Sustainable Energy Handbook

Module 5.4

Off-grid Rural Electrification - Standalone PV Systems

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1 What are the general principles of individual off-grid rural electrification?

In countries where access to electricity is less than 10% in rural areas, the financial effort for increasing the electrification rate requires planning and prioritisation of the limited finance available for rural electrification. The electrification strategy of a central decision maker is driven by:

- priority loads such as public institutions (schools, health centre, administrative centre, trade centre) and large population clusters outside the main cities
- least cost approach for each electrification scheme among a range of solutions including on grid and off grid technologies (mini grid and solar home systems)

As a result of this strategy:

- Off grid solutions are proposed by central planners to priority loads and neighbouring dense population clusters that are distant from the main grid (e.g. over 5-10 km)
- The electrification of populations by central planners in isolated areas that are not close to a priority load may be delayed by many years and even decades.

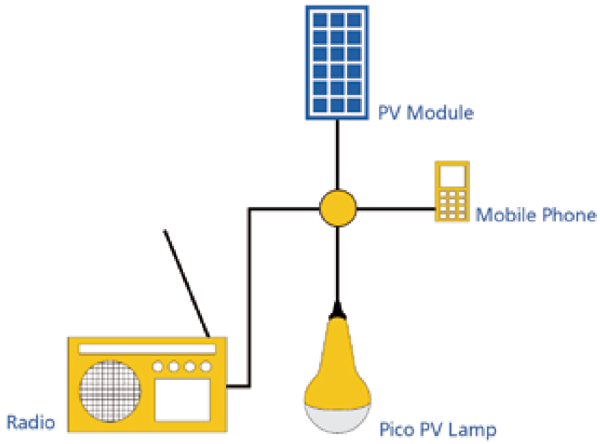
In isolated services areas (e.g. that are distant from the main grid – e.g. over5-20 km) where loads are fairly distant of each other (e.g. over 500 meters) or are in limited number (less than 20 customers**), individual off grid** solutions avoid the high cost of deploying a local distribution network that would connect all these distant loads to a single local generator or would mutualise the use of individual generators.

A standalone individual power system is an off-grid system that supplies a single rural customer with one or several generator sources (hybrid system) and various electrical appliances. According to the power dimension, they can be grouped into four categories: portable lights (i.e. rechargeable & solar lanterns), mini kits (i.e. pico hydro & pico solar systems), Home Systems (supplied by solar SHS or pico-hydro) and Residential Systems (generally supplied by hydro, wind or solar –with diesel backup or not). Off-grid isolated individual systems are usually implemented for pre-electrification purpose (ahead of deployment of on-grid or off-grid mini-grid systems). Most individual systems in Africa are still supplied by diesel/fuel gensets.

2 Technology overview

Based on the review of literature, there are four categories of individual off grid PV systems:

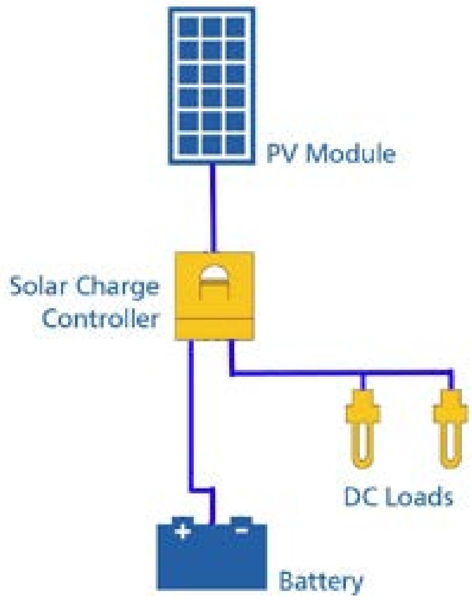
- **Solar Portable Lights (SPL) or solar lanterns:** Single light source with or without mobile phone charging outlet; Entry level products with solar panels of 0.2 – 2 W; Price ranges from $10- to $40 (average $25). These typically consist of a complete in-build unit, comprising a battery, solar panel, wiring, power regulation and lighting bulbs or diodes, most often LED's. These units are designed to be versatile and very tough to survive in remote and hostile conditions without requiring significant on-going maintenance



Source: ARE

- **Pico PV system (PPS):** Multi lights source applications with mobile phone charging outlet made of a kit of components; their power range is 2-10 W; their average price is $125.

- **Solar Home Systems (SHS):** Multi lights source applications with mobile phone charging outlet; Sources can power devices such as radio and TV; Price range from $150 to $350 (average $250). Solar PV home systems (SHS) consist of a number of component parts which are often supplied as a complete package which needs to be installed within a building (a household, community building or place of business). This consists of the solar panels, often installed on roofs, the battery pack, a battery charge regulator possibly coupled with an inverter for AC supply (in case of AC distribution to the electric appliances), wiring and light bulbs, as well as any other electric appliances required.



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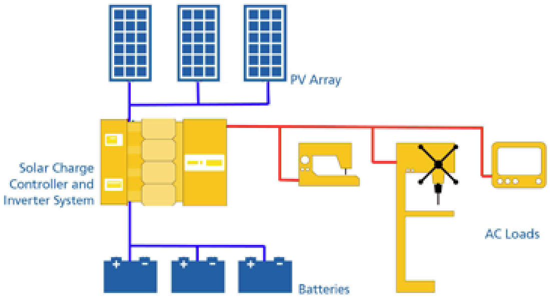
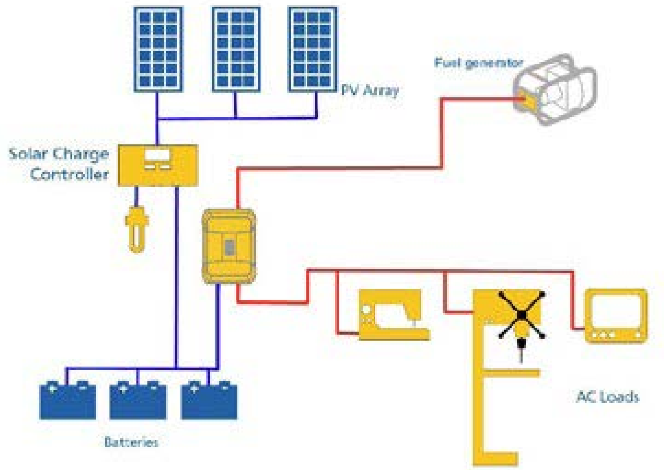
- **Residential Home Systems (RSH):** 12V systems replace diesel generators or car batteries, 12V systems can power multiple lighting points and devices such as TV and fridges; Price range from $400 to $800 (average $600)





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System description	Average Daily Consumption ADC	Recommended production voltage	Recommended distribution voltage	Loads
PPS	ADC = 5 to 10 Wh/d	12 V DC	same as production	Light, TV, radio, mobile phone charger
DC-SHS	ADC < 0.5-1 kWh/d	12 V DC; 48 V if cooling	same as production	Light, TV, radio, mobile phone charger, fac, ICT, cooling
AC-SHS	ADC > 0.5-1 kWh/d	12 - 24 V DC	220 V AC and 12/24 DC	Light, fan and cooling on DC; Light, mobile phone, ICT on AC
SRS	1-2 kWh/d < ADC < 50 kWh/d	12/24/48 V DC	220 V AC	Light, mobile phone charger, fan, ICT (radio, DVD cassette player, TV, decoder), fan, AC loads such as drilling machine, grain mill, sewing machine, mixer, etc.

Source: ARE

Lighting Africa and the International Electronic Commission (IEC) have developed technical standards for standalone PV systems which are available on the following internet address:

http://webstore.iec.ch/preview/info_iec62257-9-5%7Bed2.0%7Den.pdf

Products selected and tested by Lighting Africa complying these standards are available on the following internet address:

http://www.lightingglobal.org/products/?view=grid

3 Maintenance of the elements of the standalone PV systems

Classical elements of a standalone PV system include: solar module, charge controller, lead-acid battery, inverters and loads (appliances). The maintenance and quality management of these components are key factors for a successful and sustainable operation of PV off-grid systems. Training of local operators and cooperation with service providers can guarantee long-term professional O&M. Every single system component has specific maintenance needs.

The role and specific maintenance needs of each of them are briefly explained below:

Solar module

The output of the solar module depends on many factors: its size (installed capacity), efficiency of the technology, irradiation at the site, cleanliness of the surface, the power electronics (for instance

whether a MPPT [1] is engaged), and eventually on a tracking system (untypical for rural electrification).

Since sunny conditions are the norm for most developing countries, an installed capacity of 1kWp (typically 4-6 individual modules with a total surface of approximately 8m2) can generate more than 2.000 kWh annually. In moderate, cloudy climates, the modules may reach only 50% or less of this output. If their products are properly installed and maintained, most PV manufacturers guarantee a power output of 80% for 20 years.

Maintenance of PV modules is relatively easy as the most common technical problems occur due to misplaced or dirty modules and can be identified visually. In these situations, the energy harvested decreases and the energy balance might be disrupted. Hence, the observation of the surrounding area is essential not only to avoid shadowing, but also to decrease the risk of hot spots that damage the generator.

Solar modules can be easily cleaned with water and a sponge, but ongoing maintenance is also necessary. This should include check-up of cables and fixation, the opening and control of the junction box and the strain relief of electric cables. Visual control of the cables should be done regularly by the user to prevent eventual damage caused by animals. Finally, PV systems located near the coast bear the risk of "blooming" effects on the aluminium frame due to salty air, which can lead to corrosion if not controlled.

Charge controllers

The charge controller controls battery overcharging and deep discharging thus protecting it and guaranteeing longevity. It must provide a periodic charging method which protects the battery against sulphation and acid stratification, and should be equipped with microprocessors and power transistors to perform the three steps charging method that will help ensuring long battery life.

Charge controllers normally provide information about the system's performance through LEDs or/and LCD displays for simple models, and sound signals and/or an integrated data logger for more advanced types. Sound signals alarm the user in case of incorrect use, whereas integrated data loggers help the service provider to analyse failures.

Charge controllers only need basic maintenance: ventilation slots should be kept clean and the cable connections need to be fixed from time to time.

Lead-acid battery

When it comes to maintenance of standalone PV systems, the battery is the most sensitive component. Normally, the charge controller guarantees the battery protection and O&M but a relatively easy although important control is the visual inspection of the electrolytes filling level. The filling level can decrease due to water loss caused by gas release and in this case the battery needs to be refilled up with distilled water to the maximum mark. Due to health and security issues, this operation should only be performed by trained service personnel. Maintenance-free lead batteries do not require this type of control task.

Another potential risk for the battery is the deformation of the case due to freezing or overcharging. This too can be visually checked and verified. The battery's pole caps should also be cleaned regularly and controlled to prevent corrosion. The control of both fixed electrical contacts and a secure standing are also important tasks.

1 Maximum Power Point Tracking

Battery inverters

Battery inverters are advised for large SRS system and needed if the system uses AC power and loads. In fact, in many cases when the system's production exceeds a certain level, it will supply AC loads fed with inverters. The sizing of the inverter is guided by the system's total loads consumption capacity.

The type of battery inverter chosen is especially important. The most important characteristics are: a good efficiency at partial load use[2] (> 85% with 5 to 50% of working loads), consumption levels as low as possible in standby, energy saving modes (< 2% of nominal power) and a standby mode capable of detecting a very small load (< 2-3W). In addition, it must be able to handle surge power 2 to 3 times the rated power for a few seconds. The latter characteristics are especially important in small systems using AC power.

Loads (appliances)

In standalone PV systems, especially the smaller ones, the loads are an integrated part of the systems and have to be carefully chosen because of their impact on the efficiency and the lifetime of the system itself.

The use of energy-efficient products is very important and should be promoted and even subsidised as part of any rural electrification project/programme, whatever the technology chosen[3]. The generator should be sized according to the calculated Average Daily Energy consumption (ADC) and the storage according to the expected working time of the system with the ADC. Therefore, a thorough demand assessment prior to the project is central to ensure a sustainable system operation. Oversizing is a common problem in developing countries, but it is also unavoidable for systems relying only on non-dispensable sources of energy[4] (e.g., PV, Wind). The excessive use of the loads is also rather common in developing countries and can lead to system failure and broken loads have to be replaced with new ones belonging to the same category and with the same consumption.

If a data logger is integrated in the system, the data collected can help to train the users about their consumption. This can help the users to adjust their behaviour to the system power balance, to ensure its long-term performance. In any case, loads must be carefully handled by the users. Shocks, moisture and contamination are risks that should be kept in mind.

The choice of loads should largely depend of the type on distribution current chosen for the system. Choosing AC power has several advantages especially for bigger systems: AC loads are more common and usually cheaper and its use eliminates the need to invest in supplementary elements (e.g. inverters) to use them and finally the battery protection, fundamental to ensure a longer life time, cannot be bypassed. AC current has also a number of limitations such as the risk of using excessive loads or the loads' inefficiency when power has to be transformed in force (e.g., fridge, pump, etc.). It also does not make economic sense for small systems where DC loads are cheaper and less consuming.

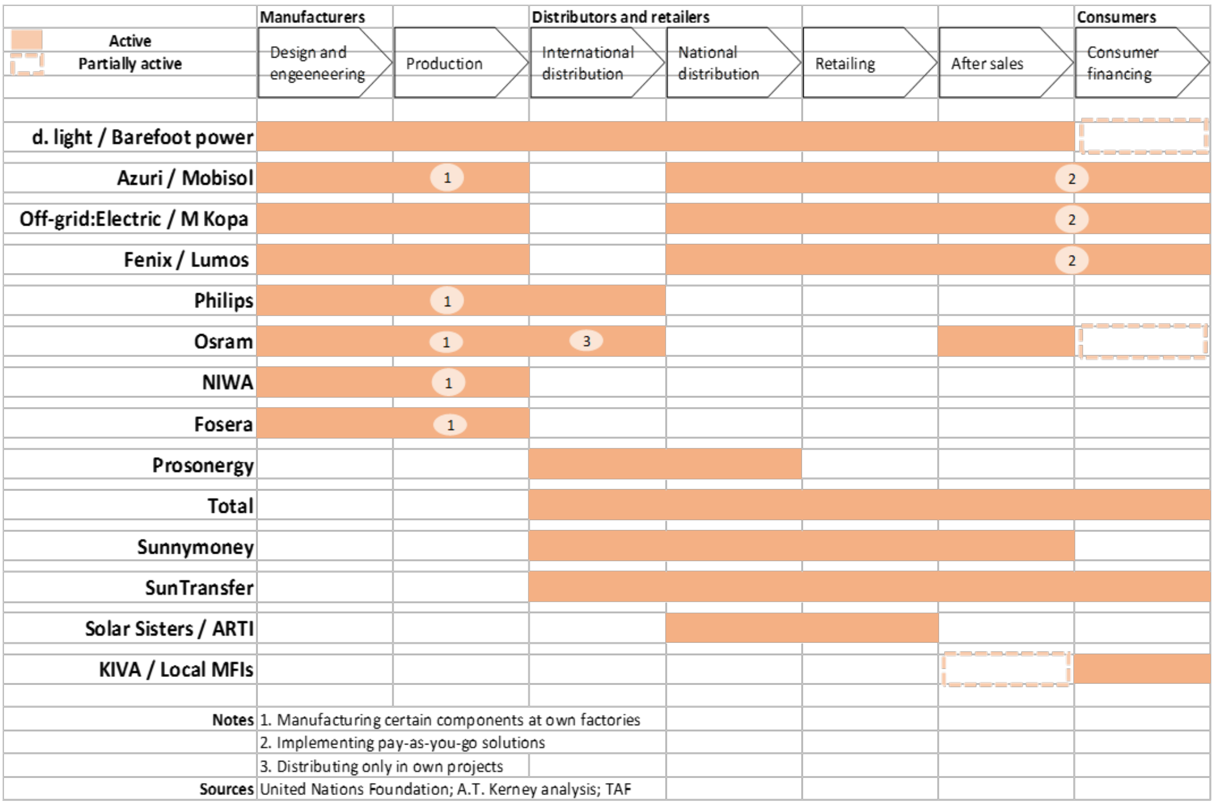
2 In a standalone PV *system,* the inverter is most of the time used at partial load use.

3 For more information *see Section*6: Energy Efficiency and demand side management

4 The only alternative to large oversizing is *the* introduction of diesel in *the system* with an inverter/charger.

4 Some key players in the off grid standalone systems industry

The coverage of the industry value chain by various service providers is illustrated below



Investors see distribution and consumer finance as the most important areas and therefore invest in companies tackling these issues.

Manufacturers focus on design, engineering and manufacturing steps. They need capital for R&D and to pass good terms to distributors.

Distributors focus on distribution, retailing and after sales. They have large working capital need (up to half the target annual revenue) because of long transport and distribution times.

Commercial banks/ MFI focus on consumer financing since at least 50% of consumers need to finance their off grid product.

5 What is the typical benchmark?

In order to provide a benchmark for off-grid rural electrification, the table below displays the average connection cost per customer according to the broad range of use on the energy ladder.

The level of revenue per customer on the energy ladder starts at round 10 US$ per year for Tier 1, increases to 100-500 $ per year for tier 2 and 3 and exceeds 1000 $ per year for tier 4 and 5.

The level of investment ranges from 70 US$ for tier 1, increases to 300-1000 US$ for tier 2, and peaks at 3000$ for Tier 3, 4 and 5.

For tier 1 to 3, standalone off grid systems (Solar lanterns and stand-alone home systems) are the most economical solution for electrifying households.

Continuous Spectrum of improving Electricity supply Attributes

Attributes	Tier 0	Tier 1	Tier 1	Tier 1.5	Tier 2	Tier 2.5	Tier 3	Tier 3	Tier 4	Tier 5
Service Description	Kerosene lighting	Task lighting and phone charging (or radio)	Task lighting and phone charging (or radio)	4 lights, phone charging and radio	General lighting and TV or fan (if needed)	General lighting and TV and fan (if needed)	Tier 2 and any low power applicances	Tier 2 and any low power applicances	Tier 3 and any medium power applicance	Tier 3 and any high power applicances
Peak available capacity (W)	-	1	5	10	20	50	200	500	2000	2000
Duration (hours/day)	-	4	4	4	4	4	8	8	16	22
Evening supply (hours/day)	-	2	2	2	2	2	2	2	4	4
Average annual consumption per household										
Load factor		17%	17%	17%	17%	17%	18%	20%	20%	25%
annual consumption (kWh/year)		1,5	7,3	14,6	29,2	73	315	876	3504	4380
Price of electricity (US$/kWh)		5,0	4,8	4,0	4,0	3,0	1,0	0,50	0,30	0,25
annual cost (US$/year)		7,3	35	58	117	219	315	438	1051	1095
Average costs (US$/household)										
Least cost		70	110	166	288	500	1800	3200	1600	1600
Likely electricity supply technology	**None**		**Solar lanterns**	**Stand-alone home systems**				**Mini grid**	**on grid**	

Source: ESMAP & TAF

6 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 models have to find ways to control customer behaviour to avoid overuse, misuse or careless use.

"Pay-as-you-go" or "pay-to-own" business models can easily disconnect a user in case of default of payment, whereas cash sale or donation models create more complication as regards to ensuring the sustainability of the individual off grid asset. Both types of models require the existence or the development of a second-hand market to cope with the risk of non-performing or volatile customers.

The Utility individual off-grid solution model

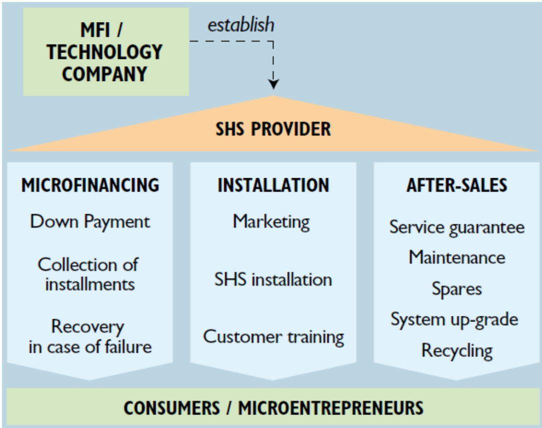
In the utility/central planning model approach, the off grid solutions are scheduled in the rural electrification master plan, approved by the Ministry of Energy and with technical inputs of the rural electrification agency. Engineering, procurement of equipment and construction is ensured by a Rural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

For individual off-grid solution, there is a hand-over of the installed equipment to the final beneficiary who receives the system as a donation (no sense of "ownership") with no "embedded" support in terms of maintenance/service beyond the guarantee period of the installer (usually 2 years). In the past, many of these programmes financed by all major donators have failed.

The private sector market driven individual off-grid solution model

There are four market driven business models for standalone systems:

1 One-Hand Model: In this model, the same organisation manages the micro-financing, installation and after-sales of the system.

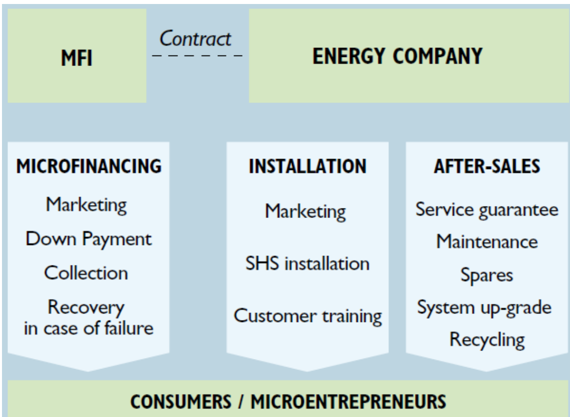


Source: ARE

The main challenge of the One-Hand-Model is that the commercial bank must become part of the supply-chain, develop stock logistics, and offer branch level staff training and maintenance services. The main advantage is that the partner bank is going to disseminate micro credit green products in its client base for which the bank has full knowledge of the credit history thus mitigating the client risk. This model has been created by Grameen Shakti, which is acting today as an energy system provider and has given more than 250.000 SHS loans and reproduced by micro credit intermediary companies such as Zara Solar and off.grid:electric in Tanzania, Solar Energy Uganda, Safaricom solar lantern and Equity bank green product micro credit in Kenya.

2 Two-Hand Model: In this model, the Micro Finance Institution (MFI) manages the micro-financing, while the technology company manages the installation and after-sales of the system.

This model is based on a long-term partnership between the local commercial bank and a committed rural energy service provider. In contrast to the One-Hand Business Model, it is more suitable for diversification and customisation of energy products. One provides the credit, the other the energy supply, knowledge, training and maintenance.

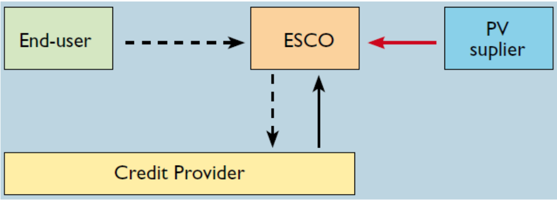


Source: ARE

This approach is more comfortable for commercial banks since it requires from them financial services only. Furthermore, the loans to energy access applicants can be bundled through the rural energy service provider. The bank takes the credit risk of the service provider. The service provider takes the credit risk of customers. A credit guarantee mechanism provides security against the payment default of a fraction of customers.

3 "Fee-for-Service" Model (or Pay-As-You-Go Model): In this model, **an energy service company** (ESCO) owns the system and provides a service to the end-users.

With both "pay-to-own" microfinance business models (one-hand, two-hand) the customers gain ownership over the system after the repayment period, but other approaches where the ownership stays with the provider (pay-as-you-go) are also widely developed.



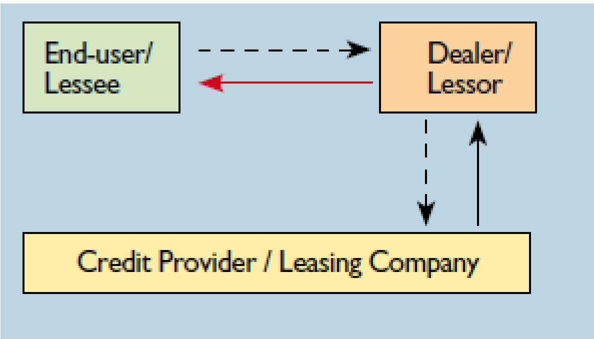
Source: ARE

In the "pay-as-you-go" model, the electricity access provider, an energy service company (ESCO) owns the system and provides a service (electricity) to the end-users. It also ensures the operation, maintenance and replacement of the system, and in exchange the end-users pay a certain sum every month for the electricity service in cash or other methods (for instance pre-paid chip cards are very popular in some places to cope with the risk of non-paying customers).

This model has become extremely popular with a myriad of start-up technology companies that are connected with and supported by risk capital funds. Some start-up technology companies have already signed strategic partnership with global technology providers (for mass production of their system's components) and also with telecom companies (for enabling and controlling the financial transaction through mobile phone).

4 Lease/Hire Purchase: in this model, the system is leased by the technology company to the end-user.

In this case, the PV supplier/dealer or a financial intermediary leases the PV system to the end-user. At the end of the lease period, ownership may or may not be transferred to the end-user, depending on the arrangement. During the lease period, the lessor remains owner of the system and is responsible for its maintenance and repair.



Source: ARE

7 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.

Social impacts are as follows:

- Longer hours and better illumination for studying
- Social cohesion and community development
- Safety and equitable development for women

Health impacts are as follows:

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

Environmental impacts are as follows:

- Reduce annual global kerosene consumption and associated greenhouse gas emission as well as carbon black emission
- Protect natural habitats against deforestation

Economic impacts are as follows:

- Free up household resources spent annually on fuel to be invested in more sustainable businesses
- Reduces household spending on kerosene or candles, and increases savings up to 10 to 15 percent of a household's income
- 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

8 What are the key questions?

Financial analysis

Are the costs per system acceptable?
Are the financial indicators (pay-back period, IRR, cost per kit distributed) acceptable?
What will be the running costs of the Standalone PV system for the final beneficiary?

Economic analysis

What is the impact of the project on the economic and incomes generating activities?
What is the expected social impact on the beneficiary population (education, health,)?

Organisations and business models

What type of organisations is the most appropriate to the local context?
What activities are currently authorised to the private sector and private individuals and what needs to be reviewed in the energy law, regulation, to allow the setting-up of new business models?

Are the foreseen distribution channels (schools (Sunnymoney), community leaders, banking network (Equity Bank), mobile telephone companies (M Kopa), etc.) relevant for the beneficiary communities?
How will be the after sales services, the business model viability, the organisational capability, the scalability of companies?

Technology

Alternative Current (AC) or Direct Current (DC)
How can adequate service quality be maintained so that user appliances and the PV systems are not damaged?
How to assess the actual needs of a community to ensure that the system is not oversized and too expensive for the targeted communities?
To whose standards/norms the standalone systems will comply?

Price and Tariff

Capability and willingness to pay of the various stakeholders?
Operation and maintenance
How and who will operate and maintain the standalone systems?

Business plan

Is a market analysis available (demand forecast, expected consumption, willingness to pay of the beneficiaries,…)?
Is a business plan available and realistic (competitor analysis, marketing plan, sales planning, per-unit economics, cash flow planning)?

Sales planning

If needed, what will be the amount of subsidy during the starting phases?

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