh/year of DC refrigerators (green triangles) and AC fridges (blue dots) for different volumes (in liters). For the same volume capacity, DC fridges consumer less energy; in other words, they are more efficient in using electricity. Technical regulation should find the right balance between protecting customers and investors while favoring innovation.

1. POWER QUALITY AND ELECTRICITY SERVICE STANDARDS

1.1. Power Quality (PQ)

Power quality refers to the diversion from the nominal values of several electricity attributes (mainly voltage, frequency, and harmonics) and how they affect the interoperability between generation sources, distribution networks, and consumption loads (receivers of electricity).

Table 2: Power Quality definitions

Source	Definition
IEEE	IEEE 1100:2005 - Power quality (PQ): The concept of powering function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment IEEE 1159:2019 ▪ Main text definition "The term power quality refers to a wide variety of electromagnetic phenomena that characterize the voltage and current at a given time and at a given location on the power system"" ▪ Glossary annex definition "The concept of powering and grounding electronic equipment in a manner that is suitable to the operation of that equipment and compatible with the premise wiring system and other connected equipment."

Power quality is usually linked to compatibility with appliances and the potential damage to these appliances or receivers if some or any of the electricity attributes change or exceed certain thresholds. Historically these standards were created to protect appliances that were highly sensitive to changes in voltage, frequency, or harmonics from the rated value at which they were manufactured to operate. However, technology developments in the last decade has made these appliances more robust and sturdier in responding to these variations.

Three categories of end-user power quality are presented in the following table:

Table 3: Proposed Power Quality Categories (TTA)

CATEGORY	POWER QUALITY REQUIRED BY THE END-USER	EXAMPLES
Power Quality I (PQI)	The most basic category, for those users that do not require a high-power quality standard of their electricity power supply. These customers consume electricity mainly for lighting, phone charging, and other similar low-consumption high-tolerance devices, and therefore technical regulation can be minimal. Frequency regulation is not restricted here.	▪ Typical rural households consuming several lighting points and charging loads ▪ Street lighting ▪ Phone charging stations ▪ Dedicated source-to-power solutions (i.e., stand-alone systems)
Power Quality II (PQII)	This intermediate category provides tighter power technical requirements than the previous category, like surge protection for transients or frequency regulation that are not regulated in PQI.	▪ Businesses ▪ Places of worship ▪ Community centers ▪ Health centers without sensitive equipment
Power Quality III (PQIII)	The most demanding power quality category: for those users and appliances that require the least disturbances (i.e., have the least tolerance for disturbances) in the electricity supply and therefore the tightest power quality regulations.	▪ Healthcare equipment, such as respirators ▪ Electric motors ▪ Light industries ▪ Rural households with heavier power consumptions ▪ Telecom stations ▪ Other critical loads

Power quality attributes:

a. Voltage

In Ethiopia, 230V is the nominal voltage level for AC low voltage distribution in a single-phase distribution line, and 400V is the nominal voltage level from phase to phase in a 3-phase line. The Ethiopia National Electricity Distribution Code (ENEDC) establishes the maximum design voltage variation for High, Medium, and Low Voltage.

In line with the ENEDC, the proposed voltage variation values for the three PQ categories are as follows:

Table 4: AC voltage variation per Power Quality Category

POWER QUALITY CATEGORY	Voltage Variation
PQI	NA
PQII	< 10%
PQIII	< 10%

In DC off-grid assets, the DC bus that distributes electricity is typically coupled to the DC voltage at the battery level (source).[8] Therefore, the variations that occur in the voltage level because of the battery's state of charge (charging, discharging, floating) is translated into variations of the voltage level at the DC distribution, too. The following maximum variations are recommended for any of the power qualities, as long as the appliances and machines can work within range:

Table 5: DC voltage variation per Power Quality Category

POWER QUALITY CATEGORY	Voltage variation
PQI	±25%
PQII	
PQIII	

Voltage imbalance. In three-phase AC distribution networks, the voltage imbalance is defined as the deviation from the average of the three-phase voltage or current divided by the average three-phase voltage or current, expressed in percentage. Voltage imbalance occurs only in three-phase and this can cause motor damage due to excessive heat. The proposed maximum voltage imbalances for each power quality category are as follows:

Table 6: Voltage Imbalance per Power Quality Category

POWER QUALITY CATEGORY	Voltage Imbalance
PQI	NA[9]
PQII	< 5%
PQIII	< 3%

b. Frequency

[8] Converters and stabilizers are optional to in DC distribution system.
[9] It is anticipated that no rural customer of PQI will require a 3-phase connection.

Frequency, defined as the nominal frequency of the oscillations of alternating current (AC) in a wide area synchronous grid transmitted from a power station to the end-user is 50Hertz (nominal value).

Frequency oscillations allow renewable energy control systems to adjust power generation to match demand (among other features) through “frequency-based active power control”. This is also called power/frequency droop. This is a very important characteristic as it is relied on by most solar PV mini-grids and autonomous renewable energy generation power plants to adjust generation based on the state of the battery charge and demand.

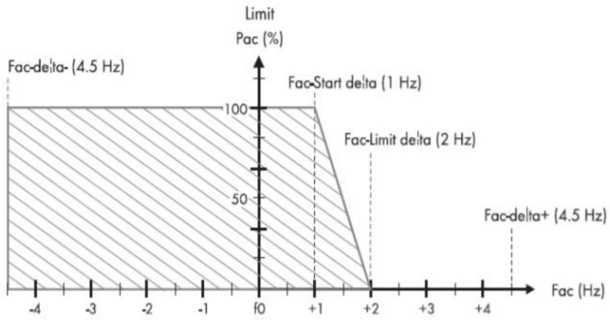

Figure 3: Frequency-based active power control example, SMA

To allow for the operability of these controls, wide ranges of frequency need to be permitted in AC grids. The proposed regulation per end-user category is as follows:

Table 7: Frequency per Power Quality Category

POWER QUALITY CATEGORY	Frequency regulation
PQI	No regulation
PQII	46Hz < f < 54 Hz
PQIII	48 Hz < f < 52 Hz

For DC grids, there is no frequency and therefore no frequency regulation.

c. Harmonics

A harmonic is a voltage or current at a multiple of the fundamental frequency of the electrical system (50Hertz in Ethiopia). It is produced by the action of non-linear loads such as rectifiers, discharge lighting, or saturated magnetic devices. Harmonic frequencies result in increased heating in some equipment and conductors and could cause major damage to equipment, such as motors and variable speed drivers. The Total Harmonic Distortion (THD) is proposed to be regulated as follows:

Table 8: Total Harmonic Distortion per Power Quality Category

POWER QUALITY CATEGORY	Harmonics (THD)
PQI	< 10%
PQII	< 5%
PQIII	< 3%

d. Transients

A transient is a sudden change in the steady-state condition of voltage, current, or both. Transients in electrical distribution networks result from the effects of lightning strikes and/or network switching operations, such as capacitor banks.

Table 9: Transients per Power Quality Category

POWER QUALITY CATEGORY	Transients
PQI	No protection
PQII	Surge protection
PQIII	Surge protection

e. Short-duration and Long-duration~~s~~ Voltage Variations

Short-duration voltage variation (also called “discontinuities” or short interruptions) are root-mean-square (rms) deviations from the nominal value for a greater time than 0.5 cycles of the power frequency, but less than or equal to 1 minute. These variations are typically caused by the operation of automatic reclosing systems like fault conditions or energizing loads that require high starting current.

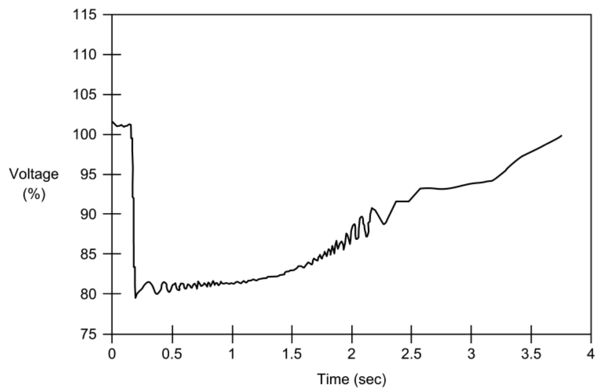

Figure 4: Temporary voltage sag caused by motor starting (IEEE 1159-2019)

Long-duration voltage variation are rms deviations at power frequencies for longer than 1 minute. Long-duration voltage variation can be over-voltage, under-voltage or simply voltage interruptions. Over-voltage is generally caused by load variations on the system and system switching operations.

Table 10: Short and Long-Voltage Durations per Power Quality Categories

POWER QUALITY CATEGORY	Short-Duration Variations	Long-Duration Variations
PQI	< 5/day	< 10/day
PQII	< 1/day	< 5/day
PQIII	< 1/week	< 1/day

f. Ripple

For DC grids, ripple is a residual periodic variation of the DC voltage due to the AC-to-DC conversion process. This ripple results from an incomplete suppression of the AC waveform after rectification. DC ripple can cause additional wear on devices designed to operate at a fixed DC voltage.

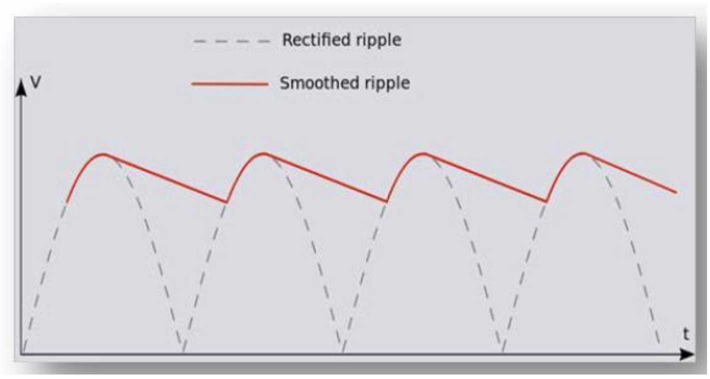

Figure 5: Ripple illustration because of an AC-to-DC waveform

Peak to peak ripple variation is important to regulate to minimize the potential wear on devices:

Table 11: Ripple variation and switching noise per Power Quality Category

POWER QUALITY CATEGORY	Peak to peak ripple (%)	Switching Noise
PQI	10%	Unfiltered
PQII	5%	Transient noise minimized
PQIII	2%	Transient + ripple noise minimized

g. Summary table

Table 12: Power Quality attributes per Category

POWER QUALITY PARAMETER PER POWER QUALTY CATEGORY		PQI	PQII	PQIII
AC	Voltage Variation	NA	±10%	±10%
	Voltage Imbalance (only 3-phases)	NA	< 5 %	< 2 %
	Frequency variations	not regulated	46Hz < f < 54 Hz	48 Hz < f < 52 Hz
	Harmonics	< 10%	< 5%	< 3%
	Transients	No protection	Surge Protection	
	Short-Duration Voltage Variations	< 5/day	< 1/day	< 1/week
	Long-Duration Voltage Variations	< 10/day	< 5/day	< 1/day
DC	Voltage variation	±25%	±25%	±25%
	Transients	No protection	Surge Protection	
	Percent Ripple	10 % peak to peak (pk-pk)	5% pk-pk	2% pk-pk
	DC ripple ¬ switching noise	Unfiltered	Transient noise minimized	Ripple noise also minimized

1.2. Electricity Service: Availability, Capacity, and Reliability

Electricity availability, capacity, and reliability are the main electricity service standards. The following tables are based on the existing Multi-Tier Framework (MTF) and IEC 62257-2 categorization for availability and capacity of the different end-user tiers of electricity.

This section uses the term "tier" as an energy categorization of a customer or connection from the service availability and capacity perspective. From the most basic category (Tier 1) to the most demanding category (Tier 2) in terms of availability and capacity of the electric service.

a. Availability is defined as the number of hours of electricity required for the different end-user tiers as per their needs, regardless of the quality of the electricity during these hours.

Table 13: Tiers of electricity service availability

MULTITIER FRAMEWORK	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
IEC TS 62257-2 terms	**E**	**D**	**C**	**B**	**A**
Daily Availability (hours)	> 4 hours		> 8	> 16	> 23
Evening Availability (7PM to 7AM)	> 1	>2	> 3	> 4	

b. Capacity is the maximum power provided for consumption and daily energy availed or served regardless of the power quality provided.

Table 14: Tiers of electricity service capacity

MULTITIER FRAMEWORK	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
IEC TS 62257-2 terms	**E**	**D**	**C**	**B**	**A**
Power Rating (W or kW)	≥3 W	≥50 W	≥200 W	≥800 W	≥2 kW
Daily energy Ratings (Wh or kWh/day)	≥12 Wh/d	≥200 Wh/d	≥1 kWh/d	≥3.4 kWh/d	≥8.2 kWh/d
Individual (I), Collective (C) or Businesses (B)	Individual	Individual	Individual or Collective	Individual or Collective	Individual or Collective
Services	- electrical lighting [1,000 lmhr per day]	- electrical lighting - air circulation - television, - charging loads (e.g., phone charging)	- electric lighting - entertainment - charging loads (e.g., phone charging) - small refrigeration	- electric lighting - entertainment - charging loads (e.g. phone charging) - refrigeration - basic cooking (pressure cooking)	Any service

c. Reliability is indicated by the total number of unplanned and planned interruptions in comparison to the agreed service availability (Tier 1 to 5)

Table 15: Proposed Power Reliability Categories (TTA)

CATEGORY	POWER RELIABILITY	VALUES
Power Reliability I (PReI)	Both planned and unplanned interruptions should ensure a 90% reliability supply throughout a year *Example: Basic households and businesses*	≥ 90%
Power Reliability II (PReII)	Both planned and unplanned interruptions should ensure a 95%	≥ 95%

	reliability supply throughout a year *Example: Schools and high consumption households (with refrigerators)*	
Power Reliability III (PReIII)	Both planned and unplanned interruptions should ensure a 99% reliability supply throughout a year. *Example: Health centers and small industrial customers*	≥ 99%

The above-defined percentages are calculated on yearly basis, adding the number of hours the service has not been available to the end-user (planned and unplanned) and dividing them to the equivalent number of hours the service should have been available as per the Tier availability (Tier 1 to Tier 5).

1.3. Safety Standards

Off-grid assets should comply with the Ethiopian electrical safety standards or national code, whether they are DC or AC. Mini-grids use complex technology that sometimes includes energy storage and they could pose chemical and electrical hazards if not properly handled and operated.

Beyond complying with safety standards, certified electricians and/or competent professionals should always be employed when executing, operating, and supervising electrical works. The decision of higher voltages than Low Voltage distribution (i.e. Medium Voltage) should be carefully considered, as the safety measures and protocols in Medium Voltage are significantly stricter and require specialized technicians. Beyond the safety implications, there is also a cost implication as the professional fees and equipment that needs to be in place has a higher cost.

1.4. Functionalities

The following functionalities should be provided as mandatory or optional depending on the category threshold of the off-grid power system. They should also be considered based on the component electrification project definitions per the NEP 2.0. The NEP 2.0 define component electrification as follows:

Table 16: NEP 2.0 Summary on component electrification

Distance to National Grid	Component electrification strategy as per NEP 2.0	Phase 1: 2025	Phase 2: 2030
< 2.5km	A. On-grid access (customers within 2.5km from national grid)	65% of the population (15 million households)	96% of the population
	B. Off-grid access, short-term pre-electrification	3.3 million households served with off-grid technologies first (Solar Home System (SHS))	3.3 million HH connected to the national grid
2.5km to 25km	C. Off-grid access, mid-term pre-electrification	5 million HH with off-grid technologies (SHS + mini-grids)	5 million HH connected to national grid (least cost)
> 25km	D. Long-term off-grid	0.9 million households (4% of the population)	

As an immediate consequence, any off-grid asset that is installed beyond 25km from the national grid is considered to be “long-term off-grid” and not planned to be interconnected to the national grid in the foreseeable future.

a. Main Grid Readiness

These technical standards suggest three levels of main grid readiness based on the maximum energy demand they serve in kVA and distance to the national grid, as per the NEP 2.0:

- **Main Grid Readiness level 0 (MGRL0)**, for off-grid infrastructure projects that fall into the long-term rural category (beyond 25km as per NEP 2.0) and have a rated peak load of 150 KVA as per the "Small Connections" category definition in the ENEDC.[10] These projects do not need to comply with interconnection procedures or synchronization protocols and standards, nor with the national distribution network construction standards, as they are expected to never interconnect to the main grid. Project developers may select any technology and materials as long as they comply with the health and safety codes of Ethiopia and they comply with other standards recommended and presented in this document.
- **Main Grid Readiness level 1 (MGRL1),** for infrastructure that may be interconnected to the national grid at some point in the future as per the projections of NEP 2.0, or for infrastructure that falls within the category of "Medium Connections" as per the ENEDC based on the maximum energy demand. For these projects, following a minimum of 1-year notice by EEU or other relevant authority, the project operator will need to comply with interconnection procedures, synchronization protocols, and distribution network standards defined in the interconnection or upgrade solicitation requirements. Additionally, the distribution network must comply with the Low Voltage and Medium Voltage standards, requirements, and interconnection voltage as per the agreement with EEU.
- **Main Grid Readiness level 2 (MGRL2),** for infrastructure that falls into the category of "Big Connections," as per the ENEDC. Here, the main grid readiness level of the mini-grid should be immediate, meaning that from the moment the project is commissioned it should be capable of interconnection with the national grid without any upgrade or retrofitting. Additionally, the transmission and distribution network standards should comply with EEU standards.

Table 17: Interconnection requirements depending on rated peak load of the assets and distance to the national grid

	RATED PEAK LOAD (thresholds from ENEDC[11])		
Distance	< 150kVA	150kVA to 5MVA	≥5MVA
< 2.5km	Only solar kits as per NEP 2.0, therefore interconnection requirements are not applicable		No market opportunities here
2.5km to 25km	MGRL1		MGRL2
>25 km	MGRL0		MGRL 1 or 2 depending on project, upon project scope, grid interconnection study

b. Remote Monitoring and Control

Remote Monitoring and Control (RMC) is the capacity to observe and manage off-grid power plants, distribution networks, and smart-meters with some degree of automation. RMC is a useful feature for technical cooperation and asset operators as it provides data that can inform maintenance

[10] Ethiopian Energy Authority (EEA), *Ethiopia National Electricity Distribution Code,* Draft, 2018.
[11] *Ibid.*

operations in remote locations and allows the evaluation of technical parameters and operability of off-grid assets or end-user consumption upon project commissioning. Three categories of remote monitoring and control are distinguished here:

- RMC of the power plant assets
- RMC of the distribution network assets
- RMC of end-user connections (smart-meters)

Following the same categorization as before, minimum remote monitoring requirements per category are proposed in the following table:

Table 18: Remote monitoring requirements depending on rated peak load of the assets and distance to the national grid

<table>
<tr><td></td><td colspan="3">RATED PEAK LOAD</td></tr>
<tr><td>Distance</td><td>< 150kVA</td><td>150kVA to 5MVA</td><td>≥5MVA</td></tr>
<tr><td>< 2.5km</td><td colspan="2">No mini-grid project falls in this space, only stand-alone power plants or kits:
▪ RMC of the power plant asset is recommended
▪ RMC of end-user connections is optional</td><td>No market opportunities here</td></tr>
<tr><td>2.5km to 25km</td><td rowspan="2">▪ RMC of power plant mandatory
▪ RMC end-users recommended</td><td colspan="2" rowspan="2">▪ RMC of power plant mandatory
▪ RMC of distribution assets recommended
▪ RMC of end-users recommended</td></tr>
<tr><td>>25 km</td></tr>
</table>

2. OPERATIONAL STANDARDS

To assess the power quality and service performance of an off-grid customer (and therefore its associated infrastructure), first the electric service performance should be measured and monitored appropriately. The amount of data to be collected and how it is to be collected should vary based on the limitations of operating in rural areas, the associated cost to the mini-grid operator, and the capacity of the regulator and other stakeholders to process and utilize this information.

As a best practice in the off-grid industry, a contractual relationship is defined with the customers (whether it's a mini-grid, a pay as you go (PAYGO) solar kit, or another technological solution), employing a standard classification of customers, gathering long-term data, and unlocking the economies of scale through aggregation. Therefore, the proposed operational standards have two components: customer accountability and off-grid accountability, as represented in the figure below.

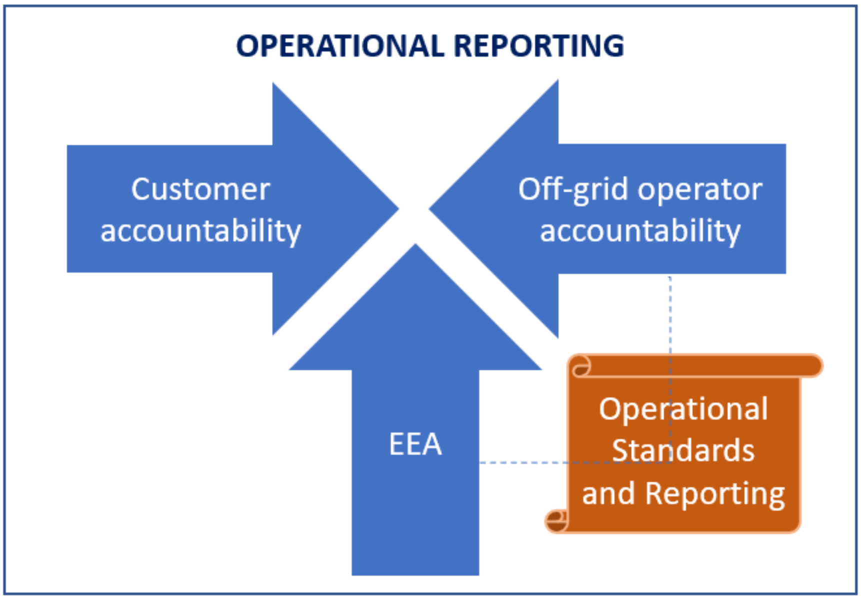

Figure 6: Operational Reporting Framework for EEA, Source: TTA

2.1. Customer accountability

Customer accountability defines a process to provide customers with trusted information on the level of service they receive and a clear way to confirm that service. Without the ability to understand personal energy usage (or in an extreme case, the potential damage of appliances due to poor power quality), the value and willingness to pay for energy services will be reduced. To help maintain strong customer support, customers must understand that they are receiving the service that they pay for, and mechanisms must be in place to verify their power delivery.

2.1.1. Level of service monitoring

The following monitoring capabilities at the customer point of connection are recommended:

a) Ability to check the voltage at service drops
b) Ability record electricity consumption
c) Ability to record hours of service at service drops

These three attributes above will give a sound indication of power quality, energy availability, and power reliability at the customer point of connection. Note that the level of service verification does not require that all elements to be measured continuously, although it is important to monitor these attributes at the customer level at least periodically and maintain a historical record over time. The use of smart meters facilitates the collection of robust real-time data across some or all these domains, but may be cost-prohibitive for some off-grid infrastructure.

2.1.2. Service agreement

To ensure a common understanding, **a service agreement that defines the expectation between the consumer and provider of energy services must be in place**. The service agreement must define the terms of service, including the details of the level of service to be delivered, tariffs and fees, payment processes, compliance with applicable standards and regulations, customer responsibilities, customer complaint procedures, and other relevant information.

For full transparency, the service agreement should also specify the type and frequency of service data that the off-grid operator will provide to the customer, as well as clear processes for addressing customer concerns if the appropriate service is not provided.

2.2. Off-grid operator accountability

In all mature energy markets, like the short to medium term off-grid market in Ethiopia, an entity is responsible for ensuring appropriate safety and provision of a specified level of service, even if that organization is not an active participant in the energy market. This organization could be a state or federal regulator, or an electrical standards body. Formal and routine reporting also allows regulators, funders, and other organizations to better understand the near and long-term technical and financial conditions of businesses in the off-grid sector. A better understanding of the market risks for current and future investments is documented through three levels of formal performance reporting:

A. Technical reporting
B. Business reporting
C. Other reporting, including social, environmental, and health

The proposed sections and content of off-grid operator reporting should always have an author and a date, for the purposes of traceability and accountability.

2.2.1. Technical reporting

The main elements of technical reporting for mini-grids include assessment of power quality and reliability, energy production and consumption, generation sources, and system efficiencies. The goal of technical reporting is not only to document the performance of the power system in terms of meeting contractual delivery of energy services, but also to report on the efficiency and reliability of those services to the relevant parties (i.e., EEA, other government agencies and project investors). This allows consumers and regulators, as well as the operator, to understand the quality of the service, the efficiency with which energy is being generated, availed, and sold, and any changes over time.

The selection of metrics or monitoring parameters will determine the choice of monitoring equipment and the method of data collection (e.g., voltage surveys for small mini-grids, power monitoring for larger power systems, etc.). Data collection methods also include the triggering thresholds, data storage and analysis technique employed, and uses for the information collected.

2.2.1.1. Technical Key Performance Indicators (TKPIs)

The following list indicates the main data that should be collected for technical reporting by the operator of the mini-grid or off-grid infrastructure:

1) Annual electricity production during the calendar year (January 1 to December 31) (kWh)
2) Monthly average load factor (%): average load demand/maximum demand
3) Renewable energy contribution: renewable energy production (kWh)/total energy production (kWh)
4) Power reliability reported for the period (January 1st to December 31st and/or monthly):
    a. At customer location (at least 5% of the total customers randomly chosen, and 1 customer that is the furthest to the power plant)
    b. At power plant location (in percentage or in hours)
5) Technical diesel generator (genset) data
    a. Total fuel consumption (liters) for the same calendar year (if applicable)
    b. Total hours operated by the genset and operating hours
    c. Total liters of oil needed for maintenance
6) Assessment of power quality events – report of any power quality events including the magnitude, duration, and time of occurrence of the following:
    a. Over and under voltage

   b. Voltage transient
   c. Power interruptions
   d. Over and under frequency
   e. Phase imbalance
   f. Harmonic distortion

2.2.1.2. Technical documentation

In addition to the above-mentioned technical data, other documents should be readily available in digital and physical copies at any moment from the commissioning point, including:

- Power plant commissioning report
- Distribution network commissioning report
- O&M logs
- Single line diagrams
    - Power plant
    - Distribution network
- As-built technical specifications
- Data-sheets, warranty certificates, and manuals of the major components
- Documentation on monitoring systems (if applicable)

2.2.2. Commercial reporting

A primary objective of business reporting is to create transparency on the operational soundness, financial condition, and growth potential of the mini-grid operating entity. This is important for the regulatory bodies, incentive providers, customers, lenders, and potential public or private investors. This reporting will help provide the basis for accurate risk assessment that can result in a higher level of confidence and lower cost of capital.

2.2.2.1. Commercial Key Performance Indicators (CKPIs)

The proposed main elements for business reporting include the following:

1) Customer portfolio information, in the following manner:
    a. Total number of customers
    b. Number of connections per tier of service
    c. Number of connections per sector (residential, commercial, government or institutional and large consumers);
2) Number of new connected customers for the reported period
    a. Total number of new customers
    b. Number of new connections per tier of service
    c. Number of new connections per sector (residential, commercial, government or institutional and large consumers);
3) Payment collection rate by tier of service and sector. Payment collection rate defined as the ratio of number of customers who pay the issued bills/tokens/prepaid fees over total number of customers being served by the mini-grid;
4) Electrification of the serviced area (%) defined as the total number of connections served by the operator divided by the total potential number of connections within the boundary of the off-grid operator;
5) Hardware expenses for equipment replacements, consumables and similar items;
6) Number of staff employed in the mini-grid and their associated cost;
7) Insurance expenses;
8) Land rentals and way-leaves, if applicable;
9) Transport costs (including fuel);
10) Total operating expenses;
11) Total fuel costs for the reported period;
12) Revenues by sector and by tier of service; and
13) Total and monthly average revenues from power sales.

Reporting can be completed at any interval, although annual reporting is recommended to EEA at a minimum.[12] While the level of business reporting discussed above is desirable and valuable, it is also expensive. Further, to be fully credible, it must be audited, which adds expense. The value of detailed reporting must be balanced against costs, to select an appropriate level of tracking and reporting.

2.2.3. Other Key performance Indicators (OKPIs)

2.2.3.1. Social KPIs

Social KPIs give an indication of the social acceptance of the mini-grid by the community. The following outputs are monitored:

1) Number of formal complaints by the community (individuals and groups);
2) Improved livelihood indicators or feedback (e.g., jobs created since project commissioning, improved services, hours saved by switching from non-electric tasks to electric, increased income etc.);
3) New infrastructure after project commissioning; and
4) Visitors to the mini-grid (a separate logbook for visitors is recommended).

2.2.3.2. Health, safety, and environmental KPIs

The recommended KPIs in this section should give an indication of the environmental impact of the mini-grid, safety, and health risks associated with mini-grids:

1) Health and safety incidents with short descriptions of events and root cause analysis; and
2) Waste management reporting, indicating:
    a. Waste generating items descriptions;
    b. Amount of the waste generated in correspondent units (liters, kilograms, or units);
    c. Location where the waste has been placed or disposed; and
    d. Opportunities for recycling this waste.

2.2.4. Monitoring progress

Operator accountability will only be achieved if a process is put in place that holds utilities responsible for the contractual commitments made to their customers, investors, regulators, and other relevant stakeholders. This, in turn, will require defined procedures for the monitoring, reporting, and verification of the technical and business elements discussed in the preceding sections. The monitoring process can be described in three stages:

Figure 7: Data Monitoring Stages

1. The first stage in the process is data acquisition. Acquiring the data for an off-grid asset will likely be a combination of hand-recording specific values and automated data acquisition systems.
2. Data aggregation is the second stage of the process. Based on informational needs, the type of data collection, and data delivery options, raw plant data collected in the first stage will be analyzed and summarized either locally or at a corporate headquarters.

[12] After the presentation on the *Draft Technical Standards and Green Mini-grid Feasibility Study Guidelines* and EEA feedback on the document held through Zoom platform on the 08th of August 2020. The consultant and EEA agreed that annual reporting would be an appropriate frequency given EEA's capacity to process this information.

3. Summary information about the operation of the power system can then be communicated to project stakeholders at specific intervals. Since different stakeholders require different information, data systems can be created for larger programs to ensure that the specific information is transferred securely to each of the different project stakeholders in a similar (and thus more useful) manner.

2.2.4.1. On-site monitoring

The onsite monitoring method uses the off-grid operator staff to evaluate the operation of the site, including by:

- Ensuring overall correct functioning of the asset;
- Checking for the presence of any malfunction in any component;
- Measuring equipment to detect faults;
- Interacting with the customers concerning supply and service satisfaction;
- Interacting with the community in regards with the social impact of the mini-grids; and
- Checking all occupational, health, and safety standards.

On-site monitoring involves reporting any information gathered during staff operations and maintenance of the mini-grid. This information would be recorded in different formats which should be stored in a proper filing system and used to produce reports required for compliance or decision-making purposes.

2.2.4.2. Remote monitoring

In a remote monitoring method, a cellular telecommunication network is used to establish connection between the operator of the plant and the assets. The owner/operator can record the data such as the performance of the PV array and temperature, battery voltage level and state of charge, the total energy produced, and other elements at predetermined times and on a regular basis.

2.2.4.3. Verification

Independent verification is a critical part of any accountability framework. Verification processes should cover the entire project timeline, incorporating a formal commissioning of the power assets, commissioning of any data collection processes, ongoing assessment of asset performance, and general reporting.

The intended verification process should be developed in the early stages of the project so that the requirements for data acquisition, reporting, and verification are identified and the associated costs are considered in the development of the project.

2.2.4.4. Restoration times

Restoration times are defined as the number of hours the electricity services is restored from the moment it was interrupted, either by a planned or unplanned event. When defining restoration times to mini-grid operators and off-grid operators, it is important to benchmark the below proposed values with the current restoration times of the national utility (EEU) in rural areas, as the required restoration times should not be stricter than the current benchmark of the utility in rural areas. This will ensure that costly and difficult to achieve requirements are not imposed.

Table 19: Recommended restoration times by Power Reliability Category (Source: TTA)

CATEGORY	POWER RELIABILITY	VALUES	PROPOSED RESTORATION TIMES
PRI	Both planned and unplanned interruptions should ensure a 90% reliability supply	≥ **90%**	**7 days maximum** from any planned and unplanned

	throughout a year		interruption
PRII	Both planned and unplanned interruptions should ensure a 95% reliability supply throughout a year	≥ **95%**	**4 days maximum** from any planned and unplanned interruption
PRIII	Both planned and unplanned interruptions should ensure a 99% reliability supply throughout a year.	≥ **99%**	**2 days maximum** from any planned and unplanned interruption

2.3. Key Performance Indicators Summary

Table 20: Off-Grid Key Performance Indicators (KPIs) Summary

	TKPIs	CKPIs	OKPIs
1	Annual electricity production during the calendar year	Customer Portfolio information: • Total number of customers • No. of connections per tier of service • No. of connections per sector	Number of formal complaints by the community
2	Monthly average load factor (%); average load demand/maximum demand	Number of new connected customers: • Total number of new customers • New customers per tier of service • New customers per sector	Improved livelihood indicators or feedback
3	Renewable energy contribution	Payment collection rate by tier of service and sector	New infrastructure after project commissioning
4	Power reliability: • At customer location • At power plant location	Electrification of the serviced area	Visitors to the infrastructure
5	Technical genset data: • Total fuel consumption • Total hours operated by the genset • Total litres of oil	Hardware expenses for equipment replacements, consumables and similar	Health and safety incidents
6	Assessment of power quality events	Number of staff employed in the mini-grid and their associated cost	Waste management report
7		Insurance expenses	
8		Land rentals and wayleaves	
9		Transport costs (including fuel)	
10		Total operating expenses	
11		Total fuel costs for the reported period	
12		Revenues by sector and tier of service	
13		Total and monthly average revenues from power sales	

PART 2: GREEN MINI-GRID FEASIBILITY STUDY GUIDELINES

Introduction

1.1 Background and rationale

Mini-grid companies and developers in sub-Saharan Africa come from a range of different market backgrounds (PV utility scale, SHS, general electrical works, etc.), and some of them might build their first mini-grid in Ethiopia. They often possess insufficient practical and theoretical experience in the mini-grid field, and they may lack an understanding of the common challenges and obstacles of developing this infrastructure on the ground.

Within the context of the new NEP[13], which aims to achieve 35% off grid access by 2025 and universal access across the country by 2030, mini-grids should play an important role in reaching remote rural communities. A rise in private sector involvement is expected and required to develop such infrastructures. As such, feasibilities studies will be of utmost importance to define where mini-grids will be the most technologically and economically suitable. **Ultimately a feasibility study should determine if a mini-grid is a suitable technological solution for a given site(s) and flag any important risks that may undermine the success and sustainability of the project.**

This guide lays out the minimum steps, industry best practices, and lessons learned from previous experiences for the mini-grid developers to carry out detailed, technically-sound GMG feasibility studies. This guide also aims to assist the EEA in understanding the steps that a GMG feasibility study should cover. This guideline can be used as a checklist and a reference as it reviews the mini-grid developers' feasibility studies as part of the licensing application.

In brief, this guide aims to support mini-grid developers to:

- Develop GMG detailed feasibility studies;
- Design technically sound solar PV mini-grids; and
- Understand key deliverables as part of the technical feasibility study.

The inputs, tools, and recommendations cited in this guide are based on the current regulatory and funding frameworks in the region, the consultant experience, and relevant inputs and insights raised by other local and international companies and public agencies.

1.2 Intended audience

These guidelines are targeted at the EEA and other relevant public institutions in Ethiopia (i.e., MoWIE, EEU, etc.) as well as to international and local developers and investors already present or interested in participating in GMG market development. The guidelines lay forth clear information, tools, and streamlined processes to successfully develop detailed feasibility studies of GMGs.

[13] Ministry of Water, Irrigation, and Electricity, *National Electrification Program 2.0*, 2019. https://www.powermag.com/wp-content/uploads/2020/08/ethiopia-national-electrification-program.pdf

1.3 What is a Detailed Feasibility Study (DFS)?

A GMG DFS is a comprehensive and exhaustive study based on on-the-ground data and a detailed technical and economic/financial analysis. It presents enough information to determine whether the project should be advanced to implementation. Such information should include fundraising plans, procurement goals, installation planning, commissioning details, and operation phase elements.

The DFS aims to evaluate the **viability of the project's technical, social, environmental, and financial terms** through an assessment of the potential energy demand. The energy demand is determined through a socio-economic study of the community. This study includes an on-site survey investigating the demographics, energy needs, and the communities' willingness and ability to pay. From the collected data and other relevant information available, a load profile is built and a preliminary sizing of the associated mini-grid can be performed. Costs are also estimated and the final key indicators estimating the viability of the projects are established.

2 Steps to a Detailed Feasibility Study

2.1 Site Assessment

2.1.1 Introduction to site assessment

An initial set of data is required to perform a first baseline assessment of the communities targeted to allow planning of the survey. This data should include, at minimum:

- Location of the site (district, province, region and most importantly the GPS coordinates);
- Population and number of households; and
- Current electrification status.

This data can usually be collected from governmental organizations (such as national institutions of statistics) or from previous studies realized as part of other development projects. The reliability of such data can vary widely depending on the area concerned; it is therefore essential to check them against the information collected from satellite imagery.

Assessments on each selected site will then be performed to obtain the socio-demographic characteristics of the following:

- Population and number of households;
- Economic and productive activities practiced by the population;
- Current electrification status;
- Willingness and ability to pay of potential end-users;
- Existing governance structures in the community or area (such as community associations or water community committees); and
- Households, businesses, and institutions demand assessment.

These characteristics will form the backbone of the DFS, as they will be used to determine the energy demand per site and the associated cost estimations of the mini-grid.

2.1.2 Surveys

This chapter describes the surveys that a developer must carry out for the site characterization and needs assessment of the end-users. At an initial stage of the project, at least two different types of surveys can be defined:

- The village-level survey; and
- The end-user surveys.

Ahead of a survey, the appropriate sample size needs to be defined using the data initially obtained on the population of each village.[14] The tolerable margin of error and the budget allocated for the survey will be key factors to determine the sample size.

2.1.2.1 Socio-demographic characteristics of target village

Surveys assist in understanding the characteristics of both village and regional dynamics. A village survey should at minimum contain the elements shown in the table below. These characteristics are often identified through focus group discussion, including with the village chief or village elders, his council, and other community-based organizations (such as women's groups, cooperatives, water associations, etc.) While determining these characteristics, it is recommended that developers take photographs of the community, the identified land for power plants, and important loads (e.g., grain mills) to determine productive uses of electricity (PUE). Coordinates of potential clients should also be noted.

Table 21: Main information to be gathered through a village survey

Infrastructure	- State of the access road to the village - Distance from the national grid - GSM network coverage - Land availability for power plant(s) and characteristics (soil type, ownership, distance from center, inclination, existence of trees and other obstacles) - Water infrastructure (existing water supply points)
Organization	- Administrative and political structure of the village - Associations (e.g., women's, carpenters, etc.) - Other similar community projects - Committees that could participate in the project (e.g., tariff committees that can negotiate with project developer and represent community clients) - Savings groups
Social	- Main source of income for the village (e.g., agriculture, fishing, livestock, small commerce, public sector, etc.) - Possible electricity improvements for marginalized peoples, including women, the elderly, the disabled, children and youth, etc. - Main obstacles for increasing household income (e.g., farmers, fishermen, entrepreneurs) - Existing conflict resolution mechanisms in the village (rule of law, others)

[14] Several tools can be found online such as the Sample Size Calculator (https://www.surveysystem.com).

Financial	- Income (minimum, maximum and average) - Sources of income (e.g., salaries, remittances, etc.) - Seasonality of income
Demographics	- Population, expected growth rate - Number of households and annual growth - Distribution between men and women - Share of female heads of households - Share of elderly (> 60 years) - Educational demographics (primary, high school, university, etc.)
Energy needs	*Residential:* - Number of households with fuel generator; what the generator powers (lighting/ productive use/ TV/ fridge/ others) - Number of households with solar panel; what the solar panel powers (lighting/ productive use/ TV/ fridge/ others) *Commercial and productive uses:* - Number of existing businesses (e.g., shops, grain mills, workshops, etc.) - New businesses likely to appear after the GMG arrives *Public institutions:* - Number of schools in the village, distance from power plants - Community water uses (public health, labor, power, etc.) - Number of health centers or hospitals - Number of places of worship - Number of local administrative buildings

The demographics data needs to be crosschecked with the information initially collected for site selection. The coherence of these numbers is important to obtain a realistic evaluation of the energy demand.

End-user survey

The end-user survey aims to assess the socio-economic status of the potential end-users, their energy needs, and willingness to connect to the GMG and pay for electricity services.

The end-user survey includes a series of questions for the potential residential, commercial/ industrial, and institutional clients of the mini-grid. This survey is intended to collect information on the purchasing power, energy needs, current energy uses, expenses, and other pertinent concerns of end-users. The questions should cover the following topics:

- End-user's occupation;
- Monthly income and seasonality;
- Disposable income for electricity;

- Current energy uses and expenses (e.g., kerosene lamps, torches, rechargeable batteries, private or shared fuel generator, phone charging, etc.);
- Willingness to support the project (by providing workforce, materials, etc.); and
- Willingness to pay for electricity tiers and services.

For the end-user survey, the project developer will need to employ a few enumerators to gather a representative sample from the target communities. In addition to the previous data gathering, the developer will also need to calculate willingness to pay from the potential household clients.

Prompts for the willingness to pay survey must be carefully designed to capture realistic information. **Anonymity in the survey should be considered by the developer**. It is recommended that an estimation of the cost of electricity service is prepared beforehand and potential clients are asked if they would be willing to meet that figure, and, if not, adjust the cost or the service level to be provided based on the survey outcome. Alternatively, the estimation can be updated by analyzing the percentage of monthly household income that would be required to pay for electricity.

For clients other than households, the developer should gather information on the following:

- For commercial and productive uses:
  - Type (e.g., shops, grain mills, workshops, etc.);
  - Running times and possible shifts;
  - Current energy sources and expenses;
  - Equipment compatibility of fuel-based machines; and
  - Cost and willingness to pay for retrofitting to connect (if needed).
- Public institutions:
  - Type (schools, health centers, hospitals, community buildings, etc.);
  - Current energy sources and expenses; and
  - Sources of funding to pay for the operator.

The following table shows an example of different types of businesses and institutions to consider when gathering the initial data.

Table 22: Sample type and number of businesses and institutions table, survey demand

Type of Businesses	No. of Businesses	Type of Institutions	No. of Institutions
Car/motorbike repair shop		Church/Mosque/Religious centers	
Bicycle repair shop		Primary school	
Market		Secondary school	
Small Shops or Kiosks		Health center	
Salons/Barbers		Police Station	
Grain Mills		Other	
Carpentry			

The developer will assess the current use of energy employed by existing businesses and public institutions in the community. This may come in the shape of diesel generators, lighting (e.g., clinics may have kerosene or traditional lighting), or other sources. Monthly expenditure will also be registered. For agricultural-related businesses or activities, which are often seasonally based, data gathering will be done based on seasons or services (e.g., agricultural value chains such as cooling or drying).

2.2 Geospatial analysis

Geospatial analysis using Geographic Information System (GIS) tools is useful to identify, assess, and select ideal mini-grid sites.

Geospatial data should be collected for the following data categories:

1. **Population and localities:** Distribution of the human population and its density is one of the main drivers of distribution cost. The High-Resolution Settlement Layer (HRSL) dataset provides estimates of human population distribution at a resolution of one arc-second (approximately 30m).[15]
2. **Electrical distribution network:** This should be provided in the National Rural Electrification Master Plan. Third party data and satellite images showing brightly lit areas at night (which may indicate existing electrification) might be used if no official data is available.
3. **Solar resource:** There are several databases available (SolarGIS, NASA, NREL, etc.)[16]
4. **Security:** Collect information on the location and severity of conflicts in the envisaged area with descriptions of the groups involved and the recommended level of security. This data is typically supplied by international security agencies and foreign affairs offices.[17]
5. **Accessibility:** This is critical for localization, logistics, and analysis, like measuring distance to the grid. The dataset provided by OpenStreetMap (OSM) on road data is among the most used accessibility datasets.[18]
6. **Phone Coverage:** Maps the availability of cellular data and mobile money networks for payments. If the area does not have access to a mobile network, a satellite connection point must be integrated into plans. Once the geospatial data has been collected, it can be integrated into the GIS tool by creating layers for further analysis. Localities can be filtered based on population and distance from the national grid using the above-mentioned categories. Once these layers are filtered, the aerial images of each locality can be visually inspected and analyzed based on different parameters:
    1. Community size;
    2. Population density; and
    3. Other factors, such as:
        a. Community access to tarmac road;
        b. Permanent, semi-permanent and temporary structures;
        c. Presence of institutions (schools, health centers, and others);
        d. Agricultural activity around the community; and
        e. Presence of lakes, rivers, or streams near the community.

These parameters will help gather initial relevant demand data, and to correlate that data with the information gathered through surveys and previous assessments.

2.3 Recommendations

- Preliminary GIS analysis must be conducted prior to on-the-ground data gathering. It is extremely important to correlate the information gathered under both analyses.
- The analysis of current energy consumption and expenditure (correlated to the ability to pay of the population) is critical, as this will provide insight into the realistic current capacity to

[15] Produced by the Facebook Connectivity Lab in collaboration with Columbia University, the dataset can be downloaded from the CIESIN website: https://www.ciesin.columbia.edu/data/hrsl/.
[16] One of the most used is the one provided by SolarGIS: https://solargis.com/.
[17] See guidance from the United Kingdom: https://www.gov.uk/foreign-travel-advice and France: https://www.diplomatie.gouv.fr/fr/conseils-aux-voyageurs/conseils-par-pays-destination/
[18] OpenStreetMaps can be accessed via: https://www.openstreetmap.org/

pay of different clients. However, the willingness to pay analysis will also provide additional information and understanding for future demand growth and socio-economic trends within the community.
- Identifying PUE is another key factor. Anchor clients are financially the most attractive ones and will help secure financial viability.
- This stage will build the bedrock of the GMG; therefore, gathering enough and reliable information will require having a significant sample of surveyed clients.

2.4 Expected products for the site assessment in a DFS

The minimum expected products to be delivered by the developer for the site assessment of a DFS are:

- Exact location of the community;
- Good quality GIS map of the community with clients geo-registered on it;
- Basic socio-demographic characteristic table; and
- Energy consumption and expenditure table.

3 Electricity Demand

3.1 Methodology: Tiered energy packages

A GMG's capacity to power commercial and productive uses (and consequently to enable economic growth and increase demand) is vital for its sustainability as a financial investment. In contrast to typical SHS, which are more appropriate for small residential applications, mini-grids can provide energy to large residential consumers and to productive users.[19]

Other than MTF service levels, other tier-based concepts exist in the GMG market, such as the demand assessment methodology, based on the Energy Daily Allowance (EDA)[20]. EDAs are standardized energy tiers or packages assigned to the different levels of users. They are all multiples of the basic EDA (275 Wh/day), which is the required daily energy for minimum electricity use for lights, phone charging, and other low-consumption appliances. Each tier can supply a specific type of service during a day, as shown in the following table.

Table 23: Indicated service offered by each EDA

Tier	Indicative service	Estimated EDA (Wh/day)
Tier 1	Lights, phone, radio	275

[19] National Renewable Energy Laboratory, *Productive Use of Energy in African Micro-Grids: Technical and Business Considerations*. https://www.nrel.gov/docs/fy18osti/71663.pdf
[20] EDA is a concept developed by TTA and widely used in many GMG worldwide.

Tier	Indicative service	Estimated EDA (Wh/day)
Tier 2	Lights, phones, fan, radio, TV, other small appliances	550
Tier 3	Lights, phones, fans, TV, other small appliances, fridge	2,200
Tier 4	Lights, phones, fans, TV, other small appliances, freezer, and productive use appliance	3,850

Each type of connection is classified under different tiers according to the estimated energy use, and an EDA is allocated to each tier. The process for tier classification and EDA allocation differs slightly for household, commercial/productive, and institutional connections.

The use of meters with daily energy limitation ensures that the client's individual consumption does not exceed the assigned EDA. This way, the power plant will never exceed its capacity, which ensures reliable electricity service and makes the mini-grid operator's financial and business planning more predictable.

3.2 Importance of demand estimates

The first step of the feasibility study is to gather data for the development of the project, with the aim of selecting specific sites for GMGs, estimate electricity demand, and understand the economic and social aspects of the target communities.

Electricity demand estimates are a key factor in GMG financial sustainability because it directly impacts the size and design of the generation unit and distribution line, and therefore the cost of the initial CAPEX. An analysis of existing and foreseeable appliances, current consumption, forecasted consumption when the GMG arrives, characteristics, and alternatives must be estimated and evaluated.

Part of this complexity and sizing challenge can be attributed to the lack of data regarding load profiles from productive use of energy in operating systems. While residential customers make up most of the connections, commercial and productive local businesses have much higher electricity consumption per connection and are more adaptable to the solar generation peak during daylight working hours.

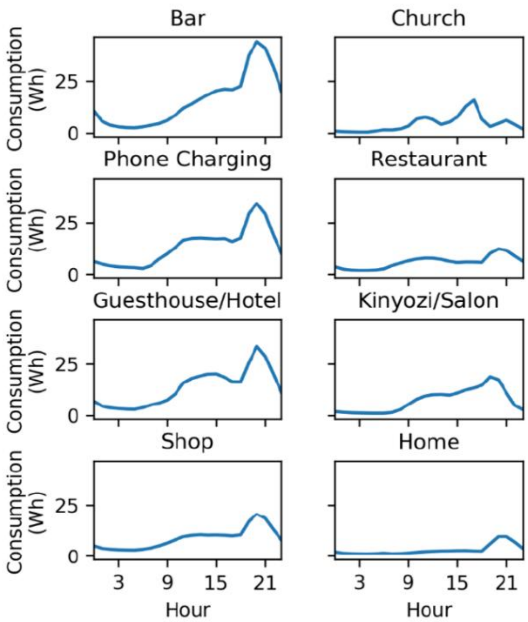

Figure 8: Productive use load profiles (Source: Williams et al. 2018)

Actual load data of operating mini-grids has been shown to be a better predictor of future consumption than surveys (Blodgett et al. 2017). When designing mini-grids to incorporate productive use loads, it is worthwhile to compare survey data with this operational data, aiming to adjust or confirm estimates. Additionally, it is valuable to review these load profiles and determine which types of business are best suited for operation at the time the loads occur. Finally, this data can be used to better understand what types of productive uses and businesses are currently operating in rural villages and how and when are they operated.

Within each product group, there is a diverse range of technologies which have different system size requirements.[21] Product specifications of typical productive uses are shown in Figure 9~~Figure 6~~.

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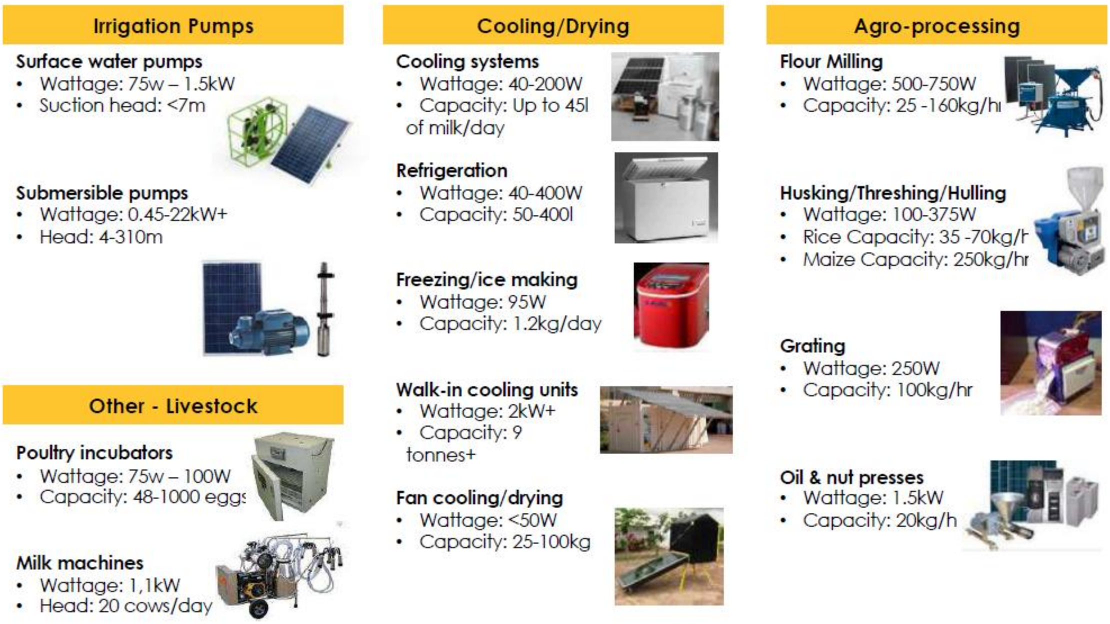

Figure 9: Product specifications of typical productive uses (Source: Lighting Global 2019)

[21] World Bank Group, *The Market Opportunity for Productive Use Leveraging Solar Energy (PULSE) in Sub-Saharan Africa*, September 23, 2019. https://www.lightingglobal.org/resource/pulse-market-opportunity/

The estimation of the electricity generation provided by the mini-grid throughout its lifecycle is a critical factor for the correct power plant sizing. An incorrect estimate of the energy required at deployment, and over time, will cause non-optimum sizing of components, which will lead to an inadequate power plant for the service requirements, financial inutility, and eventually GMG failure.

Additionally, generation capacity shortages will keep the service from meeting clients' expectations, cause frequent service outages, and reduce the lifecycle of batteries. This will affect the confidence the clients in the infrastructure, and consequently reduce their willingness to pay. On the contrary, an oversizing of the generation plant will increase installation costs which can translate into higher energy prices for consumers and jeopardize the financial sustainability of the investment.

CAPEX is one of the primary obstacles to deploying GMGs. There are several ways to reduce CAPEX, including:

- Diversification and appropriate choice of energy resources;
- Provision of efficient appliances;
- Adaptation of the consumption curve to the production curve through demand-side management (DSM) techniques; and
- Reactive power compensation.

The estimation of demand will be based on the application of these criteria and on energy efficiency measures—both from the consumer's point of view and from the design point of view.
It may occur that a significant amount of electricity demand grows over time, either because some potential clients are not connected from the beginning, or because demand grows after time. For this reason, when sizing GMG´s components, demand must be considered based on future growth and a connectivity rate, or on progressive connectivity until a certain year of the project.

As a general recommendation, sizing for estimated demand and connections in years 3-5 will result in an MGM with sufficient, but reasonable, overcapacity that leaves space to ensure that short-term demand growth can be served.

3.3 Current electricity demand

Following the data collection through the on-site survey, the developer will need to establish the level of household and anchor clients demand per energy tier. For this, **Error! Reference source not found.**~~Table 23~~ and **Error! Reference source not found.**~~Table 24~~ should be employed, respectively.

Error! Reference source not found.~~Table 2~~4 shows the estimated demand (Wh/day) per user in the community based on the identified tiers by the mini-grid developer, indicating the user´s tier level and the level of GMG sharing (as some users may prefer to use other generation equipment such as gen-sets or SHS).

Table 24: Sample household demand per tier mini-grid connections table

Tier	Estimated demand (Wh/day)	Share for mini-grid
Basic		
Medium		
High		

Error! Reference source not found.~~Table 2~~5 is an example showing existing users in the community and their estimated daily demand from the mini-grid.

Table 25: Sample anchor loads information table

Anchor load	Description and comments	Estimated daily demand from the mini-grid (Wh/day)
Police Station		
Grain mill (existing)		
Grain mill		
Retail shop		
Primary School		
Secondary School		
Health Centre		
Welding Workshop		
Car/Motorcycle Repair		
Retail shop		

3.4 Demand side management (DSM)

DSM for mini-grids involves adjusting electricity demand to suit generation patterns of renewable energy technologies. In the case of GMG, the goal of DSM is to shift demand towards daytime hours when solar energy is generated, minimizing demand at night, when electricity is supplied by the batteries to prolong battery lifecycles. This can be done either manually or automatically, through advanced or smart meters, by giving financial incentives, or by offering additional energy and power flexibility.

3.5 Demand stimulation

Stimulating local demand for electricity is a critical factor for GMGs to grow their profitability over their lifetime. Anchor productive uses of energy are critical for stimulating local demand.

Figure 10~~Figure 10~~ compares the initial CAPEX requirements and financial performance of several different productive uses. It shows which of the productive use opportunities considered have high investment requirements and the likely cost of promoting different productive uses through the provision of equipment to business owners. The figure also shows the electricity demand for the different equipment, which helps inform the anticipated installed capacity of the micro-grid. For entrepreneurs, the figure shows the expected investment cost for the different productive uses compared to the anticipated monthly sales and net profit. The figure will increase awareness among entrepreneurs of the likely range of power consumption for different appliances, which allows them to consider how to consume electricity more efficiently.

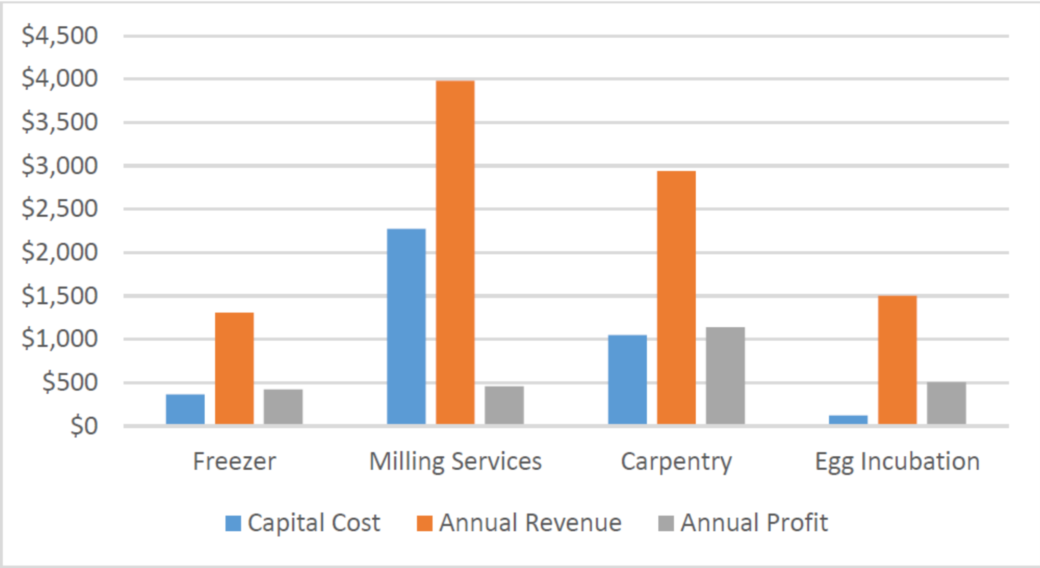

Figure 10: Investment requirements and financial performance of different productive uses (Source E4I)

In Nigeria, Green Village Electricity (GVE) has experimented with financing productive use equipment such as grinder motors. GVE has been able to increase utilization to 74% of peak capacity for its mini-grid by providing loans for soft-start electric motors, and the company expects further adoption will raise utilization to 90%.[22]

3.6 Consolidation of inputs into the studies

To choose the desired level of consumption for future clients, developers must first approximate their associated fee levels so that the consumption level is in agreement not only with the level of services required, but also with clients' ability and willingness to pay. Previous experiences in different regions in Sub-Saharan Africa can be a good starting point.[23]

As mentioned previously, using meters with daily energy limitations (based on the tier of the client) makes it easier to estimate the rated peak load for each planned connection. To validate the data, it should be compared to consumption data for other areas with access to electricity that share similar socio-economic characteristics. Existing GMGs, public/private developers, or mini-grid industrial associations in the region can sometimes provide valuable data. However, when comparing with data from another country, one must assess whether the regulatory framework or funding-subsidy structure is comparable, and whether differences may affect the consumption data.

Using standard tools and processes for data acquisition, storage, and analysis is recommended to help minimize human error. As an example, KoBoToolbox is an existing suite of tools for field data collection in challenging environments.[24]

Feedback from surveys is used to understand what services the local population requires. Results commonly show that lighting is the priority service, followed by phone charging and entertainment activities (such as TV or radio) for residential clients. Surveys also identify existing types of productive use. GMG business models and financial sustainability rely heavily on energy demand originating from potential anchor clients based on their productive and commercial activities. GMGs

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[22]Rocky Mountain Institute, *Mini-grids in the money: Six ways to reduce mini-grid cost by 60% for rural electrification, 2018.* https://rmi.org/insight/minigrids-money/

[23] For more details, please refer to ECREEE Guide Micro-réseaux photovoltaïques hybrides "Annexe 2 : Exemple de calcul des coûts et revenus d'exploitation".

[24] For more on KoBoToolbox, refer to: https://www.kobotoolbox.org/.

with only residential clients are often not profitable. For this reason, GMGs that serve strictly residential clients are not recommended if utilizing a market-based approach.

Each tier is associated with an average daily electricity consumption as presented above. The aggregation of number of clients per tier, individual load profiles and typology of clients (productive uses versus residential), and an average consumption per type of clients is used to define or build the village load curve and main input for sizing of the GMG. An example of a village load curve is shown in Figure 11~~Figure 11~~.

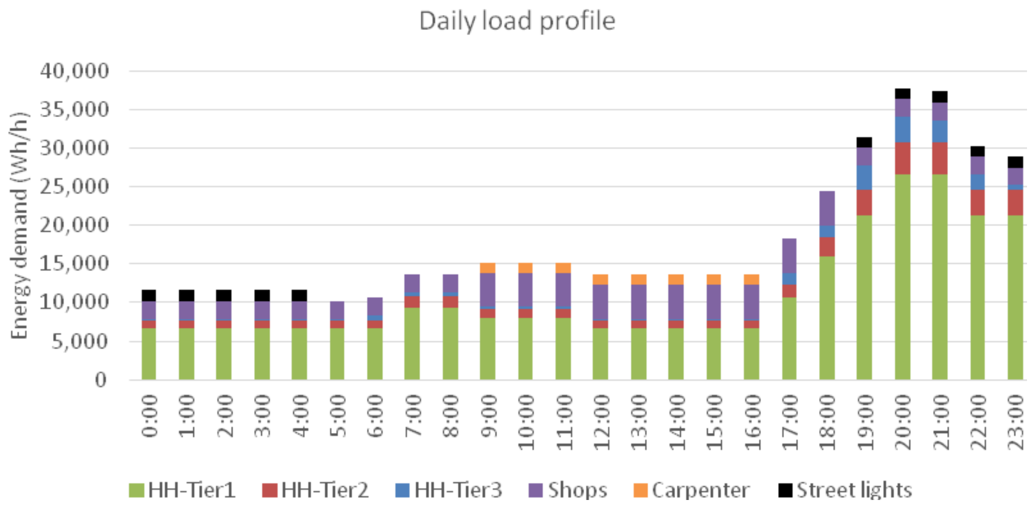

Figure 11: Typical daily load profile of a village (example built by TTA)

Once the community or village load profile is built for year 1, the developer can forecast the load profile into the future, typically for year 4. In the Ethiopian context, following the guidelines provided in the ENEDC, the load forecast should be projected to year 5.

3.7 Recommendations

- As data gathering and demand analysis are critical for mini-grid financial sustainability, it is recommended that sufficient resources are mobilized to create a reliable community load profile.
- The first GMGs are often used to test the approach and gather lessons learned. Subsequent projects can employ a clustering approach for projects in the same region to scale up the business and bring down investment and operational costs.
- DSM and promoting energy efficiency are critical approaches to drive costs down and improve the final sizing of the plants.

3.8 Expected products for the DFS Electricity Demand

The minimum expected products to be delivered by the developer for the DFS are:

- **Demand analysis per clients, including tiers; and**
- **Daily load profile (24-hours) of the community or intended service area**

4 Mini-grid components and sizing

Sizing refers to selecting the appropriate capacity of the PV generator and batteries, as well as the necessary power of the battery inverter and (backup) genset (if one exists). After the size of the main components is decided, a detailed design will determine the type and sizes of solar inverters or charge controllers, the arrays of PV modules, the connections between battery cells and banks, and other elements of the project. The length and cross section of the AC and DC cables connecting the modules and the distribution line can also be estimated.

For component sizing, existing techno-economic tools can be utilized in analysis. However, prior to the employment of specific software, it is first recommended that developers understand all the mini-grid components and their characteristics as well as the way these components interact. Software employed to calculate the proper sizing of a GMG requires a deep understanding of the variables, the behavior of the components, and the relationships between the two. The next sections describe the main GMG components and the usage of the software. IEC 62257 series software is highly recommended as it is the backbone of rural mini-grids.

4.1 Generation

A solar PV mini-grid generation plant is made up of the following main components, described in the sections below.

A	B	C

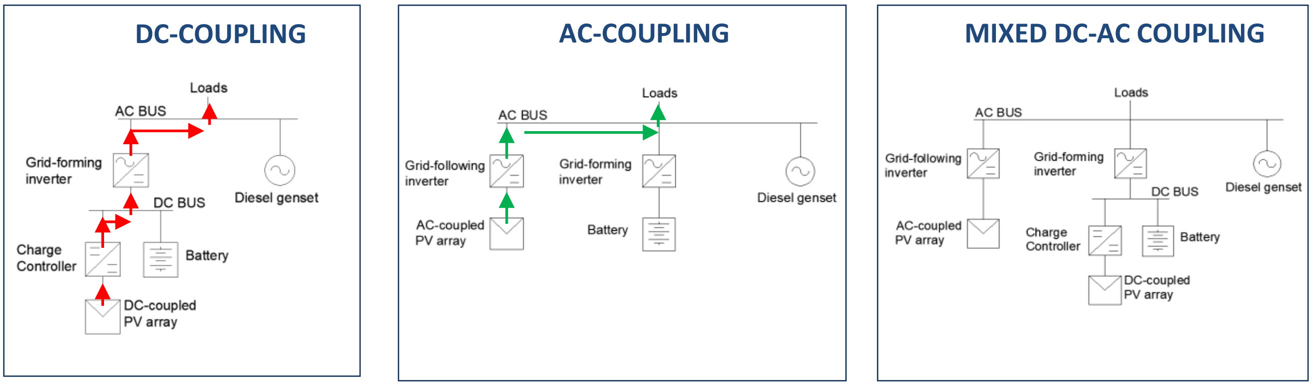

Figure 12: AC-coupled, DC-coupled and hybrid AC/DC-coupled solar PV mini-grids

4.1.1 PV support structure

The most common PV support structures are based on standard aluminum or galvanized iron profiles, which are either fixed to the ground, a roof, or a canopy. PV canopies are more expensive but have several advantages compared to ground-mounted structures: The canopy can provide shelter to the batteries and the power electronics improving the security of the assets. The shadowing of the PV modules can also help to reduce the temperature of the assets, increasing the lifetime of the components while protecting the PV panels from theft.

It is important that metallic structures are well-designed, specifically suited to solar PV applications, and appropriate for the environmental conditions of the site (e.g., wind and humidity).

4.1.2 PV array

The PV generator is composed of solar PV panels, including photovoltaic cells transforming solar radiation into electrical energy of DC. When designing the photovoltaic field, the following parameters must be considered:

- Orientation (depending on the latitude and the sizing month): The PV panels generate maximum yield when facing south in the Northern hemisphere or facing north in the Southern hemisphere. It is also possible that an East-West double-tilt mounting structure for high-power density design panels can be an option for flat roofs or roofs with low slopes.
- Tilting of the panels: Depending on the angle of the PV modules and the season of the year, the modules will produce a different yield. For the ECOWAS and Mauritania sub-region, the optimum tilt is below 20°.
- Absence of shadows.

It is advisable to install active or passive anti-theft and anti-vandalism systems for security reasons. This measure, coupled with community involvement and canopy installations as close as possible to the center of the village are usually the most effective ways to secure PV panels in a GMG. Conversely, fenced ground mounted PV fields are more accessible for maintenance.

Based on this final demand of the mini-grid, the performance ratio of the plant (PR) and the peak sun hours (PSH) of the region, the optimum PV capacity to be installed is calculated by the formula:

$$C_{PV}\ [kW_p] = \frac{Demand\ of\ microgrid\ [kWh/day]}{PR \cdot PSH\ [h/day]}$$

4.1.3 PV inverter (AC-coupled) / Charge Controllers (DC-coupled)

The PV inverters are responsible for converting the DC current produced by the PV panels into the AC current, for its injection into the AC network of the grid (generated by the battery inverter).

In the case of a DC-coupled mini-grid, the conversion is performed by a Solar Charge Controller, responsible for controlling and optimizing the battery charge from the PV modules.

4.1.4 Battery inverter / chargers

The battery inverter converts the electrical energy produced by the photovoltaic panels and stored in the batteries in DC into alternating current of a quality equivalent to that of the national grid (400/230/120 V and 50-60 Hz depending on the country).

Generally, the inverters will be bidirectional, so that they can also convert the AC generation (from the AC coupled solar PV or a renewable source of AC injection, the genset or the national grid) to DC so that it is stored in the battery.

The main parameters for the selection of the battery inverter are the nominal power and the peak power. Special attention must be paid to these parameters since the efficiency of the inverters is low when they work in low part loads.

4.1.5 Batteries

The battery is a rechargeable electrochemical cell, capable of storing electrical energy through a reversible chemical transformation. Thanks to the battery, a photovoltaic plant will have the autonomy to satisfy consumption demands at any time, regardless of the solar generation.

The most used batteries for GMGs are lead-acid stationary ones: they are suitable for slow and deep charges / discharges and have a large cycling capacity. Among these, the most common are the OPzS (O: stationary, Pz: armored tubular plate, S: liquid electrolyte, with positive tubular plate, open and liquid electrolyte) and OPzV (O: stationary, Pz: armored tubular plate, V: gel electrolyte with positive tubular plate, gelled, closed and maintenance-free electrolyte). In general, OPzS batteries will be used because of their lower cost, their greater number of life cycles and better behavior at high temperatures. If periodic maintenance—like refilling of electrolyte—cannot be easily ensured, OPzV batteries are preferable.

Sizing of the batteries is the estimation of the necessary capacity to be installed that will ensure the desired autonomy of the plant. For this calculation, the inputs needed are the depth of discharge (DOD) and the battery voltage (V). Bearing all the above in mind, the capacity of the batteries is given by the formula:

$$C_{bat}[Ah] = \frac{Demand[Wh/day] \cdot Autonomy[days]}{V[V] \cdot DOD}$$

Figure 13~~Figure 13~~ presents a summary of the pros and cons in terms of performance characteristics of the four main battery technologies commonly used in off-grid projects, namely lead-acid, lithium-based, nickel-based and flow batteries.

Lead-acid batteries are the most mature and tested technology for off-grid projects but have lower efficiency in comparison to lithium-ion technology, which have an excellent energy efficiency rate even when discharged completely, as well as a higher energy density. Nickel-based batteries perform better in extreme temperatures, while the flow batteries have excellent cycle performance.

Battery	**Pros**	**Cons**
Lead-acid	High rate discharge performance	Low energy efficiency - Poor or Medium cycling performance
Lithium-ion	Long cycle life expectancy even with 100 % DOD with excellent energy efficiency rate	One poor cell can reduce drastically the cycling performance
Nickel-metal	High rate discharge performance - Extreme temperature - 45°C - + 80 °C with good cycle performance. Accept deep discharge	Charge mode must be well managed. Medium energy efficiency
Flow Battery (or REDOX)	Excellent cycle performance with long term discharge - Energy storage can be easily adjusted	Low energy efficiency - Poor performance at high discharge rate

Figure 13: Performance characteristics of battery chemistries (source: Claude Campion, 3C Projects, France)

Figure 14~~Figure 14~~ shows the main battery chemistries used in GMGs (lithium-based, lead-based and nickel-based) and selection criteria depending on the existence or not of a backup genset and the temperature of the battery room.

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		Off-Grid PV+Battery			Off-Grid PV+Battery+Diesel/H2		
		High Temp >35° C	about 23°C or Air-Cond	Low Temp <0°C	High Temp >35° C	about 23°C or Air-Cond	Low Temp <0°C
Lithium	NMC - NCA	+	++	0	+	++	0
	LMO	+	++	0	+	++	0
	LFP	++	+++	0	++	+++	0
	LTO	++	+++	0	+	++	0
	LMP	+	+	0	+	+	0
Lead	Tubular PbSb Vented (OpzS)	+	++	+	++	++	++
	Tubular PbCa Gel (OPzV)	0	+	+	+	++	+++
	VRLA Pure lead	0	+	+	++	+++	+++
	Flat PbCa Gel	0	+	+	+	++	++
	Flat Thick plates vented	+	+	+	+	++	++
	VRLA PbCa + PbC paste	-	0	0	+	+++	+++
	VRLA PbCa AGM	--	-	0	-	0	+
	Automotive or Truck	--	-	-	--	-	-
Nickel	NiCd vented	++	++	+++	++	+++	+++
	NiCd sealed	0	++	++	++	+	++
	NiMH	++	+	++	+++	++	++

Figure 14: Battery Selection for GMGs (source: Claude Campion, 3C Projects, France)

OPzS

The main advantages of OPzS batteries are lower price, useful life, good performance at high temperatures, and the possibility of equalization charges, which allow the balancing of the series of elements of the battery.

However, OPzS require maintenance to replenish electrolytes, emit flammable gases (hydrogen in small quantities) which must be exhausted, and are delicate and subject to greater restrictions in transportation (since the acid must be transported separately).

OPzV

The primary advantages of OPzV batteries are lower maintenance requirements and no restrictions for shipping. On the other hand, their price is higher than OPzS (around 25%) and they offer a shorter life cycle.

In general, it is recommended to opt for batteries of the OPzS type except when basic maintenance cannot be guaranteed locally (due to lack of trained technical personnel, isolation of the site, difficulty in obtaining distilled water, etc.), or when the security conditions do not allow the installation of flooded batteries; in this case it is advisable to opt for a gel battery type like OPzV.

Lithium-based batteries

Lithium-based batteries represent a good economic and technical alternative to lead-acid ones and are gaining more market share due to their decrease in cost. The most common technologies for stand-alone solar applications combine lithium with nickel-manganese-cobalt (NMC) or are lithium iron phosphate (LFP).

Advantages include higher energy density, longer life, and allow for higher current discharges, over lead-acid batteries.

Drawbacks include larger up-front investment, requirement of more sophisticated control electronics, and lithium-based batteries usually cannot be recycled as well as lead-acid batteries.

4.1.6 Backup genset

The genset can have different functions depending on how the installation is designed:

- Auxiliary (sporadic use): In case the solar resource is not sufficient, or any part of the plant breaks down. Also enables equalization and maintenance charges for the lead-acid batteries.
- Peak hours (daily use): To cover the energy or power demand gap for a few hours daily.

The power of the genset is normally expressed in kVA (apparent power).

Contrary to photovoltaic production, one of the great advantages of the genset is that their use (and therefore their production of electricity) can be planned. This flexibility makes them a great complement to the solar plant.

Current photovoltaic inverters generally include synchronization mechanisms with gensets which greatly facilitate their interconnection and integration into the management strategy of the GMGs. This automatic start/stop feature is recommended for any genset meant to be integrated in the GMGs.

For the usual power range in GMGs, diesel engines are usually used with 1,500 rpm equipped with a single-phase or three-phase alternator depending on the configuration chosen for the GMGs.

In general, the genset performs one or more of the following functions:

- Avoids oversizing the photovoltaic plant (leading to CAPEX reduction) to respond reliably to the most critical periods of the year (low solar radiation);
- Replaces battery inverters in the event of failure or shutdown due to maintenance, ensuring continuous electrical service;
- Periodically completes full charges and equalization of the battery to keep it balanced and extend its life;
- Performs an additional charge of the battery when the state of charge is too low due to adverse weather conditions; and
- Covers peak power during daylight or nighttime hours.

The choice of the nominal power of the genset will be made considering its functions and the intended operating regime.

In general, the genset must be able to guarantee a continuous active power at least equal to the total power of the inverters (so that it can replace them if needed) and also guarantee the peak power demand.

4.1.7 Protection of persons and equipment against electrical hazards

The calculation and design of electrical protections, earth connections, network distribution lines, subscriber connections, internal installations in homes and businesses, productive uses, and public buildings and their protections are governed by the general rules applicable for low-voltage electrical installations; at the location where the work is carried out and by the usual practice of the national electric companies.

In this respect, there is no major difference from other rural distribution networks. However, there are some elements specific to mini-grids:

- All active equipment in the photovoltaic installation (regulators, inverters, etc.) must be properly protected against over voltages of atmospheric origin for both electrical input and output connections;
- It is necessary to provide a general switch allowing the total switch of consumption on the auxiliary generator in the event of disconnection of the photovoltaic plant;

- It is advisable to carry out the grounding connecting of the metal frames of the photovoltaic modules and the support structures with the earth of the building, separately from the general electrical outlet linked to the neutral, the negative pole of the batteries, and the chassis of the electronic equipment;
- For the dimensioning of the section of the conductors of the electrical distribution lines, the maximum intensity should be limited by the power of the photovoltaic inverters and the auxiliary generator of the mini-grid. The voltage drop at the most distant point in the low-voltage (LV) network will also be calculated based on this maximum power of the equipment installed;
- The street lighting lines can be controlled preferably from the photovoltaic plant, allowing the activation of its operation at twilight and regulation of hours of operation according to the charge of the plant; and
- Installation of the meters should preferably be carried out outside homes. Meters must be sealed and with the connection conductors suitably protected on arrival, which prevents access to contacts and connections and allows visual inspection and detection of possible fraud.

4.2 Distribution Network

The distribution network includes the following elements and considerations:

- The grid for the distribution of energy produced by the mini-grid power plant, which can be distributed through low voltage (if distance < ≈1 km) lines or medium voltage (if distance > ≈1 km) lines according to the distance and power demand in the line's edges (voltage drop);
- 3-phases versus 1-phase, if there any existing 3-phases clients (unlikely) the project developer may consider part of the distribution network being 3-phases. Cost is also an important consideration;
- Safety, while evaluating Medium Voltage versus Low Voltage safety should be strongly considered as the electrical hazards of operating a MV line are much more dangerous than LV lines;
- The street lighting infrastructure (sometimes integrated into the existing distribution network´s poles);
- Connection drops, connection accessories, cabling and supporting structures of each subscriber or group of subscribers;
- The electric meter, connection board, and connection protections; and
- The household internal wiring and appliances (optional).

When designing the distribution grid, if the GMG projects are to be interconnected (less than 25km from the national grid) to the main grid (EEU), the GMG must consider the parameters described under main grid readiness levels MGRL1 and MGRL2.

4.3 Techno-economic analysis

The techno-economic analysis will pre-determine the sizing of the GMG plant as well as some important financial metrics, including the expected revenues and the required CAPEX and OPEX investments for single or multiple GMG site projects. Specific software can be employed to do this calculation.

The major outputs under this analysis will be: i) Return on investment; ii) Payback; and iii) Key financial metrics to assess the bankability and profitability of the project and the level of funding required. Such key financial metrics can be the internal rate of return (IRR) and the Net Present Value (NPV) of the project.

As GMGs are long-term investments with middle- or long-term payback, it is key to understand and show the financial metrics to demonstrate a bankable project. If the output is not attractive enough, a new iteration will be required to assess how to improve the business model. This will imply modifying the technical and economic approach and variables (as inputs), which in exchange will produce new major outputs.

The bankability of the project will be always related to several metrics. For example, the IRR may be the most important metric for an investor, but if the payback period is too long or the positive cash flows come too late in the project lifecycle, it will not be seen as an attractive investment.

It is important also to understand the target (size of ticket; expectations in terms or return) and type of vehicle (equity; debt) of potential investors upfront.

As mentioned throughout this guide, it will be very difficult to show an attractive and profitable business model if it includes only household needs and does not demonstrate an increase in demand over time. The evidence of productive uses is therefore mandatory, as is demonstrating the project's enabling of economic activity in the village.

4.3.1 Techno-economic analysis tools

As mentioned previously, different software can be employed to undertake the techno-economic analysis (e.g., Homer Pro or RetScreen).

Although software is an efficient tool for calculating major technical, economic, and financial metrics quickly and reliably, it represents only an important first step in this process. Software does not usually provide all necessary techno-economic indicators, hence additional work needs to be done using custom-made spreadsheets.

For example, when using Homer Pro, additional techno-economic analysis must be done to complete a DFS. Some missing elements include:

- The simulations only include the generation plant. The distribution line must be designed and budgeted apart, as well as the cost of client-connections. These costs must be added after the first techno-economic calculation.
- Homer Pro only simulates costs and not revenues. A financial model must be elaborated in parallel, in order to carry out a cash flow analysis. The main inputs like annual CAPEX, OPEX and electricity generation can be imported from Homer (or any other similar software).

Once the techno-economic analysis has been undertaken using specialized software or custom-made spreadsheets, some of the key items to be analyzed are:

A. Technical

- Number of clients per type (residential, institutional, commercial, and industrial, related to TIER framework)
- Demand forecasts per clients' type and aggregated
- Size of the components
- Other technical indicators (performance ratio, battery autonomy, excess power)
- Reliability of service (e.g., hours of service availability, SAIFI, SAIDI)

B. Economic

- Macroeconomic assumptions: exchange rate; inflation; cost of transactions
- Pricing: connections fee, tariff and services related (and appliances, if included)
- Initial CAPEX and recurrent OPEX

- Amount and type of public subsidy support required (i.e., grants)
- Selling, general and administrative expenses (SG&A)
- Bankability of the project (IRR, NPV, payback period)
- Average revenue per user (ARPU)
- Cash flow results
- Gearing: debt to equity ratio

C. Other (social/environmental)

- Timeline planned for construction and operations (long term)
- Greenhouse gas savings (compared to alternative generation technology)

5 Important additional considerations

5.1 Maintenance plan

An essential factor for a successful GMG project is good maintenance and sound technical supervision. Usually, it is the responsibility of the GMG operator to ensure the maintenance and control of the equipment installed up to the point of connection of the distribution network with clients' indoor installations.

Since these facilities are often located in remote locations - where it is often difficult to find and secure qualified personnel permanently - the assets should be designed in a simple and durable manner to minimize the maintenance required. Maintenance must be planned from the beginning of the project. During the procurement, a stock of spare parts should be acquired, along with necessary tools for maintenance and instructions provided by equipment manufacturers. The project's maintenance plan should be based on reviews of the operation of the asset and corrective actions that identifies weaknesses and improvements to be implemented during the lifetime of the installation.

The existence of several GMGs in a region (bundling of mini-grids) can become a key factor in lowering and optimizing the costs of periodic maintenance visits by qualified technicians.

In general, three different levels of maintenance can be distinguished which can be performed by one or more organizations or enterprises under the supervision of the plant manager or operator, and which are described in the following sections of this chapter.

5.1.1 Basic daily maintenance

Basic daily maintenance of the installation does not require skilled personnel and can generally be carried out by residents of the community. This allows quick responses in the event of an incident or breakdown in the plant. Often this task is taken on by more than one person to ensure the presence of a responsible operator at all times. These tasks are the caretaker's responsibility.

This type of preventive un-skilled maintenance is important for the operation of the assets. It includes basic monitoring and control tasks that must be completed on a regular basis to ensure the proper functioning of the assets and the efficient resolution of problems that arise. The personnel in charge do not require a high level of training in electricity or photovoltaic plants, but it is essential that they have received specific and practical training to understand the meaning of the various indicators and alarms in the control room, the basic elements for handling the plant, and the protocols to be followed.

Common operations of basic daily maintenance, with a weekly frequency, are as follows:

- Verification of the general indicators, alarms, and warnings which would signal a malfunction;
- Control of the state of charge of the batteries and of the auxiliary elements (generator, etc.);
- Checking the level of the electrolyte in the batteries and, if necessary, filling with distilled water (not necessary in the case of sealed batteries);
- Cleaning the surface of the photovoltaic panels if necessary (normally during the rainy season, this task can be postponed);
- Control of the absence of shade on the photovoltaic panels (at least for 3 hours before and afternoon);
- Cleaning and maintenance of technical rooms and space of the photovoltaic installation;
- Generator commissioning, if necessary;
- Control and supply of the fuel reserve;
- Control and supply of the distilled water reserve (unnecessary in the case of sealed batteries);
- Revision of the stock of spare parts and tools; and
- In case of alarm or malfunction that cannot be solved by the caretaker, give notice to the technicians responsible for corrective maintenance and managers established by the operator.

Under no circumstances should the personnel in charge of basic daily maintenance be handling the generation facilities beyond their technical capacities and the tasks assigned to them.

5.1.2 Specialized preventive maintenance

Specialized preventive maintenance must be carried out regularly by expert personnel bound by contract with the operator. The personnel must have in-depth technical knowledge (at the level of a professional electrician) on low-voltage electricity and extensive experience in photovoltaic plants. Usually, the specialized technicians are based near the GMGs to keep travel costs reasonable. Bundling approaches also helps reduce the costs for specialized preventive maintenance if several GMG plants are in proximity to one another.

The main goals of preventive maintenance tasks are to:

- Detect and correct malfunctions in the generation equipment;
- Anticipate serious breakdowns (supported by the monitoring system);
- Ensure the proper use of the facilities; and
- Ensure the life of the equipment.

Under the preventive inspection, carried out every three months, following checks must be included:

- Correct condition of support structures and fixings;
- Good state of the photovoltaic modules and their connections;
- Absence of shadows on the photovoltaic unit;
- Production of the different groups of photovoltaic modules;
- Good performance of photovoltaic regulation (regulators or inverters for connection to the grid);
- Good mechanical and electrical state of batteries;
- Battery equalization is done as programmed;
- Equipment configuration parameters have right values;
- Proper functioning of probes, data acquisition system and monitoring;
- Correct operation of the genset and change of oil and filters if necessary;
- Proper operation of electrical protections;

- Alarms, fire safety and other security features are up to date;
- Distribution lines and street lighting are in the proper state; and
- Correct operation of the central unit's consumption devices and auxiliary services.

The frequency of performing preventive maintenance tasks must be strictly observed. For more information on (1) standard technical specifications for power quality, reliability, and availability and (2) a standard accountability and performance reporting framework, please refer to the Quality Assurance Framework for Mini-Grids from NREL.[25]

5.1.3 Specialized corrective maintenance

Specialized corrective maintenance concerns work following a breakdown or a malfunction of equipment that could not be detected or resolved during the execution of preventive maintenance tasks. This corrective work often involves the replacement of one or more components. The availability of proper spare parts is therefore essential for the effective completion of this work. In addition to maintaining a complete stock of spare parts to ensure rapid resolution of incidents, operators must maintain an efficient supply channel for the various components of the installation for replacement. For this, and when designing the GMG, it is important to always select distributors that have reliable suppliers in the national market. Once the parts that make up the spare parts stock have been used, they must be replaced immediately so that the stock of spare parts always includes a specific number of reserve units. It is recommended to have replacements on hand for approximately 2% of PV panels and at least one unit for each electronic component for example inverters and regulators.

Corrective maintenance work must be carried out by technical personnel with specialized training in photovoltaics and other equipment that comprise a GMG. Often, the same technicians in charge of preventive maintenance can also be responsible for corrective maintenance. If more complex failures must be dealt with, they must be able to rely on external specialized support (e.g., manufacturers or specialized firms).

5.2 Risk Assessment

Some of most relevant risks (technical, operations, and financial) are listed below. The list of existing potential risks is much larger; however, most relevant ones are defined in Table 26~~Table 26~~.

Table 26: Risk Assessment for GMG

Activity	Risk
Deployment of a low voltage network	Theft of electricity from the distribution network
	Vandalism
Receipt of customer payments	Risks of embezzlement / corruption / theft / security / assaults
Establishment and operation of a local company	Currency risk: Major part of the investment and operation costs (including debt) will be in hard currency, while revenues are in local currency
	Risk of inconvertibility: Risk that the local currency will not be convertible, degrading the business plan and possible default with financiers, lenders

[25] National Renewable Energy Laboratory, *Quality Assurance Frameworks for Mini-Grids,* 2016. https://www.nrel.gov/docs/fy17osti/67374.pdf

	Transfer risk: Risk that the company's currencies can no longer be transferred abroad and possible default with financiers, lenders.
	Risk of rising inflation mechanically affecting costs. Without compensatory measures, negative impact on the business plan
	Regulatory change
Financing of activities	Liquidity risk: Risk that the working capital will not be sufficient or that the expected financing arrives later than planned
Commercial, marketing, and technical operations	Inability of teams to support the volume of business
Sales and marketing operations	Appearance of a substitute product
	Misunderstanding of market expectations
	Underconsumption of customers/ potential customers
	Customer dissatisfaction
Connection of homes to the low voltage network	Bodily injury / electrocution
Construction / civil engineering	Personal injuries / electrocution
	Corruption and fraud
	Risks related to suppliers
	Risks related to access to the site (rain, roads, etc.)
Maintenance and technical operations	Bodily injury / electrocution
	Poor sizing of capacities (estimate of demand)
	Reliability of the equipment (quality of the equipment installed)
	Risks related to access to the site (rain, roads, etc.)
	Risk of battery explosion
	Poor quality of telecommunications networks
	Lightning risks
	Battery recycling
Use of computer systems	Data loss
	Risks of hacking, spying, data leakage and protection of privacy
	Delays in the implementation of the integration of mobile money
Human resource management	Matching skills to needs

	Employee retention rate
	Capacity building and training

5.3 Recommendations

- A techno-economic analysis can be done with or without specialized software. It is important to have good input data, such as demand, costs, and renewable energy resource. Models only work if the input data is accurate.
- When estimating project CAPEX, all unit costs should be under the same conditions, depending on the desired budget (e.g., EXW[26] or installed costs). International logistics, local transportation, insurance, and storage should not be overlooked.
- Component selection must consider various parameters such as price and quality, but also availability in the local market and after sale services. Technology providers must be well selected and have a good reputation and experience of minimum 5 years.
- Battery selection is tricky. Although the prices of lithium-based batteries are falling and there is increasingly more local market availability, experience using them in rural electrification in remote locations are limited. The selection must consider predominantly robustness, reliability, simplicity, and low maintenance needs.

5.4 Expected outputs for the DFS

The minimum expected products to be delivered by the developer for the DFS are:

- Techno-economic analysis
- Preliminary maintenance plan; and
- Risk assessment of the GMG

6 Modularity and expandability

GMG designs can be modular and expandable to meet future demand needs. In a solar PV mini-grid, the power generation plant is composed by PV panels charging the batteries through charge controllers (DC-coupled architectures) or through battery inverters (AC-coupled architectures). The energy from the batteries is then converted into alternate current to feed in the distribution line through the battery inverter.

The generation plants can be easily expanded in terms of generation, power capacity and energy storage, as described below:

- **PV generator:** A set of PV panels and charge controllers (if DC-coupled) is called a solar basic unit (SBU), which in each design is one or more controller connected to several panels. Expansion of the generation can be done through adding SBUs, if:
  i. The DC bus can support the total current of the PV; and
  ii. The maximum charging current of the batteries is respected.
- **Storage:** Storage can also be expanded by adding battery banks, with each bank having a battery voltage level (12/24/48 or other). The restriction to adding storage is that the battery cells should be the same as the existing ones (manufacturer and model) and that the total number of battery banks placed in parallel should only be done according to manufacturer guidance.
- **Battery inverters:** Battery inverters can be added in parallel in case the power demand increases.

[26] Ex works (EXW) is an international trade term that describes when a seller makes a product available at a designated location, and the buyer of the product must cover the transport costs.

In all cases of expansion, in addition to the restrictions mentioned, other restrictions concerning communications should be considered. Each manufacturer allows a certain number of components to be placed in parallel due to communications limitations.

Similar to expanding the mini-grid by adding components, components can also be **removed** and placed in other mini-grids (SBUs, battery banks or inverters), if the respective limitations are considered. The only challenge would be the PV structure, which is more challenging in dismantling and installing in a different place.

7 Drawings

The following set of preliminary drawings should be performed as part of a feasibility study:

- **Site Layout:** A map of the village should be provided indicating a potential location of the plant and using satellite imagery.
- **Single Line Diagram (SLD):** A simple electrical drawing of the generation plant, including all the main components, should be provided.
- **Distribution Network Layout:** A preliminary plan of the distribution network should be provided with the lines and poles clearly indicated. The number of poles and the total length of the distribution lines should also be showed on this drawing and include information on phase one to phase three.

These drawings will act as a foundation over which a preliminary design could be made if the feasibility study concludes positively.

8 Components Summary

As part of the detailed feasibility study, the GMG developer should present a summary description of high-level sizes and quantities of the power generation plant and distribution network. A recommended template is provided in the following table:

Table 27: GMG Main technical characteristics summary

Solar PV Installed Capacity (kW_{peak} at STC conditions)	
Installed capacity of any other generator (kW or KVA) and type of technology (wind/biomass/specify if other)	
Power conversion capacity (kVA)	
Back-up genset capacity (kVA)	
Storage technology	
Battery bank voltage level	
Battery bank capacity (kWh)	
Battery bank autonomy (hours)	
Distribution line voltage (s)	
Distribution line phases	
Total distribution line length (meters)	

Furthest distance from generation to consumption (meters)	

PART III: CHECK-LIST OF OVERALL RECOMMENDATIONS

Part III of this document summarizes the overall recommendations by the consultant to EEA to take into consideration in the upcoming regulations and directives, implementation, and monitoring of Green Mini-grid projects in Ethiopia.

OVERALL RECOMMENDATIONS ON PART A: OFF-GRID TECHNICAL STANDARDS

- **Off-grid technical regulations standards**. The proposed technical standards go beyond mini-grids and can be applied to any off-grid technology chosen by the project implementer (national grid extension, mini-grid or stand-alone power plant). The proposed standards categorize the service level provided to the end-user, from least to most technically demanding.
- **Output-based technical regulations.** It is recommended to regulate outputs of the electricity service; the document proposes in four (4) main categories of technical regulation:
  - **Power Quality (PQ):** three (3) power quality categories are defined as per the end-user requirements that are served through that power quality category
  - **Power Availability (PA):** five (5) categories of power availability (daily energy and maximum power consumption) are defined based
  - **Power Reliability (PRe)**: three power reliability categories are proposed based on the end-user requirements
  - **Operational requirements or Key Performance Indicators (KPIs)**
- **Defining mini-grid thresholds on rated peak load** and not based on the installed generation capacity. The rated peak load in Kilovolt-Amps (kVA) is the maximum value of load, real or planned, that occurs in a given period of time.[27]
- Mini-grid compatibility with the main grid and remote monitoring requirements should depend on the distance from the national grid on the rated peak load the mini-grid is serving.
- **Key Performance Indicators (KPIs).** Part A of this document recommends 6 technical, 13 financial and 6 other (social and environment) KPIs to be **reported annually** to ERA. Beyond these recommended defined indicators, the consultant's advice that **ERA consults the private sector** (in particular the current private and public mini-grid operators in the country) **on the adequacy of these proposed indicators.**

PQ PARAMETER PER PQ CATEGORY		PQI	PQII	PQIII
AC	Voltage Variation	NA	±10%	±10%
	Voltage Imbalance (only 3-phases)	NA	< 5 %	< 2 %
	Frequency variations (Hz)	not regulated	46 < f < 54	48 < f < 52
	Harmonics	< 10%	< 5%	< 3%
	Transients	No protection	Surge Protection	
	Short-Duration Voltage Variations	< 5/day	< 1/day	< 1/week
	Long-Duration Voltage Variations	< 10/day	< 5/day	< 1/day
DC	Voltage Variation	±25%	±25%	±25%
	Transients	No protection	Surge Protection	
	Percent Ripple (peak to peak)	10 % pk-pk	5% pk-pk	2% pk-pk
	DC ripple ¬ switching noise	Unfiltered	Transient noise minimized	Ripple noise also minimized

[27] For a more precise definition, please refer to page 10 of this report.

OVERALL RECOMMENDATIONS ON PART B: GREEN MINI-GRID FEASIBILITY STUDY GUIDELINES

- The **GMG feasibility study guidelines** lay down the **minimum steps, industry best practices, and lessons learned** from previous experiences for the mini-grid developers to carry out detailed, technically-sound green mini-grid (GMG) feasibility studies.
- The consultant proposes these guidelines as a result of the literature review and consultations carried out with EEA and stakeholders, identifying **a gap in the current enabling framework for mini-grids in Ethiopia**. While some regulations mention the need of carrying out and submitting a feasibility study, no dedicated document provides specifications or guidelines in how to conduct a feasibility study
- **Standard methodology for estimating the energy demand: tiered energy packages as a standardized methodology** for estimating the energy demand. By having a common methodology of estimating the electricity demand, ERA will be more familiar and operational while reviewing this critical part of a feasibility study among the different mini-grid proposals to be reviewed
- **Recommended standard outputs of a Detailed Feasibility Study (DFS):**

Site Assessment	▪ Exact location of the community ▪ High quality GIS map of the community with clients geo-referenced ▪ Basic socio-demographic characteristic table ▪ Energy consumption and expenditure table
Electricity Demand	▪ Demand analysis per clients, including tiers ▪ Daily load profile (24-hours) of the community or intended service area
Mini-grid sizing, design, and assessment	▪ Techno-economic analysis ▪ O&M plan ▪ Risk assessment of the GMG
Drawings	▪ Site Layout ▪ Single Line Diagram (SLD) ▪ Distribution Network Layout
Others	▪ Mini-grid Component Summary

- A techno-economic analysis can be done with or without specialized software. It is important to have good input data, such as demand, costs, and renewable energy resource. **Models only work if the input data is accurate.**