Off-grid Rural Electrification - Mini-grid Systems

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1 What are the general principles of off-grid mini-grids?

The present module focuses on off-grid rural electrification with mini-grid solutions which offer more power & energy than individual systems, e.g. for socio-economic activities & development.

A mini-grid will basically include a power generator and a network to distribute the electricity to the accessible consumers, to avoid the high costs of extending the main grid to these isolated areas. Those consumers should then be distant from the main grid (e.g. over 5-20 km), fairly close to each other (e.g. < 150m or density > 50 customers/km²) and with sufficient load demand (>200kWh/year).

The size of mini-grids can range from **10kW** for 40 customers to few MW for more than 4000 customers. Micro-grids are usually between 1 and 10kW for very small villages (<50 customers).

Most of existing mini-grids in Africa are supplied by fossil fuel-based gensets or in a lesser extent by mini-hydro power plants. Nowadays, given the environmental concern and the significant renewable cost reduction, the trend is the hybridization of existing diesel mini-grids (adding renewable sources) or to design new "green mini-grids" with either hydro, biomass or hybrid (wind, solar, diesel) power systems, depending on the availability of renewable energy sources and on load profile on the demand side (as illustrated by the figure below).

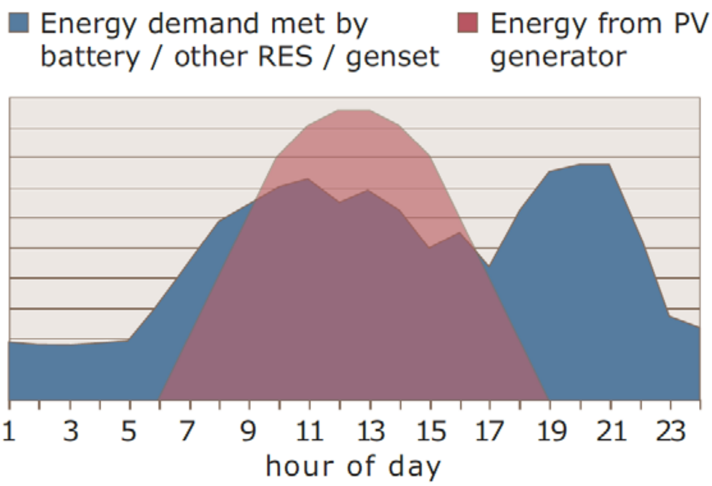

Figure 1: Typical rural load profile and solar production

Source: ARE, 2013

The instantaneous demand (kW) of a village can easily vary over the day from 10% to 100% of the peak power demand. Thus the so-called "load factor"[1] can be rather low in rural off-grid systems (15-30%). Matching the daily demand and the fluctuating renewable energy production is a key issue in off-grid systems and the recourse to storage systems has to be considered, in particular to increase the share of renewables.

[1] The load factor is defined as the average load divided by the peak load in a specified time period.

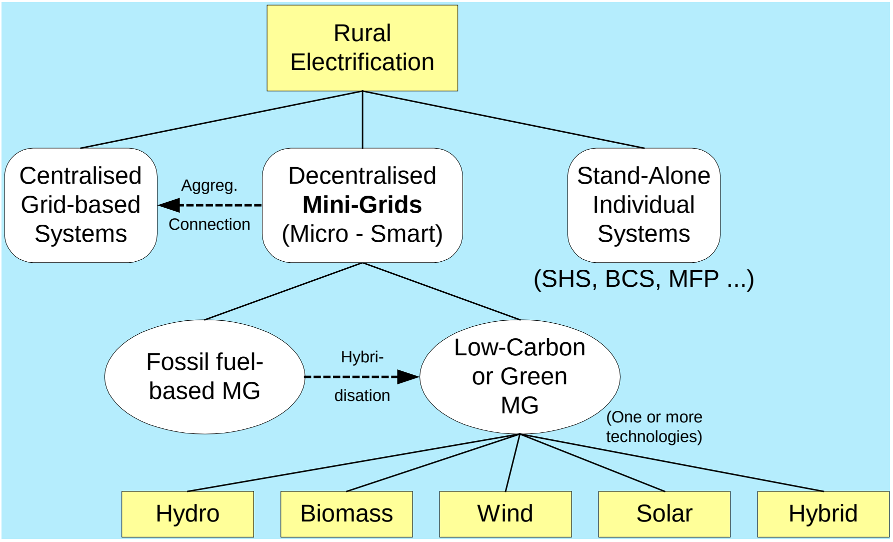

Figure 2: Rural electrification approaches

Source: IED, 2012

The right mix between thermal fuel oil generator (diesel engines) and renewable energy generators (solar PV, wind, biogas, biomass gasifier) determines the least cost solution for the local generator:

- 100% diesel-fed systems have lower capital costs, but higher running costs due to pricy fuel purchase, supply scarcity and the substantially lower lifetime of the generator. A renewable energy-based generator would generate electricity with a levelised cost that is lower than the marginal cost of generating this electricity with fuel oil.
- 100% renewable energy system have much lower running cost, but higher capital cost due to renewable energy technologies (RETs). Adding a small diesel genset can avoid expensive over-capacity of renewable sources and storage systems for a reliable power supply.

The optimum configuration of a hybrid generator is somewhere between these two extremes depending on:

- The characteristics of the renewable energy sources that determines the availability of the renewable generators
- The aggregated load duration curve on the demand side.

Given the standard RET costs, the **least cost generating solutions** usually start with hydro, followed by biomass, then hybrid systems using wind and/or solar energy.

Over the last decade, despite a huge potential, the development of "green mini-grids" and programme roll-out in Africa was hindered by several technical, financial and regulatory barriers ("market failures"). The main challenge is the **financial sustainability** of the off-grid mini-grid solution given the low incomes of the rural beneficiaries. This key challenge also consists of finding the best operator model to overcome the set of barriers, as there is no "universal solution" for off-grid electrification.

2 Technology overview

The **main components** of a mini-grid are the power generator (with or without storage), the distribution network, the service drop and the customer installation.

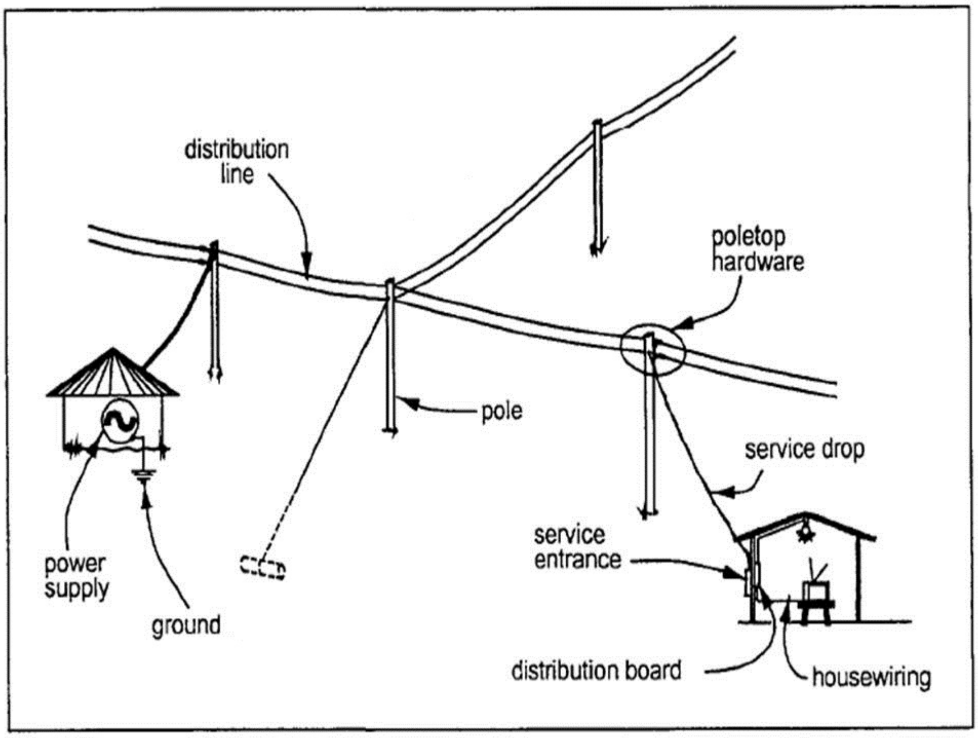

Figure 3: Typical Off-Grid Mini-Grid System

Source: Mini Grid Design Manual – ESMAP/WB 2000

2.1. Power Generation

All over Africa, there are commonly 4 types of power generators for mini-grids: diesel gensets (most common), hydro power plants, biomass plants, hybrid systems. Many configurations are possible by mixing different sources and storage solutions, mainly depending of the local resources and demand.

Power Generators	(+)	(-)
Conventional fuel genset (Diesel/gasoline/ CNG (Compressed Natural Gas))	Widely spread in Africa Rapid implementation Low investment cost (CAPEX[2])	High running costs (OPEX) Limited hours/day High environmental impact
Hydro Power (Micro 10-500kW/ Mini 0,5-10MW)	Water storage (limited) Continuous supply (24h)	Seasonal variation Water use impact (irrigation)
Biomass (Biodigesters/ gasifiers/ biofuels/ cogeneration)	Low cost renewable "fuels" Liquid or solid fuel storage	Seasonal variation High maintenance level By-product disposal
Hybrid systems (solar/wind/diesel/storage)	Low running costs Continuous supply (24h) Environmentally friendly	Intermittent source Expensive storage required Complex energy management

[2] CAPEX means capital expenditure ; OPEX means operating expenditures

Hydro potential is actually very site-specific and concentrated in specific locations. **Biomass** power plants should be close to biomass production areas. **Wind** and **solar** are more diffuse resources although sufficient wind speeds are recorded only on specific spots. Solar energy, although the most diffuse (low energy per m², low capacity factor), has the widest coverage and can fit more easily with scattered remote households. **Capacity factors** of power plants (ratio of actual output to its potential output) vary with RETs: 10-20% for solar PV, 15-30% for wind, 20-50% for micro & small hydro, 10-90% for biomass and >90% for diesel.

Unlike diesel gensets, renewable energy technologies (RETs) require power conditioning units to regulate the power production (controllers, regulators, convertors, inverters, rectifiers, etc.).

2.2. Storage

The need for **storage** over a couple of hours or days will depend of different parameters as the daily load curves & demand peaks, and the renewable energy source intermittency. Usually well-sized diesel generators, hydropower systems and biomass generators can run continuously as their "fuel" can be stored (fuel tank, biomass warehouse, water weir/dam). However, with irregular solar & wind resources, energy storage might be needed to increase the penetration (renewable share in the system). In this case, excess electricity will be stored to 'regulate' the generating system while it is in use. In small mini-grids (i.e. under 300 kW) lead-acid battery banks are typically used (initial investment cost ~ $150-200/kWh capacity and storage unit cost~ $0.20-0.50/kWh). Given the economic and environmental impacts of chemical batteries, the new trend is to reduce or to avoid storage with improved management electronics and to increase penetration rate of renewables in off-grid systems.

Multi-generator system allows better matching with the demand. However more sophisticated energy management systems (EMS) are required to ensure fuel savings and efficient use of renewable source(s). The next figure illustrates the possible configuration of multi-generator or hybrid system (Cf. Handbook module on rural electrification with hybrid systems).

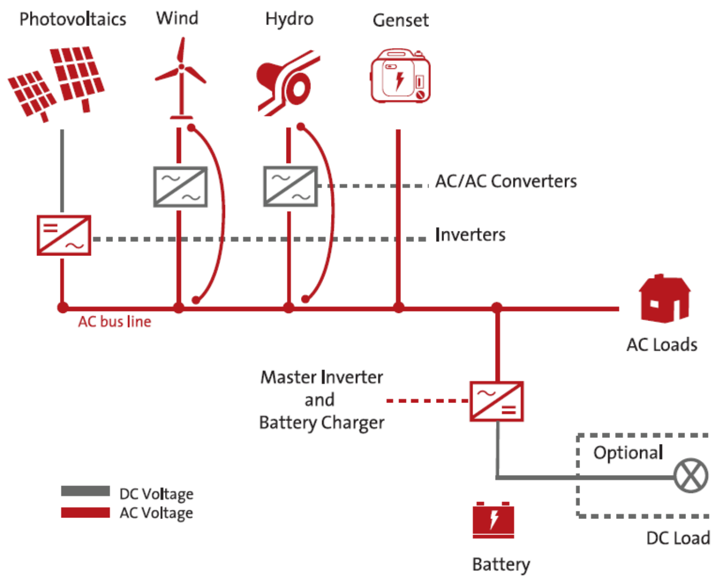

Figure 1 : Hybrid multi-generator system with AC coupling

Source: ARE/USAID, 2011

2.3. Distribution network

A distribution network carries electricity to the consumers or loads at a limited distance of the generators.

System designers shall decide on the type of distribution system:

- Alternative or direct current (AC or DC)
- Nominal voltage(s): LV or MV (see below),
- Single or three phases, or single wire earth return (SWER)
- Grounding system, etc.

This decision impacts the cost of the project and will determine the types of service and appliances that can be utilised.

Low voltage distribution network (< 1kV, typically 220-380V) is preferred for technical and economic reasons but some local configurations may require **medium voltage** (MV) lines (1-35kV, typically 15 or 33kV) to reach far consuming clusters (usually beyond 1-2km from generator). Typically LV line costs range from $5,000 to $8,000/km and MV lines (with MV/LV transformers) cost $13,000 to $15,000/km.

Three phases system allows higher energy transport and the use of specific appliances as conventional motors for productive uses.

It also influences, on the longer term, interconnection conditions when the main grid will come.

2.4. Service Connection

The **service drop** includes the cables and accessories to connect the nearest LV distribution pole and the consumer's meter.

The **service entrance** system includes all the equipment located on the end-user side, such as customer board (with meter and protections), grounding, in-house wiring, and electrical appliances (light, radio, TV, fans, motors, etc).

System designers shall also decide on the type of metering and recording depending of the billing systems. There is a wide range of technology options between the basic current limiters associated with flat rate tariff, conventional meters and the sophisticated pre-paid meters with data loggers.

2.5. Smart management systems

Mini-grids in remote areas are relatively complex to operate efficiently and to manage economically. Very promising devices or smart technologies emerged with RETs development and enable better mini-grid system control (energy generation and distribution) as well as customers' management (fee collection, misuses, thefts, etc.). Smart technologies will improve performances and sustainability of electrification schemes.

For instance, mini-grids have strong incentives to pursue demand-side management and to optimise mini-grid system design (reduce capital cost for generation units).

Smart management systems offer attractive options to monitor remotely the mini-grid performances and to assess the demand profile and growth. This will help taking energy efficiency measures, planning mini-grid upgrading or main grid interconnection.

Smart management concepts for mini-grids also increasingly use ICTs (Information and Communication technology) as smart meters & remote payment through GSM network. In Kenya

for instance, the tariff collection process is automatized by interlinking tariff payments with the widespread telecommunication network, allowing people to pay bills via their mobile phones (e.g. M-PESA mobile-phone based electronic payments system in Kenya).

2.6. Mini-Grid Standards

The International Electro-technical Commission (IEC) has published Technical Specifications IEC 62257, a set of standards covering technical and organisational aspects of mini-grids (design, installation, maintenance, contracting) and a checklist of good practices.

3 Economic aspects of Mini-grids

The economic analysis of a mini-grid project should start with the cost estimation. However the reference capital & operating costs (CAPEX/OPEX) for the different options, as shown in the next table, varies considerably with technologies and site location. The detailed calculation of the least-cost option and the levelised cost of electricity (LCOE[3]) needs to be done for each specific project and site.

Table 1: IED Reference costs for Green Mini-Grids (DFID, 2013), based on field experience and on IRENA study, 2013

Technology -based MG	Size range (kW)	Power plant investment ($/kW)	LCOE ($/kWh)	Operating time (h/yr)
Diesel genset	5 – 300	500 – 1500	0.3 – 0.6	On demand
Hydro	10 – 1000	2000 – 5000	0.1 – 0.3	3000 – 8000
Biomass-gasifier	50 – 300	2000 – 3000	0.1 – 0.3	3000 – 6000
Wind hybrid	1 – 100	2000 – 6000	0.2 – 0.4	2000 – 2500
Solar hybrid	1 – 150	5000 – 10000	0.4 – 0.6	1000 – 2000
MV distribution	*33kV*	*13,000 - 15,000*	*$/km (site specific)*	
LV distribution	*380V*	*5,000 – 8,000 $/km*	*A rough estimate of the required length is 30 customers per km.*	
Connection costs	*Ideally $350 per customer (but CAPEX/customer varies $350-3500)*			

The mini-grids economics should also take into account realistic load factor and capacity factor to estimate safely the to-be-sold kWh cost (sold kWh are lower than produced kWh), the potential revenues and the financial viability.

4 What are the organisational models?

Different approaches to operation exist depending on local socio-economic conditions and on the regulatory situation of each country. Ownership of the system and responsibility for maintenance and care are the two key factors. All operator models have to find ways to control fee collection and customer behaviour to avoid overuse, misuse or careless use.

There are four major business models for mini-grid so-called Utility, Private, Community and Hybrid operator models. The preferred choice of model depends on national, social and political

[3] The Levelized Cost of Energy (LCOE) is the constant unit cost (per kWh) of a payment stream that has the same present value as the total cost of building and operating a generating power plant over its life.

circumstances as well as on the demand profile and on the size and structure of the mini-grids. Today, more and more governments are trying to attract private financiers and private mini-grid operators in view of constrained public budgets. But serious risks and limited returns impede their involvement.

4.1. Utility mini-grid model

In the utility/central planning model approach, the mini-grid solutions are scheduled in the rural electrification master plan, approved by the Ministry of Energy and with technical inputs of a Rural Electrification Agency. Engineering, procurement of equipment and construction is ensured by a Rural Electrification Agency tapping in a rural electrification fund set-up from a levy on the national tariff and from long term loans / grants provided by donors.

The newly built mini-grid in rural areas is generally handed over to the utility for technical operation, sale of electricity and billing of customer according to the national tariff. The economic loss (difference between revenue collection based on national tariff and operating cost of the rural grid) is financed by the utility from its regulated revenue. Such losses are factored by the Regulator in the revenue requirement for the tariff calculation and are spread to all rate payers including grid connected ones (cross subsidies).

There is an emerging variant to the utility/central planning business model for mini-grid; this is the **utility/local government** business model whereby a mini-grid is initiated at local level under the authority of a local government that has become responsible for the development of public service infrastructure in its constituency (or governorate or county).

4.2. Private company mini-grid model

In this business model, a private entity plans, builds, manages and operates the mini-grid system. The funding depends on private equity and commercial loans as well as some form of government support, e.g. grants, subsidies, results-based financing, or public sector loan guarantees. Pure private sector operator models in which all the investment comes from private sources are rare but do exist. The private sector is often better suited (than utilities) to manage efficiently smaller mini-grids.

Scalable private sector models include the franchise approach, the ABC (Anchor-Business-Community) approach, the clustering approach, the local entrepreneur approach, the private O&M contractor, the private concessionaire, the private generator (IPP) and the private distributor. All of these approaches are designed to meet the challenge of collecting the fees from end-users at each site while facing inevitable management and operational costs.

1) **Franchise model:** In this model management costs are bundled at the franchiser level and minimises this burden for the franchisee. With a large number of franchisees, economies of scale in theory outweigh the additional management costs of the franchising structure.
2) **ABC business model:** The private sector is interested to finance and distribute power through a rural mini-grid to customers if they can have one or more stable and reliable anchor and business loads (industrial or institutional).

   This is the purpose of the so-called A-B-C model where:

   - **A**nchor customers as agro-industry, tea factories, telecom tower or pumping station ensure continuous and predictable load improving the bankability of the mini-grid,
   - **B**usinesses as rice mills, shops, crafts ensures large loads which increases the amount of sold electricity and reduces the unit cost of supply,

- Community which requires affordable electricity at lowest prices and is only seen as a top-up to the revenues from the first two customer groups.

3) **Clustering Model:** In this model, a number of villages situated close to each other are electrified by non-interconnected mini-grids that are bundled under one operational management structure to save on overheads, labour, travel and transport costs. This clustering principle can be applied to all models.

4) **Local Entrepreneur Model:** In this model, the local entrepreneur approach takes advantage of the fact that a local entrepreneur is constantly on site. The local entrepreneur operates the system and owns parts of the generation and distribution assets. He typically has a well-established social network, reducing costs for security, Customer Relationship Management (CRM), money collection, etc.

5) **Private Electrical Service contractor (ESCO):** In this model, the investment is fully financed by the public sector and donors. The construction works are done by other contractors which are selected based on a bidding process by the public authority in charge of renewable energy.

   The electricity service company (ESCO) operates and maintains the system once it has been set up and sells electricity. Those private service companies usually bid for such contracts. Their offer includes a formula of how they are being paid for their services. If things go well, the private company recovers its costs and makes a (small) profit.

   The tasks of the private company comprise power production and distribution, maintenance of the system and commercial tasks (meter reading, billing, collection, etc.).

   This model involves limited risks for the private company and does not require it to contribute to the financing of the investment costs. Finding private operating companies for power generation is normally not difficult. The distribution activity alone in rural area is much less profitable and attractive for private sector.

6) **Private concessionaire of a mini-grid:** This model assumes that the private company is granted the electricity supply monopoly in the concession region during a certain period, typically 15 – 25 years (concession contract).

   The company has the responsibility to implement incremental investments mentioned in the concession contract (such as mini-grid extension on small distances) and to operate the mini-grid.

   A large portion - typically between 60% and 80% - of the initial investments costs of the mini-grid is financed by the public sector and donors in the form of subsidies. Only a small portion has to be financed by the private company. Depending on the size of the concession, the amount can be substantial, however. The private companies who invest or contribute to investment will try to maximize the return on equity and to minimise the risks of running mini-grids in rural areas (dispersed population, weak capacity to pay).

7) **Private generator of a mini-grid:** The private investors interested by off-grid business are more attracted to become an independent power producer only (IPP) and to sell power to one customer (utility or mini-grid operator / off-taker) with suitable and guaranteed "feed-in-tariff".

   The off-grid power generation should be supported by regulatory framework through a long term power purchase agreement (PPA) with a creditworthy off-taker entity. The tariff of the power purchase agreement should enable a full recovery of the annuitized capital expenditures (CAPEX) and all incurred operating costs (OPEX). For volatile OPEX cost like fuel oil, a pass-through cost arrangement is recommended in order to avoid a mismatch between the revenue

of the mini-grid and the cost of fuel oil. In those conditions, private developers of an off-grid power generation plant can more easily invest and safely recover their stakes.

8) **Private distributor of a mini-grid:** The off-grid power distribution business model is less-demanding technically but is much riskier as the revenue is strongly dependent on the electricity sales to households. The revenue is directly affected by the number of customers, the average consumption by customer.

   Private developers prefer having reliable anchor customer(s), if investing in distribution and becoming a rural distributor. But those key customers are relatively rare in rural Africa.

4.3. Community based mini-grid model

In this business model the initiative is taken directly by the local population who feel ignored (or un-prioritized) by the tenants of the utility business model. The end-users can group themselves under a cooperative (non-profit organisation under the cooperative act) or under the authority of the local community or village with an empowered decision committee and capacity to raise funds and secure partnership with private sector.

In community-based models, the local community owns, operates and manages the system and provides all services for the benefit of its members. The financing is typically highly grant-based with some community contributions (financial or in-kind). The planning, procurement of equipment, installation and commissioning is often done by third parties, as local communities rarely have the technical and economic expertise to develop and implement mini-grids. To allow long-term operation of the system, it is essential that community operated mini-grids at least at tariffs that cover reinvestment/depreciation, operations and maintenance costs. Small community models require working social and decision-making structures in the village to prevent conflicts. Larger community-driven cooperative models running generation in the multi MW scale are more formalised and depend less on local structures. Communities most often use the cooperative approach for mini-grid ownership and management.

4.4. Hybrid model (often Public Private Partnerships)

Hybrid business models typically try to integrate success factors of the above mentioned models while eliminating risks. To do this the ownership and operation structure is subdivided into power production (national utility), power distribution and power sales and assigned to the different private and public partners. The ownership structure is often linked to the operational structure.

Generation and distribution of electricity may be split and carried out separately by government utilities, private companies or communities in the form of small power producers (SPP) and small power distributers (SPD). Alternatively, the duties and responsibilities can be split according to who builds, owns, operates and maintains the system. It is essential to clearly define roles and responsibilities prior to commissioning. No matter which form of hybrid model is used, it depends on a regulatory framework that accommodates 'mixed' ownership and management, as well as the political will of the utility to allow or pursue it.

Summary of business models for mini-grid rural electrification

Business Models	Borrower	Owner Asset	Remark
1. Utility based	1 Existing Utility	Utility	Known by most FIs
2. Private company			
2.1 Franchise	1 Franchisee possibly backed by Franchiser	Franchisee	Management performance enforced by Franchiser
2.2 A-B-C Business Model with Anchor Loads	1 New Private Utility	A-B-C Company	Anchor-load based
2.3 Clustering Model	1 New Energy Service Company	Energy Service Company	Existing client based; economies of scale
2.4 Local Entrepreneur Model	1 Existing entrepreneur	Entrepreneur	Well established social network
2.5 Private ESCO Contractor	1 New Energy Service Company	N civilians	Weak creditor base - unproven
2.6 Private Concessionaire	1 New IPP	Concessionaire	Contract-based. Ongoing investment obligations
2.7 Generator – IPP Model	1 New Generator	IPP	Contract-based
2.8 Private Distributor	1 New Distributor	Distributor	Weak creditor base – unproven
3. Community based	1 New Community	N civilians	Weak creditor base - unproven

5 What is the environmental and social impact?

Off-grid solutions have a considerable impact on the life of hundreds of millions of people enabling future economic developments in the poorest parts of the world.

1) **Economic impacts** are as follows

- Reduces household expenditures on kerosene, candles or dry cells, and increases savings up to 10 to 15 % of a household's income
- Free up household resources spent annually on fuel to be invested in more profitable businesses
- Generate new income, stimulate economic activities, and offer new opportunities for small businesses by lengthening the day
- Multiply trade activities and job creation to increase state income and facilitate overall socioeconomic development
- Reduce rural exodus

2) **Social impacts** are as follows;

- Longer hours and better illumination for studying
- Social cohesion and community development
- Safety and equitable development for women
- Improve access to information and communication technologies (ICTs as radio, TV, mobile phone, internet), i.e. news, business information, and distance education

- With renewable energy technologies, in particular for micro- and mini-hydropower, mini-grid projects should be properly addressed with local population to avoid social conflicts regarding way leaves, land use (agriculture) and access to the water (irrigation).

3) **Health benefits** are as follows:

- Improve safety by reducing hazards associated with flammable fuels and candles
- Reduce indoor air pollution with significant effects on consumers' health
- Improve quality of health care services

4) **Environmental** impacts for renewable energy-based mini-grids are as follows:

- Reduce noise and odours from gensets
- Protect natural habitats against deforestation
- Reduce annual global kerosene consumption and associated greenhouse gas emission as well as carbon black emission (cf. box below)

Avoided carbon emission

To assess the avoided carbon emissions of a renewable energy based mini-grid, one should evaluate the displaced energy from fossil fuel resource, based on the penetration factor of each renewable technology. 2 calculations can be done to compare first with pure diesel genset based mini-grid, and second to a connection to the national grid.

[Avoided Emission] = [Penetration Rate] x [Energy Demand] x [Emission factor]

The diesel genset emission factor is about 1300 kgCO2eq/MWh for diesel genset in the range 10-100kW (source: IPCC)

The National grid emission factor varies with the country energy mix: from 2 kgCO2eq/MWh in Congo RDC (mainly hydro) to 800 in Burkina Faso (mainly fuel).

The penetration rate (energy) depends of RET technologies and project characteristics. Typical values are: 80-100% for Hydro; 50-80% for Biomass[4]; 20-40% for Solar and Wind. The balance is covered by grid or diesel backup.

- However, waste collection and recycling scheme should be considered at early stage of project design for wastes, batteries and other system components at their end-of-life.

6 What are the major studies required?

There are different project promoters (private, community, investors) that can submit mini-grid projects for financing support, and thus different feasibility studies that can be required for screening and evaluation.

If the project promoter is a **private or community entrepreneur**, the preliminary studies should at least cover the following issues:

[4] For Biomass, typically carbon emission will be reduced thanks to the (partial) replacement of diesel consumption and to the avoidance of natural decomposition of the biomass (e.g. rice husk gasifier)

- **Market assessment** (prior moving into the market)
  - legal framework & regulatory requirements,
  - grid extension plan,
  - renewable energy potential,
  - power demand and load forecast,
  - willingness to pay
- **Business Planning** (including competitor analysis)
  - Mini-Grid design, performances and specifications
  - Operating/maintenance (O&M) scheme (ownership, responsibilities, spare parts, after-sales service, etc)
  - Economical analysis
    - (Capital expenditure (CAPEX), Operating expenditure (OPEX), LCOE (levelised kWh cost)
    - Tariff structure, subsidies, feed-in-tariff (FIT)
    - Marketing & sales plan and expected incomes
    - Cost-benefit analysis
  - Financial analysis & cash flow forecasting
  - Environmental and social impact assessment (ESIA)
  - Risk analysis

If the project promoter is a <u>**lender**</u> to the agents/clients, the preliminary studies should at least cover the following issues:

- **Market assessment** (conducted independently by a rural electrification agency)
- **Loan assessment:** to find out whether the agent / client is credit worthy. This should be a relatively simple standard procedure
- **Evaluation of the performance:** of the portfolio of loans. This should be done after a certain amount of time, to understand how the loans are behaving, their risks and to see how they can be optimized

7 What are the key issues & questions?

This section proposes to highlight the key issues to assess a mini-grid project and the key questions that should be checked before approval of a **Business Plan**.

1) Is the **project developer** reliable and creditworthy**?**

a. <u>Managerial capacity</u>, sufficient technical expertise in off-grid electrification

b. <u>Experience</u> in the country of intervention (national regulation, rural environment)

c. <u>Financial solvency</u> over the project duration; access to financing

2) Does the Mini-Grid Business Model comply with **the legal framework**?

a. <u>National policy</u>: clear national rural / off-grid electrification master plan, favourable to off-grid operators and business-driven approaches, fiscal incentives for local manufacturers and on key imported components (tax and charges), grants or loans, subsidies (not on fossil fuels), regulations, standards & certification/labelling, awareness campaigns.

b. <u>Regulatory framework</u>: adequate procedures/regulations for off-grid generation, distribution and sales; adequate procedures/regulations for private investors and operators; adequate (flexible) tariff structure for cost coverage; specific procedure/regulation (FIT ...) in case mini-grid is caught up with the main grid; adequacy of the proposed business model; regulatory gaps for effective business model; etc.

3) Is the proposed Mini Grid project **technically viable**?

   a. Accurate demand forecast& willingness to pay: to ensure proper design and high load factor. Poor load factor (over sizing) will have direct impact on revenue and sustainability.

   b. Site characteristics: Land tenure; distance to the main grid; rigorous renewable potential assessment to ensure proper design and matching of the growing demand.

   c. Proper technology choice and Mini-Grid design: to match the growing demand and to maximise the RE resource with lower kWh unit costs (LCOE); comply with national or adapted standards; ensure safety issues; increase socio-economic impacts; capability to upgrade the Mini-Grid or to interconnect to main grid

   d. Adequate management organisation: assets' ownership; adequate skills & training (designers, managers, operators, technicians);

   e. Adequate O&M organisation: adequate O&M structure & skills for generation, distribution and sales; O&M / ASS service contracts; maintenance & intervention planning; consumable stock & available spare parts; O&M manuals and troubleshooting procedures; daily/periodic logbook with all breakdowns & interventions; centralised monitoring; safety procedures; etc.

   f. Adequate sales organisation: efficient billing and cost-effective money collection

4) Is the proposed Mini-Grid project **financially viable**?

   a. The economics of mini-grid projects include development costs (preliminary studies& design, capacity building, etc.), implementation costs (CAPEX, construction, training, supervision, etc.), and operation costs (OPEX including maintenance & component replacement at end of life as batteries, electronics). Least cost option for electricity supply; affordable connection fees and customer tariffs; adequate feed in tariff if interconnected; cost-benefit analysis.

   b. The financing CAPEX and OPEX for Mini-Grids can come from 3 main sources: international finance (private equity, grants / loans through local banks & MFIs), national finance (subsidies and taxes), and community finance (consumer payments, land grant, in-kind, rights-of-way). Acceptable financial indicators (pay-back period, Internal rate of return (IRR), cost per kWh produced, distributed)

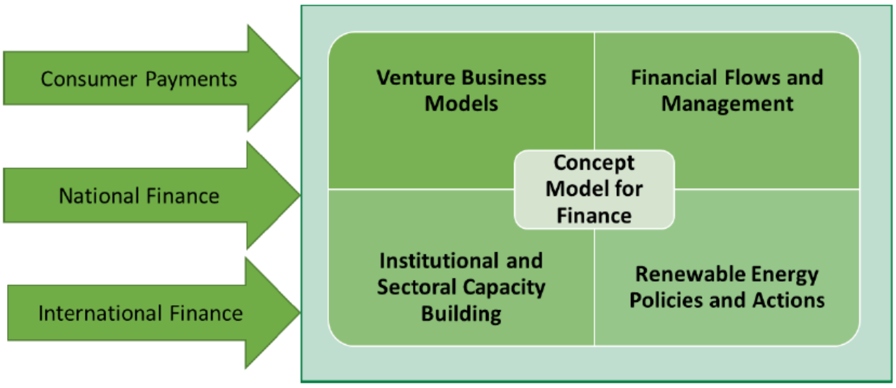

Figure 2 : Concept Model for Finance (CMF) for renewable energy mini-grids

Source: UNDP, 2014

8 Useful references

Key references on Mini-Grids

- Risk Mitigation in Mini-Grids, HNU/id-eee/ARE/GIZ, 2014
  http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/RISK_Mitigation_for_Mini-grids_EX_SUM_Final.pdf
- Mini-grid policy toolkit: Policy and business frameworks for successful mini-grids rollout, EUEI PDF, 2014 + MGPT Financial Model
  http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/INENSUS-Toolkit-EN-21x21-web-OK.pdf
- The mini-grid option: lessons learnt and factors of success, SE4All/OFID, 2014
  http://www.se4all.org/wp-content/uploads/2014/03/Background-Paper-_Mini-Off-grid.pdf
- From the bottom up: How small power producers and mini-grids can deliver electrification and renewable energy in Africa, Tenenbaum, WB, 2014
- Billing models for energy services in mini-grids, MEI presentation, GIZ workshop, 2014
- Review of strategies and technologies for DSM on isolated mini-grids, Harper, CEM, 2013
- Sustainable Development of Renewable Energy Mini-Grids, Deshmukh, CEM, 2013
- Overview of framework to attract investment into mini-grids in SADC, RECP/EUEI-PDF, 2013
- Low-Carbon Mini-grids, de Villers, DFID, 2013
- Isolated diesel grids, Bertheau, RLI, 2012
- From gap to opportunities: business models for scaling up energy access, IFC, 2012
- The history of mini-grid development in developing countries: Policy briefing, GVEP, 2011
- Parliamentarians' toolkit for building political support for energy access through mini-grids, Camco/UNDP, 2010
- Technical and economical assessment of off-grid, mini-grid and grid electrification technologies, ESMAP, 2007
  www.esmap.org/sites/esmap.org/files/Technical%20and%20Economic%20Assessment%20of%20Off-grid,%20Minigrid%20and%20Grid%20Electrification%20Technologies_Report%2012107.pdf
- China Village Power Project Development Guidebook, UNDP/GEF, 2005
  http://siteresources.worldbank.org/EXTRENENERGYTK/Resources/5138246-1237906527727/5950705-1239305592740/China0Village01ple0Who0Need0itomost.pdf
- ESMAP technical paper (September 2000), Minigrid design manual
  http://www.esmap.org/sites/esmap.org/files/TR_minigriddesignmanual21364.pdf

Case studies and country experiences in Mini-grids

- Microgrids for rural electrification: a critical review of best practices (**7 case studies**), UN-F, 2014
- Mkopa in **Kenya**: http://www.m-kopa.com/media/latest-news/
- Off-grid **Tanzania**: http://www.greentechmedia.com/articles/read/solarcity-leads-7m-round-in-off-grid-solar-firm

- EU SE4 All mission report: Rural Electrification Programme **Tanzania** – Implementation of Phase II of the Rural, Electrification Prospectus Formulation Draft Final Report June 2014.
- A least-cost electrification proposal for Kisiizi, **Uganda**, by Sten Bergman, The World Bank
- **Mozambique**, Impact assessment rural electrification, Norad 2013
- Geographic, technological and economic analysis of isolated diesel grids; Assessment of the upgrading potential with renewable energies for the examples of **Peru**, the **Philippines** and **Tanzania**. Bertheau, RLI (2012).
- Financing Decentralised Renewable Energy Mini-Grids in **India**, CKinetics, 2013

Smart technologies

- Azuri: http://www.azuri-technologies.com/
- Smart payment, Fenix solar, http://www.fenixintl.com/

Hybrid systems

- Rural Electrification with PV Hybrid Systems: Overview and Recommendations for Further Deployment, Léna, IED, IEA PVPS, Club-ER, 2013 http://www.iea-pvps.org/fileadmin/dam/public/report/national/Rural_Electrification_with_PV_Hybrid_systems_-_T9_-_11072013_-_Updated_Feb2014.pdf
- Hybrid Mini-Grids for Rural Electrification: Lessons learnt, Rolland, ARE/USAID, 2011 http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf