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Low-cost energy technologies for universal access

Preliminary candidate list of appropriate technologies, business models and enabling environment for universal access to electricity

Andres GONZALEZ-GARCIA, Reja AMATYA, Robert STONER,
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Research project

Low-cost energy technologies for universal access

The UN Secretary General's Advisory Group on Energy and Climate Change defines universal access as "access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses". The International Energy Agency (IEA) establishes that achieving a minimum basic universal access to electricity and providing clean cooking facilities for 2030 would require around $1 trillion cumulative investment. IEA also highlights electricity as the most critical energy carrier for development while the use of biomass in inefficient stoves remains one of the main causes of premature deaths.

It is clear that a problem of this magnitude cannot be seriously approached without private capital and, most likely, with the serious involvement of energy companies, although decentralized approaches (either transitory or not) cannot be ruled out and they are already taking place. Obviously this will happen only if an attractive business model can be defined. This model must include: the definition of the appropriate (low cost) technologies to be used; a regulatory framework that clearly defines the rights and obligations of all parties involved and, specifically, the rules of remuneration for the provision of the service; and the sources of finance for this activity. Such considerations are central to this research project and represent a considerable challenge for rural areas.

The purpose of this project is to contribute to the development of universal Access strategies and tools for policymakers, global businesses and practitioners, supporting the publication of periodic technologies, strategies and business models country reports with roadmaps to universal access.

This Working Paper is one of the first reports of the Low cost energy technologies for universal Access project by the Massachusetts Institute of Technology (MIT) acting through MIT's Energy Initiative (MITei) and in collaboration with Enel Foundation. The project is developed in collaboration with Comillas Pontifical University – Institute for Research in Technology (COMILLAS – IIT) under the scope of the Comillas University Massachusetts Institute of Technology Electricity Systems (COMITES) Program. At this first stage we have researched various appropriate technologies for access to electricity, which are described in detail in this document (WP1 – Electricity) and in Working Paper 2 (WP2 – Modern heat). We have investigated business practices that have been adopted around the world for the dissemination of these technologies. We have also focused on the existing regulatory, governance and financing frameworks that enable the sustainability, replicability, scalability and upgradability of these technologies and business models in order to provide long-term, reliable and affordable access to modern energy services for all.

In the second phase we will apply our methodology - including data, logic processes and the potential use of software tools described in Working Paper 3 (WP3 – Universal access) - to specific countries and regions to develop a comprehensive assessment of the appropriate modes of electrification, heating and cooking for the entire population, as well as the technologies, the business models and the enabling environments that would provide universal access to modern forms of energy services, starting with the cases of Peru and Kenya to be issued in 2015.

This publication presents the results of the Working Paper Preliminary candidate list of appropriate technologies, business models and enabling environment for universal access to electricity.

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Abstract

This Working Paper focuses on assessing the existing knowledge and successful experiences in access to electricity, reviewing the main technological, business and political approaches. Electricity supply, according to the International Energy Agency (IEA), is the most critical energy carrier for development. 1.3 billion people lack access to electricity in 2010. 84% of them live in rural areas, with the majority in sub-Saharan Africa and South Asia. Without additional dedicated policies, by 2030 the population without access to electricity drops only to 1.0 - 1.2 billion. A problem of this magnitude cannot be seriously approached without private capital the involvement of energy companies coexisting with decentralized approaches. Obviously this will happen only if an attractive business model can be defined tailored to the appropriate (low cost) choice of technologies; a regulatory framework that clearly establishes the rights and obligations of all parties involved and the availability of sources of finance for this activity. The Sustainable Energy for All (SE4ALL) initiative has established a widely accepted taxonomy of 6 access levels (from Tier 0 representing no access to modern energy supply to Tier 5 reaching up to high power appliances), so that policy targets and business model pathways can be set properly to enable the further development of the communities supplied with electricity. Accordingly, different technologies can satisfy different access levels for different household, community and productive electricity uses. WP1 analyses four electrification modes in detail, as well as their appropriate applications to satisfy this diversity of needs, according to the suitability of each solution for different environments: Pico and small lighting systems, stand-alone systems, isolated mini-grids and grid extension. Moreover, the initial choice of technology sets a pathway that will determine the future ability of the system to provide more advanced energy services up the energy ladder. It will also restrict future options concerning cost of the technological upgrades, fuel expenses, carbon emissions, safety, reliability or pollution. In this context, adapting products and services to the needs of low-income groups requires significant innovation and research. Within the limits of cost restrictions, electrification agents need to tailor their products to different customer demands and priorities, from lighting, charging cell phones or powering small radios to productive agriculture, manufacturing or commerce, and to community services such as street lights, health and education. Low-income groups also require innovative business solutions that overcome the cultural barriers, in terms of distribution channels, customer relationships, risk aversion, raising awareness of customers and gaining their trust.

Keywords: universal access, solar kits, Pico Solar Systems, micro-grids, grid extension, business models, regulation, energy policy, enabling environment

JEL Codes: Q4, Q41, Q42, Q43, Q47, Q48, N70, O13, O18, O19, O33, O38, O44, Q56

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1 Introduction to electrification technologies and business models

1.1 Concerning technologies

Expanding the definition of Universal Access "to energy services that are clean, reliable and affordable for cooking, heating, lighting, health, communications and productive uses"[1], the Sustainable Energy for All (SE4ALL)[2] initiative has established a consensus about 5 access levels[3] so that policy targets and agreements can be set properly[4]. Electricity targets are shown in TABLE 1.

TABLE 1 - SE4ALL framework access levels to electricity and modern cooking technologies

ACCESS TO ELECTRICITY SUPPLY

ATTRIBUTES	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Peak available capacity (W)	-	>1	>50	>200	>2,000	>2,000
Duration (hours)	-	≥4	≥4	≥8	≥16	≥22
Evening supply (hrs)	-	≥2	≥2	≥2	≥4	≥4
Affordability	-	-	√	√	√	√
Legality	-	-	-	√	√	√
Quality (voltage)	-	-	-	√	√	√

- Five-tier framework.
- Based on six attributes of electricity supply.
- As electricity supply improves, an increasing number of electricity services become possible.

Index of access to electricity supply = $\sum(P_T \times T)$

with P_T = Proportion of households at tier T

T = tier number {0,1,2,3,4,5}

USE OF ELECTRICITY SERVICES

TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
-	Task lighting **AND** phone charging (OR radio)	General lighting **AND** television **AND** fan (if needed)	Tier 2 **AND** any low-power appliances	Tier 3 **AND** any medium-power appliances	Tier 4 **AND** any high-power appliances

- Five-tier framework.
- Based on of appliances.

Index of access to electricity supply = $\sum(P_T \times T)$

with P_T = Proportion of households at tier T

T = tier number {0,1,2,3,4,5}

Source: ESMAP et al., 2013

[1] SG AGECC, 2010
[2] SE4All by UN has launched an international initiative joined by more than 75 countries, as well as private sector and multilateral institutions for achieving three global targets by 2030:

- providing universal access to modern energy services;
- doubling the global rate of improvement in energy efficiency;
- doubling the share of renewable energy in the global energy mix.

[3] ESMAP, World Bank, IEA, 2013
[4] Brazilian et al., 2010

This document structures the description and analysis of business models on the basis of the technology choices for the electricity delivery service:

- Small-and-Pico-Lighting-Systems (SPLS)
- Stand-Alone-Systems (SAS)
- Isolated Mini-grids
- Grid extension

Technologies for development are nothing but a mean to precisely that end. Whether we are designing a whole strategy[5], choosing between grid extension and off-grid electrification[6], or between renewable energy sources or fossil fuels[7], or implementing singular projects, we need to center the analysis on their users[8]; on the needs they satisfy and on the socio-economic changes they foster.

Accordingly, different technologies can satisfy different access levels for different uses as analyzed by Practical Action[9] for household electricity access, community and productive uses:

TABLE 2 - Indicative multi tier framework for household electricity access, adapted from SE4All

Tier	0	1	2	3	4	5
Electricity services	None	Electric lighting, radio, mobile phone charging	Tier 1 + multi-bulb lighting, air circulation, TV	Tier 2 + water heater, rice cooker	Tier 3 + refrigerator, mechanical loads	Tier 4 + electric cooking, space heating and cooling
Energy supply attributes	**Continuous spectrum of improving energy supply attributes** including: quantity (watts), duration (hrs), evening supply (hrs), affordability, legality, quality (voltage)					
Likely energy supply technology (indicative)	None	Solar lanterns	Stand-alone home systems	Mini-grids with limited supply or poor grid connection	Unreliable grid with limited supply	Reliable grid with 24-hour supply

Source: Practical Action, 2013

[5] Barnes, 2007; Behrens, Nunez Ferrer, Carraro, Lahn, & Dreblow, 2011; Kozulj et al., 2009; Leung & Meisen, 2005; Onyeji, Bazilian, & Nussbaumer, 2012; UN Energy, 2005

[6] Deaton-Steel, 2007, 2008; Szabó, Bódis, Huld, & Moner-Girona, 2013

[7] Martinot & Reiche, 2000; Richards, 2006; World Bank, 2008

[8] Brazilian & Pielke, 2013; ENERGIA International Network on Gender and Sustainable Energy, 2006; Schillebeeckx, Parikh, Bansal, & George, 2012; Yianna Lambrou & Grazia Piana, 2006

[9] Practical Action, 2010, 2012, 2013

As will also be seen in this Working Paper, technology choices in the table above are an indicative simplification for each Tier. We can find business models providing affordable and sustainable Tier 1 electrification through Stand-Alone-Systems or Micro-grids (either isolated or connected to the power network), and we can also reach Tier 5 through Mini-grids and even installing hi-power stand-alone home systems.

In any case, the important conclusion from the multi-tier SE4all framework is that the emphasis is not to be put on the technology choices, but on the energy services. Nevertheless, the initial choice of technology sets a pathway that will determine the future ability of the system to provide more advanced energy services up the energy ladder. It will also restrict future choices concerning cost of the technological upgrades, fuel expenses, carbon emissions, safety, reliability or pollution. Therefore, an adequate technology choice should not only take into account present needs and capabilities, but also future evolution of the system not only regarding household uses but also productive as shown in Table 3:

TABLE 3 - Indicative multi tier framework for productive energy uses. Practical Action.

Tier	0	1	2	3	4	5
Likely energy supply technology resource	Human power	Human power / Animal power	Animal power	Renewable power / Engine	Renewable power / Engine / Electrical power	Electrical power
Possible energy technologies for key livelihood activities						
Water pumping	Bucket	Treadle pump	Hydraulic ram pump	Water-current turbine	Solar PV water pump, motorised pump	High power electric pump
Agro-processing	Hand pounding	Animal powered mill	Traditional water mill	Improved water mill	Diesel-powered mill	High power electric mill
Small-scale manufacturing	Hand tools	Treadle tools	N/A	Mechanical lathe	Engine-powered circular saw	Electric saw

Source: Practical Action, 2013

Regarding community uses, education and health are the most essential services, but in this report will also show appropriate energy technologies and business models for street lighting, community and leisure facilities, communications and other community uses.

TABLE 4 - Indicative multi tier framework for education and health, adapted from Practical Action & SE4ALL.

Tier	0	1	2	3	4	5
Attributes of energy accessed	Continuous spectrum of improving energy supply attributes including adequacy, availability, reliability					
Basic energy services	Lighting	Limited task lighting + mobile phone + radio	Tier 1 + limited general lighting + air circulation + VHF radio cooking	Tier 2 + multiple lighting + air cooling + refrigeration + computer w/ internet + TV	Tier 3 + air cooling/ heating	All applications are feasible
Medical equipment	None	None	Vaccine refrigeration Sterilization	Low power medical appliances: microscope, testing equipment etc. Incineration	Tier 3 + high power equipment: x-ray machines, ultrasound scanners etc.	All applications are feasible
Teaching equipment	None	None	Limited computer use	Projector + Laboratory equipment + Multiple computers w/internet	Tier 3	All applications are feasible
Likely energy supply technology (indicative)	Kerosene lamps; Candles	Third-party charging; Improved cookstoves	Small stand-alone solar PV; Kerosene/gas refrigerator; Institutional cookstoves; Biomass heater	Mini-grid connection; Grid connection: Unreliable; Incinerator	Mini-grid connection; Grid connection: Unreliable + backup	Grid connection: Reliable

Source: Practical Action, 2013

1.2 Concerning business models

For the classification of electrification business models, we abide by the categorization shown in Table 5 that extends the classification of business models by Reiche et al[10]. We have added an additional technology category to the ones proposed, so to include *Small-and-Pico-Lighting-Systems*, whose cost, size and weight characteristics allow the emergence of new and distinctive business models, compared to standard *Stand-Alone-Systems*.

[10] Reiche, Tenenbaum, & Torres de Mästle, 2006

Table 5 sorts the "universe of supply options" organized by two parameters:

- Technology choice: From centralized grid solutions to off-grid small and pico solar systems.

- Form of ownership of the supply option: From state owned utilities to private, for profit firm.

The dominant historic model of grid extension by a large centralized public owned utility would be at the lower left-hand corner of the table. The small franchise model would be found at the right column within the matrix. The table summarizes the different electricity access experiences analyzed within this work.

Also according to the authors "Although this matrix "orders" the universe along the two dimensions of technology and form of ownership, these are only two parameters out of a much larger set of characteristics that distinguish one electrification option from another. These two "organizing" characteristics were chosen because they are particularly useful in focusing attention on important regulatory design issues".

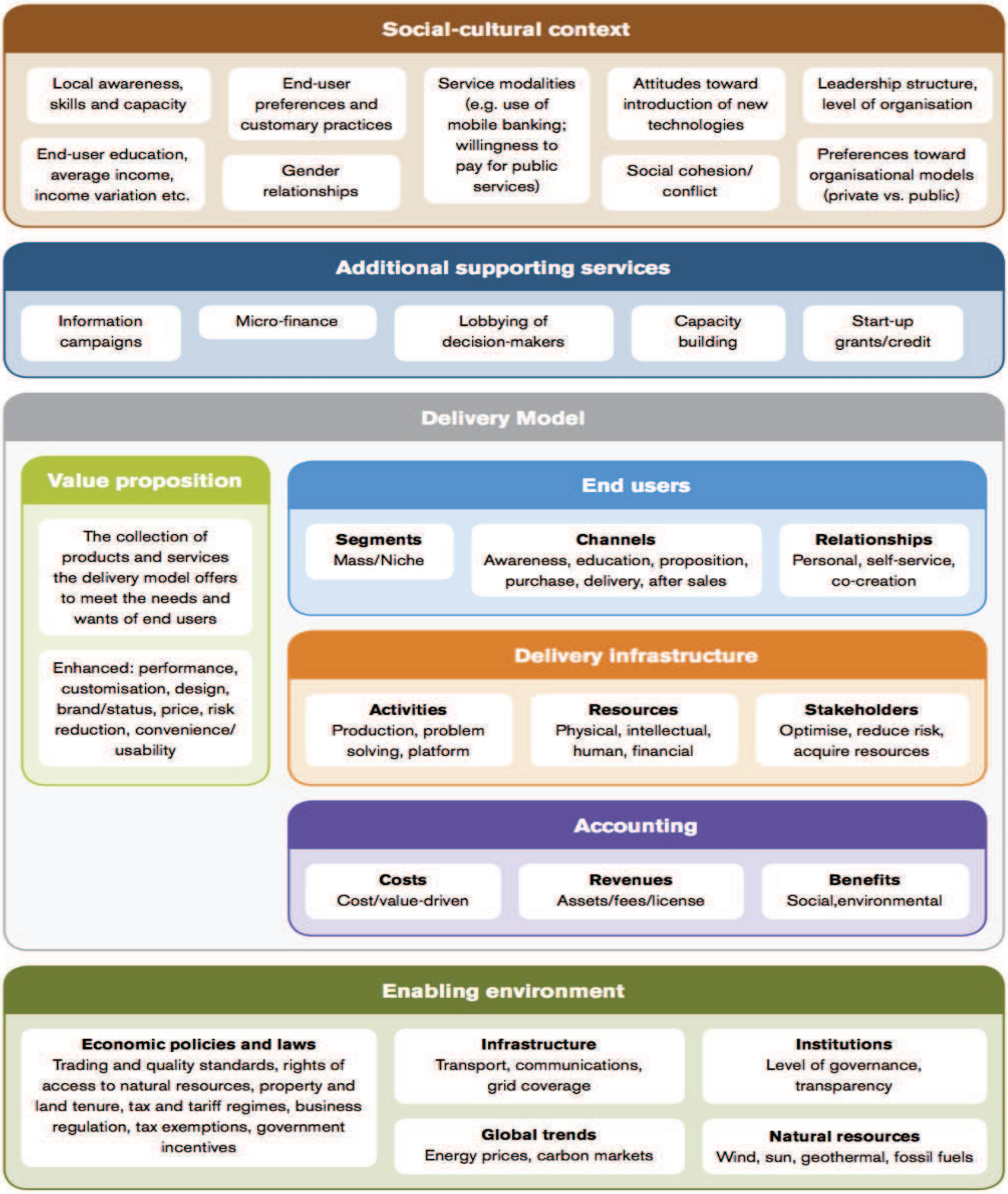
TABLE 5 - Matrix of electricity supply modes and business models analyzed in this Working Paper.

		Grid Extension	**Isolated Mini-grid**	**Stand-Alone-Systems**	**Pico Solar Systems**
For profit	*Small, decentralized*	Sunlabob (Laos)	OMC Power (Africa, India), Scatec Solar (India), Sunlabob (Laos), Asantys (Africa, Asia)	Barefoot Power (Africa), Sunlabob (Laos), Soluz (LatAm), Asantys (Africa, Asia)	Barefoot Power (Africa), Sunlabob (Laos), Soluz (LatAm), Teri (India), Asantys (Africa, Asia)
	Large, centralized	NDPL (India), ENEL (Brazil), Fenosa-Gas Natural (Guatemala), Condensa (Colombia), Schneider (Global)	NPDCAPL (India), ENEL (Chile, Peru), Dresser-Rand (Brazil) Schneider-Electric (Global),	ENEL&Barefoot Colllege (Latin America), Schneider-Electric (Global)	Schneider (Global), Philips (Africa, India), Tata Power Solar (India)
Non-profit	*Cooperatives*	Coopesantos et al. (Costa Rica), REB (Bangladesh), NEA (Philippines)	ESD (Sri Lanka), Coopesantos et al. (Costa Rica)	Costa Rica Energía Sin Fronteras (Guatemala)	
	Social enterprises		Mera Gao Power (India)	Grameen Shakti (Bangladesh), AccionaME (México), D.Light (Asia, Africa)	Grameen Shakti (Bangladesh), AccionaME (México), D.Light (Asia, Africa), ToughStuff (Africa)
	NGOs		Teri (India)	Practical Action (LatAm, Africa)	Solar Aid – SunnyMoney (Africa)
Public	*Small, decentralized*		RVEVESP (India)	Municipalities (Sunlabob) EnDev (Africa, Asia, LatAm)	EnDev (Africa, Asia, LatAm)
	Large, centralized	ONE-PPP (Morocco), Eskom (South Africa), WAPP (West Africa)		Government owned utilities in Peru	

Source: own elaboration

For mapping the building blocks of a business model, as a combination of technology, management and finance, including the contextual elements such as socio-cultural context and the necessary enabling environment, the Sustainable Energy for All approach[11] has been followed as depicted in Table 6:

TABLE 6 - Delivery Model Map

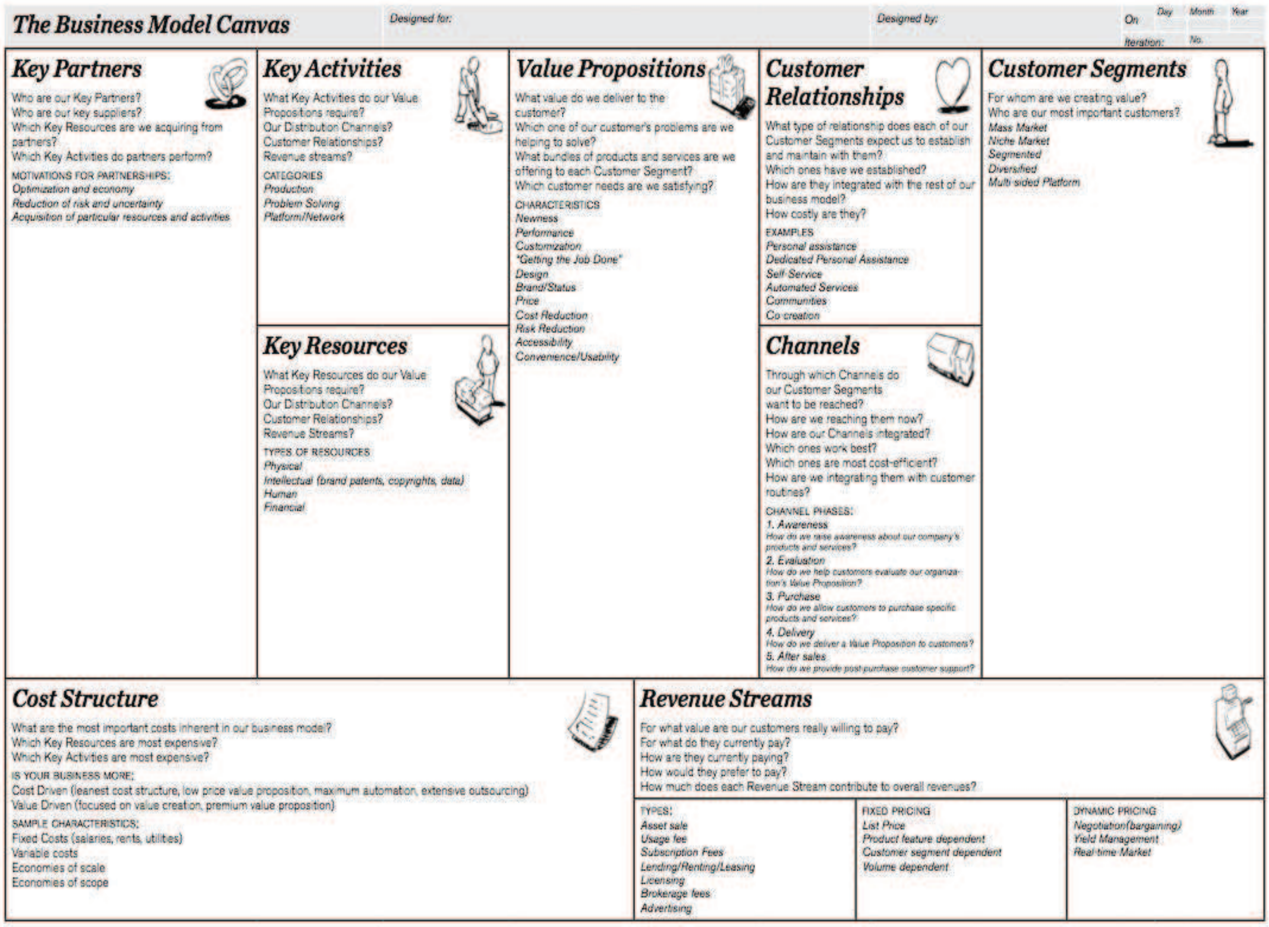


Source: Wilson et al., 2012

[11] Garside & Bellanca, 2013; Wilson, Wood, & Garside, 2012

For the analysis of each business model, we will take into account the categories settled by Reiche et al.[12] and the criteria proposed by Izquierdo and Eisman[13] in reference to the detailed Osterwalder's business model canvas[14] shown in Table 7:

TABLE 7 - Osterwalder's business model canvas



Source: www.businessmodelgeneration.com/downloads/business_model_canvas_poster.pdf

1.3 Concerning the socio-economic and cultural context

The main purpose of these systems is to provide lighting and electric appliances to users either if they are not connected to the grid (because of their low income may be combined with geographical isolation) or elsewhere they receive a very poor quality of service and require complementary power service, as well as for portable uses of light, such as mobile businesses.

[12] Reiche et al., 2006
[13] Izquierdo & Eisman, 2009
[14] Garside & Bellanca, 2013; Wilson et al., 2012

The report "From Gap to Opportunity[15]" estimates that 90% of people without access to modern energy already spends so much in traditional alternatives and batteries that they could afford to purchase modern options as solar lamps. Following the lead of mobile technologies, low price electric technologies can experience similar growths, as in the case of cell phones in Africa with a deployment of 600 million units in 10 years. The energy market for the base of the pyramid starts with solar lanterns from 20 US$ to 50$ (equivalent to monthly capacities of payment under 8.50$/month), and then continues with a full range of solutions like rooftop solar home systems, micro-grid or low-cost grid connections that take from around 10$/month up to the actual expenditure of developed countries. The report calculates these amounts considering standard investment and operation and maintenance costs for each technology, without taking into account any kind of subsidy. In most actual cases, governments, aid agencies or donors cover the cost of the investment, so the customers should only have to pay, partially or totally, for the operation and maintenance costs, thus being able to sustainably afford higher tiers of energy access.

In this context, adapting products and services to the needs of low-income groups requires significant innovation and research[16]. Within the limits of cost restrictions, electrification agents need to tailor their products to different customer demands and priorities, from lighting, charging cell phones or powering small radios to productive agriculture, manufacturing or commerce, and to community services such as street lights, health and education. Low-income groups also require innovative business solutions that overcome the cultural barriers, in terms of distribution channels, customer relationships, risk aversion, raising awareness of customers and gaining their trust.

According to the International Energy Agency[17] around 84% of people without electricity live in rural areas, most of them in developing Asia and sub-Saharan Africa while the rest usually live mainly in the suburbs of large capitals or in newly urbanized cities or villages, for instance in many places where new extractive or harvesting communities are being established to satisfy the increasing demand for natural resources.

As for rural communities, Pérez-Arriaga and Moreno[18] coordinated a study regarding the characteristics of technology for development in isolated rural areas, those where low income and isolation make grid service unaffordable in favor of off-grid electrification, also portrayed by Izquierdo and Eisman[19]. The first conclusion of these studies is that the diversity of different isolated rural communities regarding their socio-cultural characteristics, economic and institutional structure, resources, education… all of them vectors that determine the suitability of different business models for power delivery either to nomad shepherds in the Sahel, indigenous islanders in Chiloé archipelago (Chile) or remote villagers in Peru, Kenya or India.

[15] International Finance Corporation, 2012
[16] Wilson et al., 2012
[17] IEA, 2011
[18] Arraiza & Conde Zurita, 2011; Izquierdo et al., 2011
[19] Izquierdo & Eisman, 2009

Despite their differences, these are the main concerns to be taken into account when approaching rural communities for their transition from traditional to modern energy sources:

- cultural resilience: Isolated communities have endured the globalization influence, keeping their cultural values and language. Electrification agents must approach these communities with respect and care for their traditions. The success of the universal access process depends also on the ability of the business models to accommodate the energy transition to meaningful values and concepts of the local cultures[20].

- Impacts of poverty: Poverty has to be considered not only regarding low income levels, because it is a multi faceted reality with impacts on health, education, infant mortality or environmental problems. Agents should carefully evaluate the priorities of their programs, considering their potential contribution (positive or even negative) to all these problems.

- Lack of access to other basic infrastructures: Absence of electrification usually comes hand in hand with lack of running water, telecommunications, sanitation, health, education and cultural services.

- Community organization: Local institutions have a major role to play in raising awareness, education and promotion of electrification technologies. Their involvement, as well as the involvement of users, requires their freedom to adopt and to adapt these new energy services to their own needs and desires. Their community links have helped them survive under very dire circumstances, and will surely be a cornerstone of energy transition.

- Political isolation: The difficulties of this population to influence the political framework have resulted in traditional exclusion from the decision making process. Because of this under-empowerment of isolated communities, authorities are tempted to neglect their service rights unless it is firmly established as a political goal and explicitly settled in the national, regional and local agendas. The emergence of Universal Access in the international energy, development and climate agendas helps in fostering the adoption of effective initiatives, but further consideration to the role of local communities and the incorporation of user-centric lens[21] for the elaboration of the energy planning must be assured. It is also the role of governments to establish of the necessary mechanisms for this population, including subsidies and affirmative actions if needed.

- High supply costs and low capacity of payment: these communities usually present hurdles for every mode of electrification. Not only isolation means much higher logistic, transmission and distribution costs. Cultural barriers and low education levels of the population involve higher transaction costs (information, bargaining, financing, policy enforcement, etc.) and need of additional efforts in raising awareness and training of users and intermediaries.

[20] Wilson et al., 2012
[21] Schillebeeckx et al., 2012

Regarding urban customers, their electrification is usually driven by their low capacity of payment compared to supply costs of grid connection, but there can be also other factors to be taken into account like weak unsatisfactory service by the network. Many dwellers of suburbs or slums have an illegal status that prevents them from establishment service contracts with electric utilities. Their income from the informal economy is also difficult to adapt to the periodic payments usually required by retailers. All this, together with lack of awareness and education, has led to lack of trust between urban poor communities and service providers[22].

Electrification requires thus a wide perspective that considers access as a factor within a set of development issues to be addressed in order to achieve Universal Access targets, but that starts from a user-centric approach that guarantees the *affordability, reliability* and *local embeddedness*[23] of the business model.

[22] World Bank & ESMAP, 2011
[23] Schillebeeckx et al., 2012

2 Small and Pico Lighting Systems

This section analyses the business models for off-grid electrification with pico solar kits and lanterns in highly isolated rural areas and for very low-income population. The purpose of the document is to identify the key features of these models, their applicability in pursue of universal access to electric power services "in the last mile" and the relevant policy and governance measures for the sustainability, reproducibility and scalability of these initiatives.

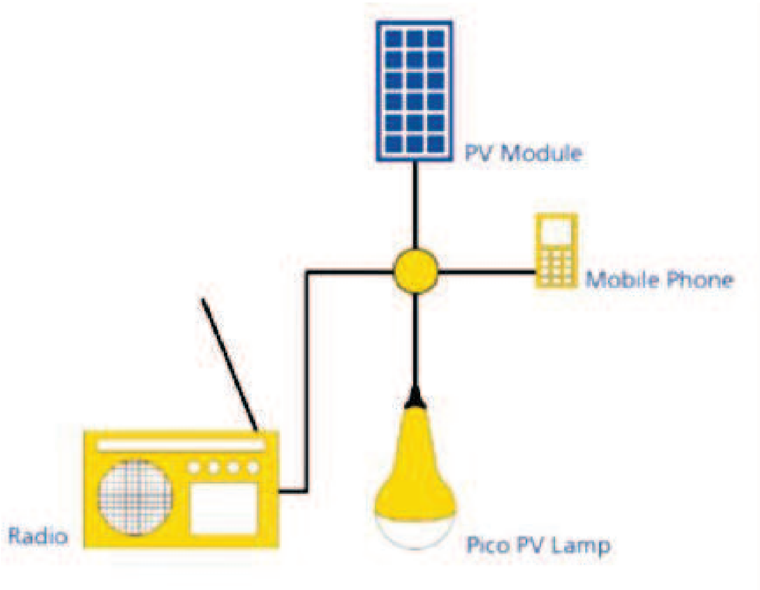
FIGURE 1 - Photo by Lighting Africa 2010

Source: Lighting Africa 2010

2.1 Introduction

The arrival of low cost Small-and-Pico-Lighting-Systems (SPLS) as solar and rechargeable lanterns or solar kits enables the emergence of new business models for electrification. Because of their low-cost, low-weight, low-maintenance and high-portability, these technologies can be purchased, installed and operated directly by individual customers. The dealers provide the equipment, additional maintenance and financing services. Therefore, these technologies are suitable for off-grid electrification of highly isolated rural areas and for very low-income population.

FIGURE 2 - Pico Lighting System



Source: Alliance for Rural Electrification, 2011

Weight of these systems is less than 7Kg and their installation must be easy enough for a person with a very basic training. The main advantage of these technologies is their high energy efficiency, not only because of the light PV panel and the use of new battery technologies, but also because of the emerging low consumption DC appliances as LED lights, DC radio or TV sets, productive and community uses. Their low weight and durability allow the emergence of new business models, in comparison with traditional Stand-Alone-Systems, Micro-grids or grid extension electrification modes.

Since 2007, the UN program Lighting Africa has promoted the development of these low cost and high efficiency illumination devices that allow the substitution of kerosene lamps and candles as well as other traditional lighting means. Business models based on Pico Lighting Systems have also been experienced to different levels of success in Bangladesh, India, Mexico, Peru or Kenya, among other countries in Africa, Asia and Latin America.

2.2 Technology

These systems can be categorized as[24]:

- solar and rechargeable portable lanterns: They only provide illumination and usually include a built in battery with a LED light and a very small PV panel for charging.

[24] Eisman, Olivares, Moreno, Verástegui, & Mataix, 2013; Lighting Africa, 2013

- Small-and-Pico-Lighting-Systems usually include 2 to 4 LED lamps, a charge controller, a phone charger or other low power appliances, with a lithium-ion battery and a small solar panel. They can be classified according to their peak power in:
  - Less than 10Wp for Pico Lighting Systems (PLS)
  - Between 10 and 50Wp for Small Lighting Systems (SLS).

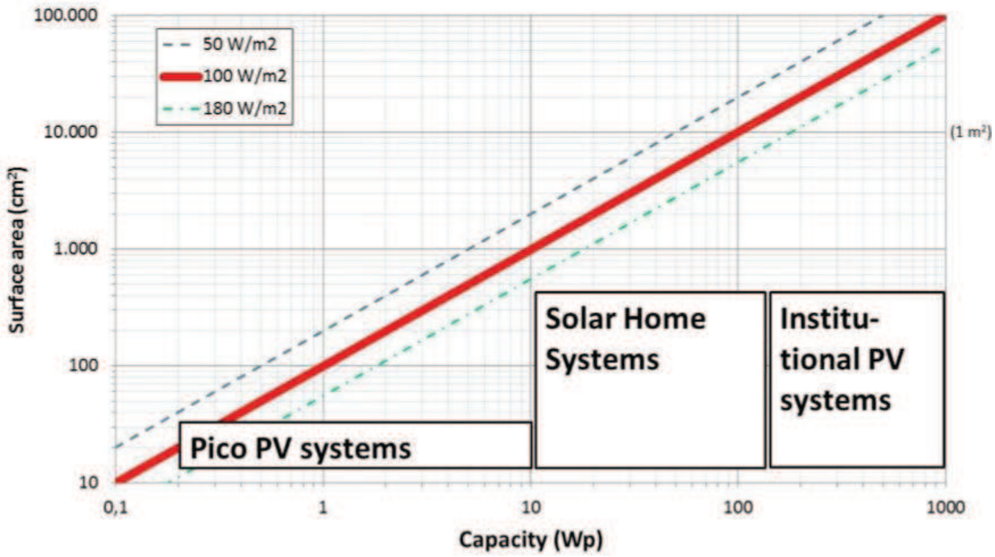
We have favored the denomination of Small-and-Pico-Lighting-Systems over Solar Systems, as charging of these systems can be achieved also by other portable renewable means, to a much lesser extent. E.g. hand crank or pedal power dynamos are sometimes suitable options for powering PLS and lanterns in applications for development[25].

2.2.1 Key technological features

Solar panels

Figure 3 shows the size of SPLS PV panels, compared to other PV systems, considering an estimation of the efficiency of small multi-crystalline cells of 100 Wp/m^2. A 10x10 cm^2 panel has a capacity of 1Wp. Crystalline PV cells would offer higher efficiencies up to 180%, almost halving the panel size, while amorphous PV cells would be 40% less efficient, nearly doubling the size.

FIGURE 3 - Approximate surface area of multi-crystalline PV panel



Source: Lysen, 2013

[25] Lighting Africa, 2013

Lithium-ion batteries

Compared to other advanced batteries, li-ion present the following advantages that make them specially suitable for SPLS[26]:

- high energy density: 150-200 kWh/m^3 – 40kWh/ton;
- Low weight: 7 Kg for an average SLS in comparison to 35Kg of a lead-acid battery of equivalent capacity;
- High efficiency: 95%-100%;
- Long cycle life: >3000 cycles at 80% depth of discharge, for an average life of more than 20 years[27];
- Maintenance-free;
- Versatility: electrodes can be optimized for different power / energy patterns;
- State of Charge & State of Health indication.

As for aging under working conditions, longer periods need to be considered, but a field study on small lighting systems installed in Peru, conducted by Acciona Microenergia, has compared the aging of four different commercial systems[28] and shows a decrease in their energy capacity between 2% and 4% after 6 months.

LED lights

High power LED lights[29] have a high brightness (over 100 lumens per watt), with over 200 lumens per light bulb and more than 30000 hours of life (more than 20 years considering an average usage of 4 hours a day).

The standard light power of an oil lamp is around 150 lumen[29], so the brightness of a standard LED light bulb would be equal or higher than this traditional illumination source, without the problems caused by their emissions and in house pollution.

Regarding quality, the same study by Acciona ME examined LED lights, measuring luminous flux (lm) and efficiency (lm/W). The study shows a great dispersion of results after 6 months of use. Some lights even improved their performance compared to initial laboratory tests in

[26] Alliance for Rural Electrification, 2011; Eisman et al., 2013
[27] Alliance for Rural Electrification, 2011
[28] Eisman et al., 2013
[29] Kilian Reiche, Grüner, Attigah, Hellpap, & Brüderle, 2010

10% (flux) and 3% (efficiency) while others showed a reduction in their performance of 26% (flux) and 13% (efficiency). These results underline the need for quality standards and assessment on PSLSs to satisfy sustainably the needs for lighting in the Base of the Pyramid, as will be detailed later in 0.

Charge controllers

This device is used to regulate the flow of electricity to and from batteries. SPLS incorporate standard but sophisticated electronic charge controllers to protect the battery from overcharging or discharging completely and from destructive spikes in voltage, and protect the PV panel against reverse polarity. It serves to lengthen the battery life and to improve performance over time.

2.2.2 Solar lanterns

As mentioned earlier, solar lanterns have been in the market now for some time, first equipped with CFLs and now with LEDs, and there has not been any standard defined about lantern quality. Considering the lack of international standards for lanterns, GTZ and Fraunhofer institute developed a detailed test method for the study of more than 50 lanterns, detecting their main problems[30]:

- poor mechanical design and workmanship;
- missing over-current protection of the LED;
- poor electrical design;
- insufficient light output;
- bad quality of LEDs and rapid degradation of light output;
- solar panels and batteries did not show their nominal values or were sized too small;
- defective protection of the battery;
- defective ballast for LEDs or CFLs;
- the main problem was related to low quality lamps, as also mentioned by Eisman[31].

[30] Kilian Reiche et al., 2010
[31] Eisman et al., 2013

2.2.3 Pico and Small Lighting Systems

To help the private sector remove the barriers for the market, Lighting Africa has specified a set of the preferences of users about their ideal PLSL[32] characteristics:

- Affordable: This is one of the most important concerns. Financing mechanisms should be made available to pay for the up-front costs, as will be discussed later in this document.
- Portable: Many people will have 1 or 2 lighting devices, but many places and purposes to light. Toilets are often detached from the main dwelling, creating the need for a portable light weighted device.
- Sufficient light intensity: Most users require a bright white light, capable of lighting the whole room, avoiding the need of having more than one device in the same room.
- Able to control light intensity: As these systems are intended for several uses, as illuminating the rooms, light should be adaptable to enable reading or to provide a dim light at night.
- Safe: This feature is especially important for families with small children. No risk of electrocuting or setting the house on fire.
- Durable: Trust of local markets is gained through offering high quality products that together with the credibility of the manufacturer after-sales service influence purchasing decisions.
- Long run time: Light should be maintained for a minimum of 4 hours a day fully charged, and most people would be wishing to use the system even longer.
- Easy to use and maintain: Easy operation and maintenance processes, simple and quick, should be favored to help the appropriation of these technologies by the newly electrified population.
- Chargeable without risk of theft: Detachable solar panels and sufficiently long cords are preferred, as people fear leaving their equipment outside the house unattended.
- Charging method: Solar charging is very well received cause of the lack of operating costs, but AC grid electricity charging was deemed the faster. As for the mechanical charging, crack handle was deemed unique and cheap, but also very tiring.
- Familiar in design: People will trust models familiar in design, avoiding designs too alien or that look complicated.

[32] Lighting Africa, 2011; Lysen, 2013

- Multipurpose: Lights will be used for very different purposes, but the users will prefer systems able also to charge a cell phone, power a radio (0.5-3W) or even a small low power TV (10-20W)

- Branding: Confidence in these new products is increased if the device is endorsed by a known manufacturer.

2.2.4 Appliances

After lighting, the next most important demand for rural homes is mobile phone charging[33]. Simple cellphones have battery capacities of 2.6 to 3.7 Wh, while larger smartphones require almost doubling that amount. With charging efficiency of 90%, charging 3 to 4 Wh for an average simple phone with a 2 W charger, would require up to 2 hours, nearly 4 for a smartphone.

Cellphones, as well as laptops and other electronic equipment, have a constant power consumption for charging, which is independent of any voltage variations in the supply. Suppliers of SPLS usually recommend charging the phones during the day to save storage loss of the battery, and charging every two days.

Operating a small radio takes a minimum of 0.5 W and a small TV (7 inch LCD) can require a power less than 10 W. A pico lighting system could be used to power all these appliances for a limited amount of hours per day. Extension of the service hours would require installing a small lighting system.

Incorporating any of the three other desirable loads for users would exceed the capabilities of SPLS: the refrigerator, the fan and the iron. As for the refrigerator, a proper design brings their consumption down to 300 Wh/day, that may require a system over 100 Wp, exceeding even the capacity of SLS. This consumption is similar to a regular 50W fan running 6 hours per day and a little less than a low power iron flat. Thus, only very light versions of these devices (as small solar or USB fans and individual fridges) could be powered by SPLSs.

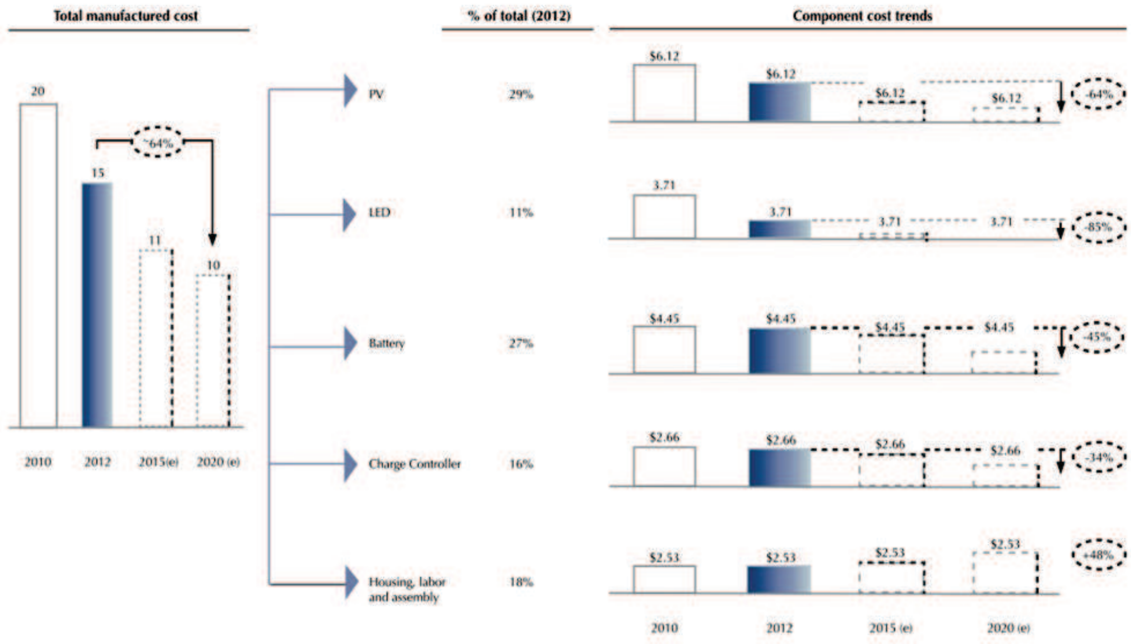
2.2.5 Advanced technologies

The prices of PV panels have been decreasing dramatically in the last few years falling to the range between US$ 0,5 and 0,9/Wp in 2014[34], and it is expected to continue decreasing further. Lighting Africa details the expected reduction in costs for every component of a pico lighting system for a constant performance, as shown in Figure 4:

[33] Lysen, 2013

[34] Global PV Pricing Outlook: Q2 2014. www.greentechmedia.com; EnergyTrend PV Spot Prices accessed on June 2014. pv.energytrend.com/pricequotes.html

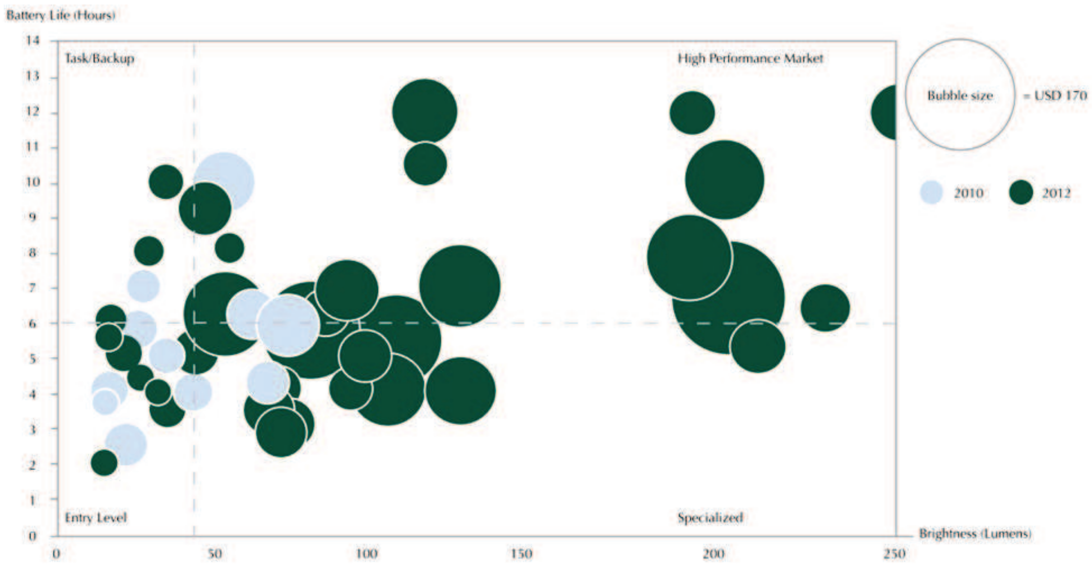
FIGURE 4 - Decomposition and forecast of the median solar-based PLS component cost (USD 2010-2020)



Source: Lighting Africa, 2013

This reduction of cost would be accompanied by a very fast increase in performance, as shown in Figure 5that reproduces the evolution of the product set between 2010 and 2012 based on battery life (hours), brightness (lumens) and price (USD):

FIGURE 5 - Evolution of PLS performance over time

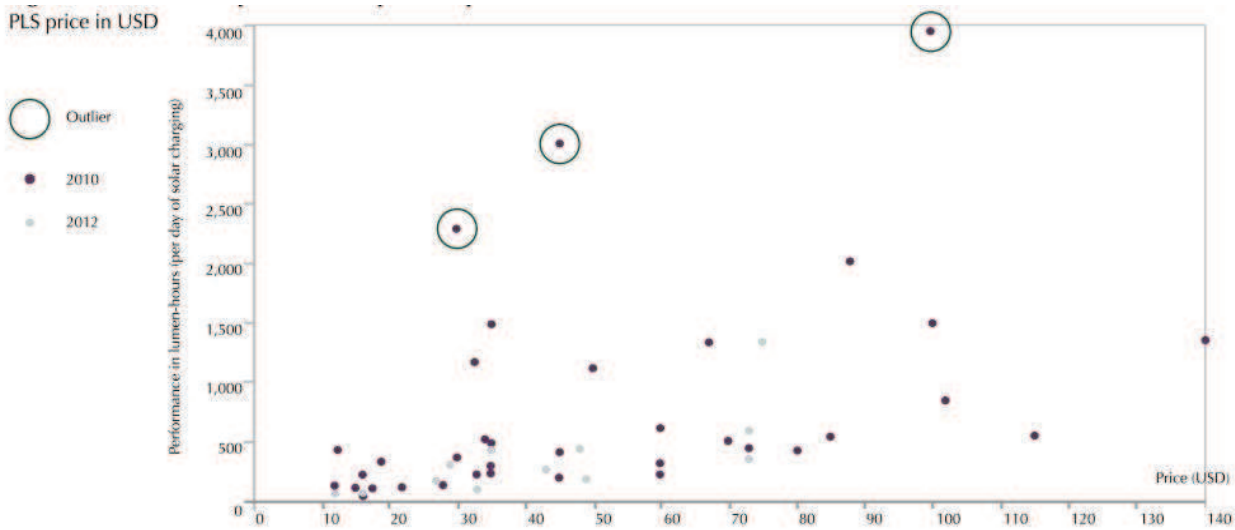


Source: Mataix, Borrella, 2012

Battery life has increased by nearly 20% in two years, and brightness has improved by 30%, and a much greater share of products fall now in the high performance segment defined by Lightning Africa in 2010[35].

A last indicator of the ongoing innovation process is the existence of high performance outliers in each price segment of PLS, giving an idea of the introduction of new upstanding products in the market, still coexisting with other with a much lower performance.

FIGURE 6 - PLS performance per unit price



Source: Lighting Africa, 2013

The estimates by Lighting Africa expect that by 2020 costs would be reduced by another 33%, the median lantern will have twice the battery life and up to five times the brightness, compared to the average system in 2012.

2.3 Business model alternatives

This section considers only those business models actually in place for small and pico PV systems and analyses them considering the criteria established by Reiche and others[36] together with Osterwalder's business model canvas and delivery model map[37], along with the categories for successful business models proposed by Eisman[38] and Mataix[39]. Please see introduction to this *Working Paper 1* for further information on the classification.

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[35] Lighting Africa, 2010
[36] Reiche et al., 2006
[37] Garside & Bellanca, 2013; Wilson et al., 2012
[38] Eisman et al., 2013
[39] Mataix, Borrella, & dir, 2012

It is important to note that many of these business models combine their business model for PSLS with other products and services, not only for other electrification modes (Stand-Alone-Systems, Micro-grids isolated and connected, water and communications…). Existing synergies will be summarized later in this document.

2.3.1 Private, for profit

Small, decentralized

Most of the for-profit decentralized experiences found are either for small retailing of SPLSs or rental/leasing models as analyzed by Lighting Africa[40].

Companies like Barefoot Power[41] chose a franchise model in Africa and now India to establish a decentralized network of for-profit agents to distribute their products. They offer business packages to small entrepreneurs to establish a distribution channel and market for their SPLS products. Property of the SPLS is transferred to the user, with the provision of additional services through additional contracts or guarantees. Other example of this approach would be OMCPower's "business in a box"[42] in India. The main benefits of this franchise commercial model are rapid scale-up due to high incentives for retail agents to market growth, an effective and standard method for training franchisees, close relationship with the retail force and to the customer base and rapid evolution of marketing, logistics and product design. A third example, with a lesser link between the manufacturer and local distributors could be the German company Asantys Systems[43], present in the markets of Africa and Asia. They offer SPLS equipment (as well as SAS and micro-grids) on a turnkey basis, providing training to local technicians and distributors. The key challenges of this model would be on one side the need to share margins with the retailers and on the other the existence of shared reputational risk for the brand owner with the franchisees. This shared branding risk demands a strong quality of service assurance system along the whole franchise network.

A different approach would be the rental or leasing of equipment, implemented for instance by Sunlabob[44] in Laos, Soluz[45] in Central America or the Light a Billion Lives Initiative by Teri[46] in India, that contract or franchise local entrepreneurs who establish kiosks for charging portable rechargeable equipment or other SPLSs. The main difference with the previous model relays on the ownership of the equipment, that in this case remains the property of the local entrepreneur. These micro entrepreneurs either rent the solar lighting systems on an hour or daily fee, or directly sell lanterns with no solar panel and charge the batteries for a fixed fee. The main advantage again is outsourcing for a rapid scale-up, affordability and payment

[40] Lighting Africa, 2010
[41] www.barefootpower.com
[42] www.omcpower.com/communities/business-in-a-box
[43] www.asantys.com
[44] www.sunlabob.com
[45] www.soluzusa.com and www.soluzhonduras.com
[46] labl.teriin.org

facilities for users, and better after sales services and equipment performance, due to controlled battery charges. This model requires a high investment for the micro-entrepreneur in charging and circulating equipment. It requires a more complex customer base management, and increases dependency of the final users from the local entrepreneur. Sunk costs in invested equipment slow down the innovation process, because of the need to amortize existing assets.

Large, centralized

These business models have been classified in[47]:

- Brand builders, as defined by IFC, are device companies "multinationals or established local conglomerates that leverage existing brand power in other areas, distribution chains, and sometimes manufacturing capabilities to sell energy access technologies – covering one or more of solar lanterns, solar home systems and cook stoves – alongside other offerings". Valid examples would be Schneider[48] in India or Philips[49] in Africa and India.

- Emerging market conglomerates are large utilities established at national level, with a sizeable services and products portfolio, capabilities and distribution to go with their scale, that take advantage of their size to develop value propositions for low income consumer segments, as Tata Power Solar[50] in India.

An interesting description of these business models can also be found in (Lighting Africa, 2010), including distributor-dealer and proprietary distribution channels, institutional partnerships and large franchises:

- Distributor-Dealer channels: Manufacturer sells its product through existing networks and distributors specialized in other consumer durables for the Base of the Pyramid (BoP) market. This model makes use of the traditional private sector supply chain through wholesale distributors and small retailers allowing logistic and marketing economies of scale, greater market penetration where other markets are already established. The main disadvantages of this model are: that the margins are split between the different agents along the chain, that it depends on previous existence of suitable market agents, that providers are very far from the "last mile" customer needs, making difficult to adapt their products to their needs, and provide a suitable after sales service; and finally that SPLSs are distributed and compete together with an undetermined number of other customer durables. Distributors will also face difficulties for funding their activities in an adequate scale to allow fast market growths.

[47] IFC World Bank, 2012
[48] www.schneider-electric.com/bipbop and www.bipbop.3c-e.com
[49] www.lighting.philips.com/main/application_areas/solarlighting/
[50] www.tatapowersolar.com

- Proprietary distribution channels: Companies integrate their value chain from manufacturers down to the retail level, so their products are sold directly to the customers. This model simplifies the ecosystem of actors, increasing the margins for the company and control over the value chain, including a close relationship with customers that allows a better feedback for product and service improvements, and after sales services, and finally it also helps to build a brand name near the customer base. But it also requires a much higher investment in creating, training and maintaining an effective sales force. It also increases the market risk and requires a much higher flexibility and adaptation from the company to the BoP market structure.

- Institutional partnerships with social organizations[51], cooperatives or micro-financing institutions with a large customer base: This model helps achieve a rapid market growth taking advantage of the existing relationship between the customers and the intermediary institution, and allows synergies with other services offered by them, and also ensures social impact according to their mission. Nevertheless, it requires a large amount of negotiation for risk sharing, cost allocation, roles and responsibilities.

- Large franchisee for an international brand: This second approach to the franchise model may reduce the branding risk, compared to the first, described above, as it allows closer control from the brand owner over the activities of the single distribution company.

2.3.2 Non-governmental, non-profit

Cooperatives

Cooperatives play a major role in off-grid electrification with Micro-grids and solar home systems, as they require a higher level of sophistication and consumer relations than those required by SPLS. For this segment, cooperatives can work as purchase hubs for collective acquisition of solar lanterns and kits by their members and community nearby. On this regard, commercialization of electrification equipment can diversify the activities not only of electrification cooperatives, but of other commercial, agricultural and industrial cooperatives providing electric equipment, information about their use and benefits to their communities, along with basic capacitation for installation and maintenance.

[51] As the *Global Sustainable Electricity Partnership* that brings together global energy utilities as AEP, EDF, Eletrobras, ENEL, Hydro Québec, RusHydro, Kansay, RWE, Chinese State Grid, CFE, Iberdrola or Tepco, with the Global Brightlight Foundation for the distribution of 50.000 solar lanterns in Nepal, Rwanda, Uganda and Haiti or to develop multiple projects in Latin America, Africa, Asia and Oceania. www.globalelectricity.org

Social enterprises

There are at least two successful approaches of social enterprises for Small-and-Pico-Lighting-Systems:

- Service providers: Acciona Microenergía [52] (Acciona ME) in Mexico and Peru, Grameen Shakti[53] in Bangladesh.

- International independent [54] manufacturers and retailers: ToughStuff [55] in Africa and D.Light[56] in Asia and Africa.

Acciona ME[57] bases its delivery model for Small Lighting on three pillars:

- Technology: Acciona ME emphasizes the use of emerging technologies adapted to the needs of the BoP users in Peru and Mexico, thus requiring manufacturers to comply with demanding quality and performance laboratory and field tests. Their equipment must have a very sound performance, light weight and be environmentally friendly. High energy efficiency of appliances (led lights, radio or even TV) allows reducing battery costs and increase the hours of service every day. This emphasis on equipment quality and performance prevents market spoilage that, as will be explained later, is one of the main threats for the sustainability of SPLS delivery models.

- Management: their service model is centered in the Center for Assistance of Users (CAU). Its location in a reference village for each region, within one day travel distance from the targeted customers, allows not only direct sales but also provision of after sales services. For Small-and-Pico-Lighting-Systems, the users can take the equipment to the CAU themselves, to receive assistance, replacements or training. Nevertheless, to raise awareness towards these systems, personnel from the CAU should regularly visit the communities to demonstrate the use of electric equipment, helping to develop the market. Local authorities can support CAUs at an early stage, but they can also be the initiative from local entrepreneurs, that receive training and backup from the central or regional offices.

- Economy: up-front cost of SPLS, though it is less than half the cost of Stand-Alone-Systems, exceeds the capacity of savings for users in the base of the pyramid. Acciona ME sets the amount for monthly installments in less than the present cost of traditional energy supply (kerosene, batteries or candles). These are different in diverse regions and socio-economic circumstances. For instance, in Cajamarca (Peru) the average

[52] www.accioname.org
[53] www.gshakti.org
[54] According to (IFC World Bank, 2012) International Independents are "*start-ups and smaller companies, mainly with Western roots, which focus on the design and marketing of a single product or segment*".
[55] www.toughstuffonline.com
[56] www.dlightdesign.com
[57] Eisman et al., 2013

monthly capacity of payment is set at around USD 5,7 while in Oaxaca (México) it reaches up to USD 15 per month[58]. Acciona stresses the role of the government for filling in the gap between the capacity of payment and the present cost of electrification (including operation and maintenance along the whole life of the equipment). The recommendation is that the state should subsidize 50% of the investment, and the other 50% should be paid by end-users, with an up-front payment of 10% plus micro-financed monthly installments of only 40% of the investment. This speeds up enormously the expansion of electrification, as the users perceive it as cheaper than their traditional energy technologies. Financing the contribution from customers can be addressed by multiple ways. Acciona ME favors micro financing institutions or cooperative approaches. As for operation and maintenance, users can pay a very low monthly fee that includes repairs and replacements service contract, or just pay for each service required.

Acciona ME also benefits from the support of Acciona, trustee of Acciona ME and one of the foremost Spanish business corporations. Their symbiosis provides larger economies of scale, shared knowledge and resources for technology and innovation, better funding opportunities and risk hedging.

Grameen Shakti[59] surpassed 1 million products sold in 2012 and plans to reach 2 million by 2015 in Small-and-Pico-Lighting-Systems together with Stand-Alone-Systems. They provide light for domestic, community, commercial and productive uses. Nancy Wimmer[60] summarizes the success of this social enterprise in their experience, innovation and economies of scales. Grameen Shakti focuses on the rural business providing a close relationship between staff and customers. Each branch provides an integral service including sales, financing, installation operation and maintenance, repairs and training for users and technicians. They stress the relationship with the local community, especially with women, also training them as technicians and managers to run rural technology centers.

Users buy on credit their own equipment, receiving a full-service for free during a warranty period. After sales service and maintenance can be continued on for an after sales fee of 12% of the cost of the lighting system per year. Grameen customers receive no direct subsidies, but buy their products through credit facilities, with a down payment of 15% plus a maximum of 36 monthly installments. A consequence of this payment method is that the price of the equipment is not so critical for the user, so Grameen can offer high quality products despite their higher costs, at a competitive price with kerosene alternatives[60]. Nevertheless, Grameen business model also benefits from large national and international programs both for access to the necessary credit for the electrification programs, and donations from aid agencies aimed at fostering and reducing the electrification costs for the final users.

[58] This population in Oaxaca could afford more expensive electrification service modes, according to their capacity of payment, but the present regulatory framework in Mexico does not allow the provision of electricity service to foreign private agents, thus preventing Acciona from establishing a fee for service approach as in Peru (see *Social enterprises in Chapter 3.3.2* for further detail).

[59] Wimmer, 2012

[60] Alliance for Rural Electrification, 2011

Regarding international supply of equipment, Grameen established a policy of local assembling and manufacturing of PV equipment that both lowers the cost of systems (because of low salaries in Bangladesh and lower taxation of these activities at a local level) and also allows the appropriation of technology by these centers, creating jobs opportunities both within Grameen Shakti and other auxiliary services related to the electrification activity.

Grameen Shakti is the main example of an alliance between a micro-financing institution and an energy provider, where the micro-financing institution establishes and owns the electricity social company. Other similar examples would be Zara Solar in Tanzania or Solar Energy Uganda. A second model would be that of SEEDS in Sri Lanka, when a micro-financing institution and approved installer companies establish a contract to provide combined energy and micro-credit services to customers. Down payment in this case is also 15% and maximum period for repayment 48 months.

Independent social enterprises, Tough Stuff and D.Light[61] have a similar business model, covering the whole value chain of solar lanterns and systems including design, manufacturing, distribution and sales, and after sales service. They offer high-quality durable and affordable lamps that provide light for 4 hours a day, and with a cost from 8 to 45 USD. Products are mass-produced in China to keep costs low. They target population out of the scope of government and electrification programs, including customers with very weak access to the grid.

Their main energy policy concern is related with lowering import duties and taxes, elimination of subsidies to traditional technologies as kerosene and empowering entrepreneurship and need of transport infrastructures for their logistic chain. Donor and government programs offering grants and free products are criticized because they undermine markets instead of stimulating them, creating false expectations and assumptions for users, that threaten the long term sustainability of these business models. Practitioners propose that grants should be used to hedge risk of BoP markets thus helping their sustainability[62].

This model focuses its value proposition in the quality and suitability of their products, devoting their efforts to product innovation and lowering costs to reach poor communities. Developing distribution channels is their main challenge, creating customer awareness for their products and establishing positive customer relationships. They approach formal companies and small-scale entrepreneurs that sell products for impoverished population as soap, drinks, cigarettes, also in the informal economy.

Thus, they benefit from a well-known and established sales force that already caters low-income groups. In any case, high up-front costs are still a hurdle for customers, so in some cases both companies have established partnerships with micro-credit institutions, or donors that subsidize this cost.

[61] Wilson et al., 2012
[62] Bellanca & Wilson, 2012

NGOs

As in the cases of cooperatives, NGOs can help their beneficiaries get better deals on solar lanterns and kits, along with information and capacitation activities. Their main limitation is that energy services require a continuous presence in the community. *Solar Aid*[63], a U.K. NGO, has sold over 400.000 solar lights in Tanzania, Kenya, Malawi and Zambia. Their distribution method involved setting up and training a subsidiary, SunnyMoney[64], as a sales and marketing force. To raise awareness, they involve head teachers to promote the benefits of solar lights and collect purchase orders directly from the students. Their revenue model involves school sales and direct sales, both including warranties. In either case the price is lower than the equivalent consumption in kerosene, but in the case of the school channel, this price is subsidized in 15 to 20%.

2.3.3 Governmental

Small, decentralized

A successful experience from this point of view would be the *Programme Energising Development* (EnDev)[65]. It is a governmental cooperation program funded and directed by governmental cooperation bodies of the Netherlands (MFA NL), Germany (BMZ), Norway (MFA NO), Australia (AusAID), United Kingdom (DFID) and Switzerland (SDC), with further contributions by the ACP EU Energy Facility, Irish Aid and others.

It establishes cooperation with national, regional authorities and other agents in developing countries to establish sustainable energy solutions and distribution schemes for domestic, community, productive and commercial uses in 24 countries in Africa, Asia and Latin America, mainly for rural communities, with an impact in more than 10 million people "for as little as 20 euros per capita". They offer a full range of technological approaches, from SPLS to connections to grid extension and cook stoves.

Their sustainability approach includes establishing tailored technical and market solutions suited to the specific local context, training and assisting entrepreneurs to start-up energy related businesses, thus securing that operation and maintenance costs will never be assumed by EnDev. It is important to note that one of the roles assumed by EnDev is to support the individual agents (profit and non-profit) mentioned before.

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[63] www.solar-aid.org
[64] www.sunnymoney.org
[65] www.endev.info

Large, centralized

Another approach[66] for the distribution of Small-and-Pico-Lighting-Systems is the government partnerships with large institutions, with a wide social base (such as micro-financing, development or social institutions, rural banks, self-help-group networks, large retailing companies and even multinational corporations) with a link to a material number of potential customers. The main benefits of this model are that it enables a very fast implementation thanks to the economies of scale achieved by a large volume of orders, centralized funding opportunities and adequate social targets aligned to the national energy policy. On the negative side, other non-governmental or for profit agents perceive the risk that government intervention may distort the market with unsuitable subsidies, making it uncompetitive. Scaling up of these systems is also restricted by the amount of funding available from the governmental program.

[66] Lighting Africa, 2010

3 Stand-Alone Systems

This section analyses the business models for off-grid electrification with Stand-Alone Systems (also called Single House Systems or Stand-Alone Home Systems) in isolated rural areas and for low-income population. The purpose of the document is to identify the key features of these models, their applicability in pursue of universal access to electric power services for different user profiles and the relevant policy and governance measures for the sustainability, reproducibility and scalability of these initiatives.

FIGURE 7 - Photo by Egg-Energy

Source: egg-energy.com

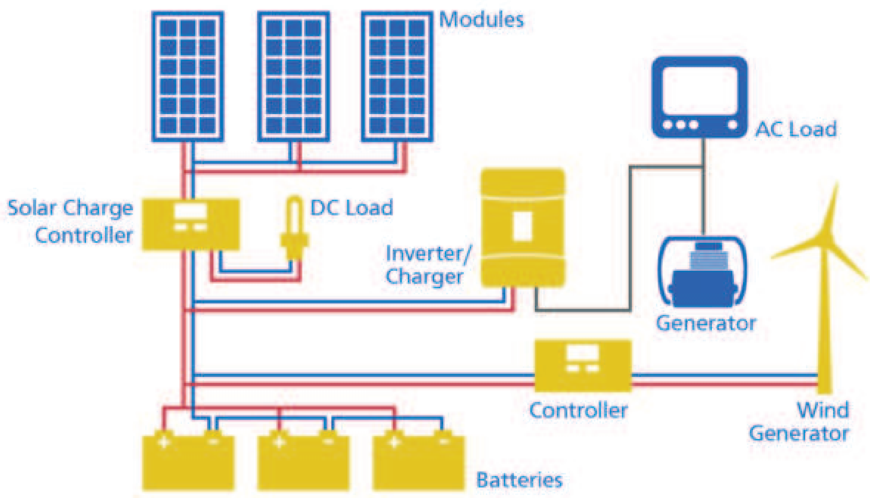
3.1 Introduction

Stand-Alone Systems within this document refers to independent power systems that provide electricity to a single house or customer. We have favored the denomination Stand-Alone Systems (SAS) over solar home systems (SHS) or solar residential systems (SRS) because:

These systems can be powered by different generation technologies as sun, wind, diesel generators, biomass or even use just batteries charged elsewhere from the grid. For instance, Figure 8 depicts a hybrid wind-solar-diesel system.

These systems may feed diverse kind of loads, not only houses or residences, like shops, schools, agro-industrial uses, medical centers, among others.

FIGURE 8 - Hybrid Stand-alone system



Source: Alliance for Rural Electrification, 2013

3.2 Technology

3.2.1 Key technological features

System configuration

The different components of a generic stand-alone system are:

- Loads: SAS can feed both DC and/or AC appliances as also seen in Figure 8.
- Generation:
  - Hybrid (as shown in Figure 8). Combinations of solar, wind, diesel, biomass (liquid, gas, solid) or mini-hydro power sources.
  - Single: Any one of the above mentioned technologies.

- None: Stand-Alone-Systems powered only by batteries supplied by a charging station[67].

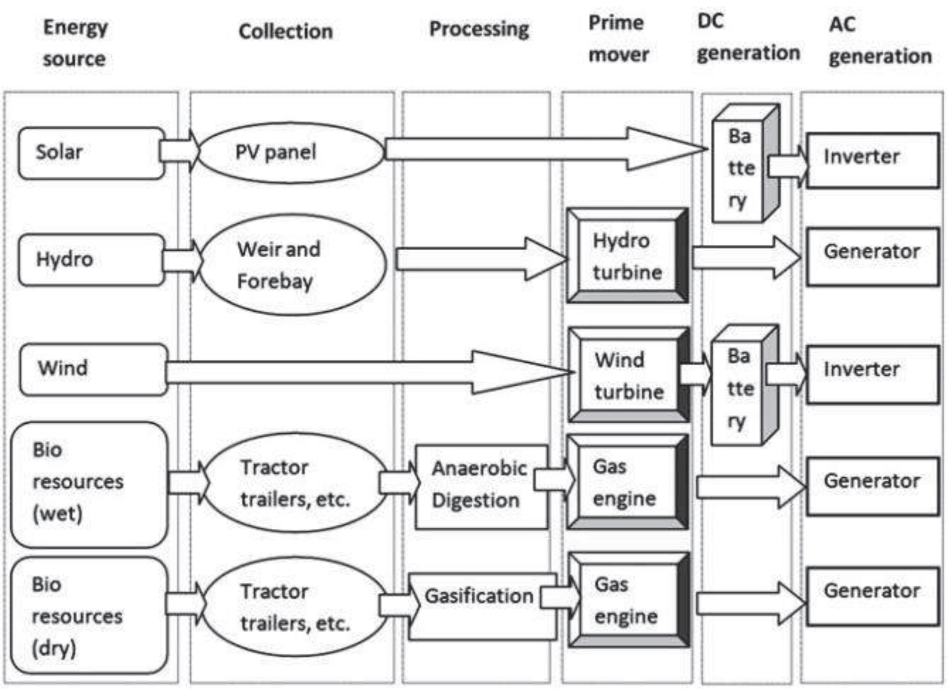
- Batteries: These are one of the main and more critical components of any SAS.

- Wiring and control: Depending on the current choice (AC or DC) and the configuration of the generation and loads, different smart devices should be needed as charge controllers for the batteries, converters for wind power generation or gen-sets, inverters for AC loads or rectifiers for DC. Although the generation is stand-alone, companies may also install adequate meters to provide users with adequate information and feedback about their consumption patterns. Higher power hybrid systems may also require an energy management system to balance the different generation technologies with the battery charge and the user consumption[68].

3.2.2 Generation

Kishore et al.[69] analyzed the different off-grid generation technologies shown in Figure 9 and that will be described in this section along with diesel generation and hybrid systems.

FIGURE 9 - Chain of operations involved in decentralized RES power generation



Source: Kishore et al., 2013

[67] For a description of the egg-energy business model of battery supply, please see *Small Decentralized* in 3.3.1.
[68] For a more detailed description regarding energy management, please see Section 4.2.4.
[69] Kishore, Jagu, & Nand Gopal, 2013

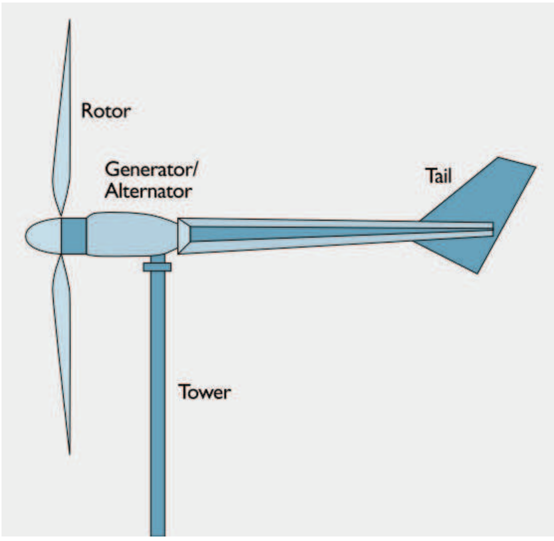
Solar

Solar energy is abundant and inexhaustible at human scale, and especially in developing countries, most of them located along the solar belts between latitudes 35ºN and 35ºS. Solar photovoltaic panels are widely used in off-grid electricity production and, because of their high reliability, low maintenance cost and lifetime of more than 25 years are very attractive for developing environments. There is a wide range of solar panel technologies (crystalline silicon, thin film, concentrating PV and other emerging technologies) and their cost has decreased enormously in the last few years, giving a boost for the adoption of solar PV for off-grid electricity production.

Wind

Power generation with small wind turbines (SWT) may provide interesting solutions for SAS, especially beyond Tier 3. The rotor diameter is less than 15m and their power output is less than 50kW AC, but their typical configuration ranges from 1 to 10 kW and less than 7m span. In remote households, 1kW – 2m pico turbines can also be used[70].

FIGURE 10 - Simplified scheme of a small wind turbine



Source: Bhattacharyya, 2013; NREL, 2001

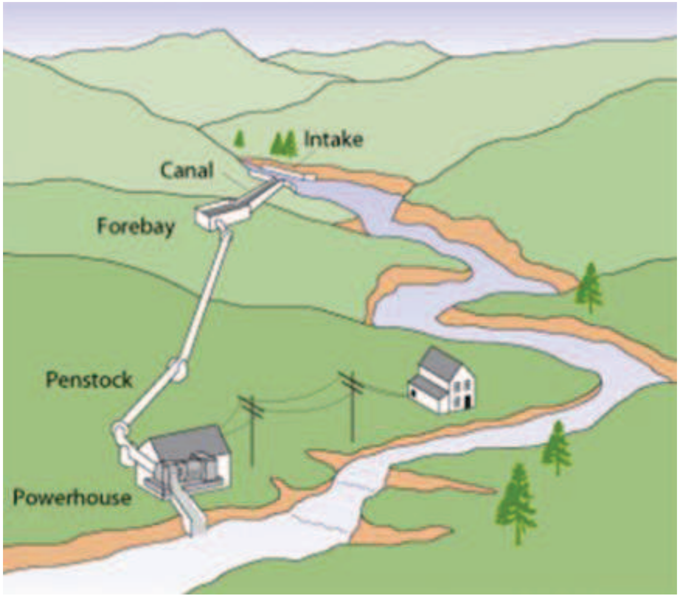
Determining the wind resources variability and seasonal changes requires long-term wind studies that are often overlooked by project developers. The up-front cost of wind turbines varies from $2500 to $7500 per kW installed, not including the cost of inverters and batteries. Thus, they do not answer the same type of needs as PV technologies as they require higher up-front costs and also higher maintenance. Finally, their per kW prices are generally lower than those of PV.

[70] Alliance for Rural Electrification, 2011

Hydro

Hydropower harnesses the energy from the water flows or falls. Water pressure powers a turbine that drives an electric micro generator. Hydro systems for SAS are within the pico-hydro (5 to 20kW), micro-hydro (up to100 kW) and mini-hydro (that could reach 1MW). Most of the micro-hydro generation is "run-of-the-river", not requiring dam or water storage, though they require water diversion and conveyance systems (Figure 11).

FIGURE 11 - Typical run-of-the-river micro hydro-power system



Source: Bhattacharyya, 2013; NREL, 2001

Consideration of hydropower for energy generation should take into account seasonality and other possible uses for the conveyed water, as irrigation or clean water supply for the population.

Though small hydro is usually considered one of the cheapest technologies for electrification in the long term, because of the very low O&M costs, the upfront cost of the electric equipment can be misguiding, as it accounts only for 25% of the installation costs, and investors should consider also the cost of civil works and the line required to reach the location of the consumers. So the cost is highly site specific and in the range from 1000 $/kW to 6000$/kW of installed capacity, with an average of 3085$/kW[71].

[71] Khennas & Barnett, 2000

Diesel

Diesel generators have been the traditional solution to decentralized electrification needs, as they present low up-front capital costs per kW, though the increase of fuel cost in recent years, the cost of transport to remote areas and their maintenance costs greatly diminish these initial advantages, as fuel consumption (around 0.15$/kWh) is the main portion of their final costs compared to 0.013$/kWh of engine maintenance, so the final cost shows an enormous spatial variance from 0.4$/kWh up to more than 3$/kWh[72].

Biomass

Biomass refers to a wide range of growing (non-fossil) organic materials that harness solar power by photosynthetic fixation of CO_2, making it a high-energy density source. Biomass is one of the primary energy resources for the developing world as more than 2.7 billion people still depend on traditional burning of biomass for heating and cooking[73].

Biomass for the production of electricity can be used in solid, liquid or gaseous form. The power produced from biomass is considered renewable if the consumption of fuel matches the production (establishing a sustainable life cycle). There are different technologies that can produce electricity based with biomass[74]:

- thermo-chemical (combustion, gasification, pyrolysis, liquefaction);
- chemical (esterification);
- biochemical (acid hydrolysis, enzyme hydrolysis, fermentation).

Combustion and gasification of solid biomass have been extensively used for off-grid power generation, as well as the anaerobic digestion of organic matter for production of biogas for combustion. Fuels can be harvested, collected or be the result of agricultural processes as shown in Table 8:

[72] Szabó, Bódis, Huld, & Moner-Girona, 2011; Szabó et al., 2013
[73] IEA, 2010, 2011, 2012
[74] Kishore et al., 2013

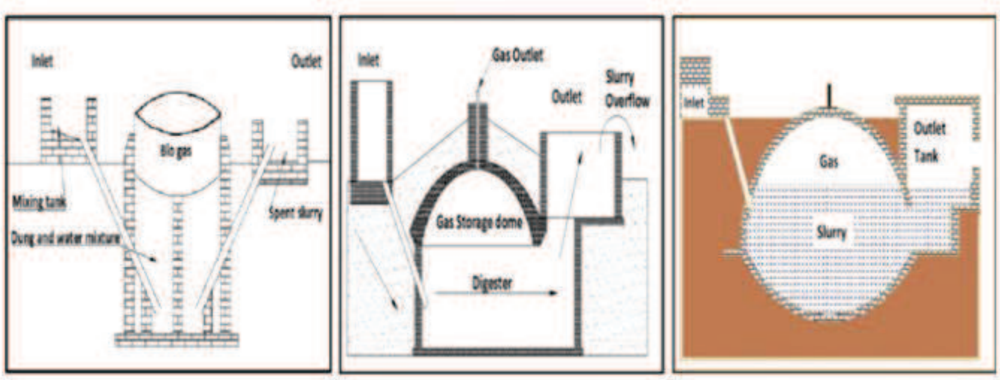
TABLE 8 - Examples of biomass suitable for gasification

Forest residue	Agricultural residue	Agro-processing residue
Forest pruning	Paddy straw	Rice husk
Wood from energy plantation	Wheat straw	Cashew nut shells
Wood from marginal lands	Maize stalks	Oil seed shells
Grasses and bushes from wastelands	Cotton stalks	Oil cakes
Wood pulp	Maize cobs	Coconut shells and fibre
Saw dust	Mustard stalks	Coffee and tea waste
Bamboo waste	Millet straw	Bagasse

Source: Kishore et al.,2013

Biomass provides a stable and firm power source, not dependent of the sun or wind weather conditions. Prices are highly dependent on the technology chosen, scale of the power plant, availability of biomass resources, transport and labor costs. The total production cost of electricity with biomass gassifiers could range from 0,08 $/kWh to 0,14 $/kWh[75]. Biogas methanation by digesters prices are also around 0,15 $/kWh[76].

FIGURE 12 - Models of biogas digesters



Source: www.fao.org

Biodiesel, usually produced by transesterification processes can also run a diesel generator set, replacing the use of fossil diesel. Very small digesters for biodiesel can cost from 1000 $ to 40000 $[77] and produce from 45 to 1800 tons per year for a final cost of electricity around 0.9 $/kWh[78].

The main weakness of biomass power plants is the need for a strong fuel supply linkage through involvement of the local community[79].Land use for biomass growing must always take into account other uses of the land, especially where food security and sovereignty present a challenge for the local community.

[75] GTZ, 2010a
[76] GTZ, 2010b
[77] Bhattacharyya, 2013
[78] GTZ, 2011
[79] Kishore et al., 2013; Palit & Chaurey, 2011

Hybrid

Hybrid power systems are those powered by a combination of complementary generation sets, either based on renewable energies or mixed with fossil fuels[80].

3.2.3 Storage

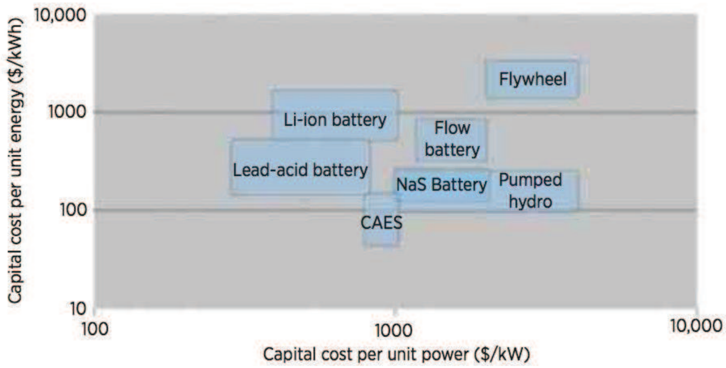
Off-grid systems are, because of their isolated and limited capacity, especially sensitive to the technical problems and over costs resulting from time variation of load and generation. Energy Storage Systems (ESS) convert electricity into mechanical, thermodynamic, electrochemical or electromagnetic energy.

They provide essential services to Mini-grids, especially to those powered with renewable energy sources, beginning with assuring power quality and service reliability within different load and generation scenarios. Larger isolated systems can also require other ESS security related applications such as spinning reserve, voltage or frequency control[81].

According to Sigrist et al. ESS applications can be grouped into power and energy applications. Power applications provide short power injections without the need of large energy storage, whereas energy applications provide long-term power injections and hence require large energy storage. In the case of SAS storage needs to accomplish mainly an energy application, as it accounts for a large share of the energy provided to users in the long-term.

TABLE shows the range of capital cost of different technologies, but only taking into account their investment costs not the operation and maintenance or replacement costs, nor the cost of transportation.

TABLE 9 - Initial capital cost per unit power vs. capital cost per unit energy for selected technologies



Source: International Renewable Energy Agency (IRENA), 2012, adapted from ESA 2011

[80] Alliance for Rural Electrification & USAID, 2011; Alliance for Rural Electrification, 2008
[81] Sigrist, Lobato, & Rouco, 2013

Cost of storage must take into account not only capital cost per kWh of the batteries but the durability of the equipment, so to guarantee the replacements along the whole life cycle of system supply, the installation, operation and maintenance costs as shown in Table 10. Storage also requires additional *balance-of-system* costs, comprising safety mechanisms, controllers and converters, smart control and communication devices and sensors.

TABLE 10 - Summary of commercially available storage technologies

	Lead-acid batteries	Li-Ion batteries	NaS batteries	Flow batteries	Fly-wheels	Pumped hydro	Large-scale CAES
Applicable grid system size [kW/MW]	≤10 MW	≤10 MW	≥100 MW	25 kW–10 MW	100 kW–200 MW	Mostly ≥200 MW	≥500 MW
Lifetime [years]	3–10	10–15	15	Cell stack: 5–15; Electro-lyte: 20+	20	25+	20+
Lifetime [cycles]	500–800	2,000–3,000	4,000–40,000	Cell stack: 1,500–15,000	>100,000	>50,000	>10,000
Roundtrip efficiency [%]	70%–90%	85%–95%	80%–90%	70%–85%	85%–95%	75%–85%	45%–60%
Capital cost per discharge power [$/kW]	$300–$800	$400–$1,000	$1,000–$2,000	$1,200–$2,000	$2,000–$4,000	$1,000–$4,000	$800–$1,000
Capital cost per capacity [$/kWh$_{cap}$]	$150–$500	$500–$1,500	$125–$250	$350–$800	$1,500–$3,000	$100–$250	$50–$150
Levelised cost of storage [$/kWh$_{life}$]	$0.25–$0.35	$0.30–$0.45	$0.05–$0.15	$0.15–$0.25	N/A	$0.05–$0.15	$0.10–$0.20
Annual operating costs [$/kW-yr]	$30	$25	$15	$30	$15	$5	$5

Source: International Renewable Energy Agency (IRENA), 2012

3.2.4 Appliances

As already explained in Section 1.3, Stand-Alone Systems are usually focused on power small and medium household services as multiple lights (from 4 to 24 hours a day), mobile charging, radios (SE4All Tier 1), small fans for air circulation, very small refrigerators or a TV set (Tier 2), but they can also feed heavier loads, even up to Tier 5 if the system is isolated both from the network and from other loads that may make a Micro-grid suitable.

Therefore, Stand-Alone Systems are suitable for any household application, from lighting to leisure, information technologies and communications including satellite dishes (30 W), laundry (0,3 kW of a high efficiency washing machine), ironing (1 kW), heaters (0,15 to 1,5 kW) almost every application would be feasible pondering an appropriate size of the system and affordability by the users.

3.2.5 Advanced technologies

The main innovation for SAS in the Base of the Pyramid is related to cost-cutting designs, but also technology improvements on generation efficiency, solar cells and batteries durability are extremely critical for future Stand-Alone-Systems.

3.3 Business model alternatives

This section considers business models actually in place for Stand-Alone-Systems and, as in the previous case, analyses them considering the criteria established by Reiche and others[82] together with Osterwalder's business model canvas and delivery model map[83], along with the categories for successful business models proposed by Eisman[84] and Mataix[85].

Please see introduction to this *Working Paper 1* for further information on the classification.

Stand-Alone Systems have been the most widely used systems for off-grid electrification until the recent emergence of small and pico lighting technologies. Thus, many of the experiences and business models already described at SPLS are also found here.

3.3.1 Private, for profit

Small, decentralized

Small for profit companies for SAS present one of the following models:

Franchise models: Barefoot Power[86], also present in the niche of SPLS (please see *Small, Decentralized* in 0), follows the same approach here for the distribution of their "Barefoot connect" product line. Through a decentralized network of for-profit agents in India and Africa, they sell solar home lighting systems (up to 60W) for residential, commercial and community uses. They follow a modular upgradable approach to be able to provide constant power for light, phone charging, TVs and fans.

Rental or leasing of equipment: Sunlabob[87] in Laos follows also this approach for renting SAS for fixed monthly fees. As described in *Small, Decentralized* in 0, they have adopted a service

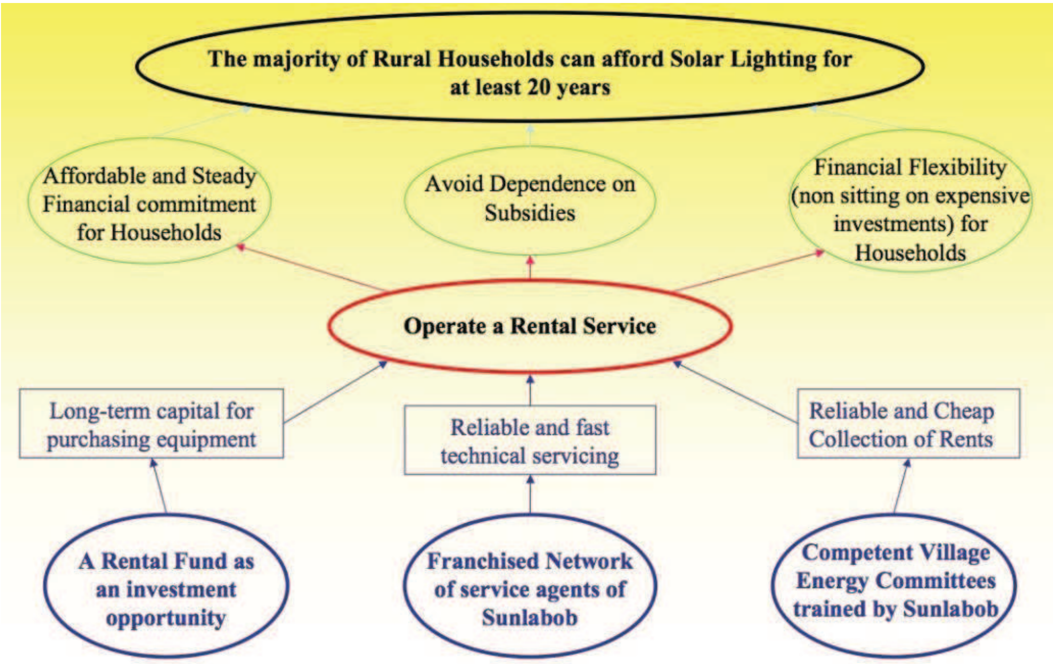
[82] Reiche et al., 2006
[83] Garside & Bellanca, 2013; Wilson et al., 2012
[84] Eisman et al., 2013
[85] Mataix et al., 2012
[86] www.barefootpower.com
[87] www.sunlabob.com

model where the user does not own the hardware, that is leased by Sunlabob and maintained by village technicians franchisees. They have established a very interesting public-private-partnership where private investors provide for a rental investment fund operated by Sunlabob and public donors also establish a trust fund that helps Village Energy Committees (VEC) to provide for the community lighting in the villages.

Direct sales: When the purchasing power is sufficient, companies offer customers buying the SAS and operating it themselves. Complementary service contracts can also be agreed for long term maintenance. This is the case of Sunlabob, which on top of renting, it also provides villages and donor agencies with the option of directly purchasing the system for community uses (houses, health centers, water pumping services), offering differentiated installation and maintenance contracts.

Fee-for-service: According to Soluz[88], that is also present in the direct sales and renting niches, this is becoming the most common choice by customers (around 1100 SAS out of 1600 already installed in Honduras are fee-for-service systems). The company maintains the ownership of the PV system assets, providing affordable monthly rents from 10 to 20 $/month, and an equivalent amount to what customers previously were expending in kerosene lighting, dry cell and rechargeable batteries. Local installation technicians employed directly by Soluz take care of the maintenance.

FIGURE 13 - Sunlabob renting SAS for individual households.



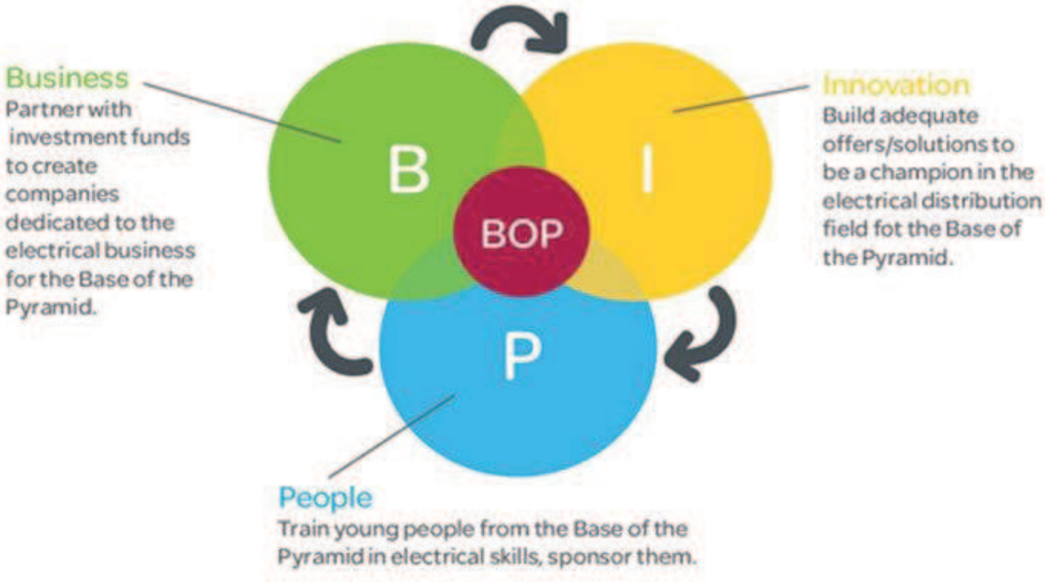
Source: Sunlabob

[88] www.soluzusa.com and www.soluzhonduras.com

Large, centralized

As in SPLS (see *Large, Centralized* in section 0 for a detailed description of different business models in place) can also find large *brand builders* like Schneider Electric on the sector of Stand-Alone Systems. They have traditionally operated through national distributors and independent dealers and retailers, where they offer their dealers support for their business management, and offer a whole range of products for any off-grid and grid connected electricity system. In 2010, they launched a business partnership scheme for access to energy in the base of the pyramid[89] called BIPBOP (Business, Innovation and People in the Base of the Pyramid). As shown in Figure 14 Schneider is engaged in bringing together local communities and governments, investors and entrepreneurs, together with the necessary technological innovation and training at the BOP, to be able to promote sustainable electricity supply in developing countries.

FIGURE 14 - Schneider's BIPBOP initiative scheme



Source: Schneider Electric

A very interesting approach of a large utility in this field can be found in the partnership between ENEL Green Power and Barefoot College[90] for the Enabling Electricity Program of rural electrification in Guatemala, Peru, Chile, Colombia and El Salvador, where local partially illiterate women between 35 and 50 years old are trained as technicians together with other Indian "grannies" at the Barefoot College in India (Tilonia, Rajastan) so later, back at home, they become active agents to train other women and to extend this model to neighboring villages.

[89] www.schneider-electric.com/sites/corporate/en/group/sustainable-development-and-foundation/access-to-energy/presentation.page
[90] www.enelgreenpower.com/en-GB/company/csr/enabling_electricity/

3.3.2 Non-governmental, non-profit

Cooperatives

Cooperative efforts for rural electrification have been in place since the late first half of the XX century in countries like USA or later in developing countries where meaningful experiences can be found in Costa Rica, Philippines and Bangladesh, mainly devoted to grid extension and Mini-grids[91]. Committed with the provision of electrification in rural areas, to reach their isolated customers they have recently engaged also in the provision of Stand-Alone Systems to very isolated customers and agro-cattle exploitations (pumping water in Costa Rica). To see a more detailed description of this cooperative business model for relatively large regions, please see *Cooperatives* in section 0.

As for small community distributed service, an interesting experience of local cooperative can be found in the experience of the Spanish Fundación Energía Sin Fronteras (ESF)[92] in Guatemala. With an investment in 180 Stand-Alone Systems for a total budget over 0,3 M$ the *Cooperativa Integral de Servicios Especiales de Energía Solar* provides Tier 3 electricity service to nearly 1000 users. A second phase for this cooperative will reach another 200 houses by 2014. The first investment is 80% funded by the Spanish aid agency (AECI) and this second effort will be achieved also with support from the Madrid Government and the ESF Foundation itself. Therefore, for a sustainable operation, membership fees cover a small share of the investment cost plus the whole operation, maintenance and reposition costs. Lacking the political commitment and appropriate regulation for electrical cooperatives as their neighboring country Costa Rica, the effort has been focused on promoting a strong cooperative with the technical and managerial capabilities required for a sustainable business model[93]. Additional efforts have been focused on proposing a suitable regulatory framework for the country[94].

Social enterprises

As already described for SPLS (please see *Social enterprises* in section 0 for further detail) we can also find two successful approaches for social enterprises in SAS: service providers (Grameen Shakti in Bangladesh and Acciona Microenergía Peru) and international independent manufacturers (D.Light for Africa and Asia).

Maybe the most successful case of business models based on SAS and SPLS is the case of Grameen Shakti[95]. One million systems installed in Bangladesh by 2011 and up to five million projected for 2015 show clearly the strength of this business model based in microcredits and

[91] Barnes, 2007
[92] www.energiasinfronteras.org
[93] NRECA International, 2009
[94] González-García, Pérez-Arriaga, Moreno, & Uriarte, 2013
[95] www.sunlabob.com

in scalability of businesses for the base of the pyramid. In this case, they follow the same strategy and business model already described in *Social enterprises* in section 0.

Peru Microenergy (FUNDAME)[96] is a non-profit social enterprise established by Acciona Microenergy Foundation in 2009. In order to provide Tier 3, 60 Wp, SAS and energy services to households and community facilities, Peru Microenergy has launched a "Light at Home" program for the provision of fee-for-service electricity to off-grid customers to be sustained over the next 20 years.

As an anchor, Peru Microenergy receives financial, technical and managerial support from the Spanish company Acciona as seed money to establish its economic self-sustainability. The break-even point for their business model requires the installation of at least 3500 Stand-Alone Systems under the regulated social tariffs (FOSE, electrical social compensation fund) of the Peruvian government. In four years, by the end of 2013, they have accomplished the successful installation of 1700 SAS in Cajamarca, Peru, with financial support from the Inter American Development Bank (IADB) and Acciona Microenergy Foundation.

Regarding D.Light[97], it follows the same approach for their stand-alone system (75 Wp Model III-HLS) as they do for cheaper Small-and-Pico-Lighting-Systems. For further detail, please see *Social enterprises* in Chapter 2.3.2.

NGOs

Most NGOs have entered the field of energy access in the last decade with uneven results. On the negative side, the usual donor approach for turnkey projects have resulted in a vast market spoilage due to lack of maintenance and repairs in the medium and long term, which resulted in several projects malfunctioning or abandoned after three or four years of use because of preventable causes, such as battery exhaustion, insufficient or no lubrication of mobile equipment in wind or hydro turbines, or burnt out light bulbs.

On the positive side, NGOs have promoted intensive innovation in the field of appropriate technologies, business models and even regulatory frameworks. Most of them are now involved in long term sustainability actions for the Stand-Alone Systems they have helped to install. Successful learning involves the need of a sustainable funding approach (either market based[98] or with a focus in integral service approaches including the support of emerging business models through public-private-partnerships[99])

[96] Eisman, 2011
[97] www.d-lightpower.com and Wilson et al., 2012
[98] Balint, 2006
[99] Dietrich & Linares, 2009; Izquierdo & Eisman, 2009; Izquierdo et al., 2011; Mataix et al., 2012; NRECA International, 2009

3.3.3 Governmental

Small, decentralized

The case of purchase of SAS by municipalities from Sunlabob, described in *Small, decentralized* in section 0, serves as a successful example of municipalities taking on the responsibility for the electrification of certain facilities by installing Stand-Alone Systems on government buildings, health centers, schools or community centers.

Though already described in Chapter 2.3.3 section *Small, decentralized*, it is important to remark the positive experience of the Programme Energizing Development (EnDev)[100] also in the niche of SAS.

Large, centralized

This perspective emphasizes the role of the government from planning to implementing the electrification process. Following the principles of traditional cost-of-service regulation, the entities that develop the electrification range from municipal public Mini-grids to nationwide or regional institutions or public enterprises.

It is interesting the analysis of the Peruvian regulation[101], which develops the coordination mechanisms with regional and local authorities, institutions and investors interested in raising the electrification rate. It administers all the resources devoted to electrification, with the exception of those destined to promote the private investment, it develops the studies, executes the electrification work and finally transfers them for their administration, operation and maintenance by state owned concessionary distribution enterprises. It allows a hybrid model of private investment, promoting at the same time state owned distribution companies.

The lack of adequate incentives for distribution companies to engage in an off-grid niche that requires a deep reengineering of their business model in those isolated areas has proved the limitations of this approach in favor of the decentralized ones mentioned before.

[100] www.endev.info
[101] Ministerio de Energía y Minas, 2007

4 Isolated mini-grids

This section analyses the business models for off-grid electrification with Micro-grids in rural areas for communities without access to modern energy services. The purpose of the document is to identify the key features of these models, their applicability in pursue of universal access to electric power services and the relevant policy and governance measures for the sustainability, reproducibility and scalability of these initiatives.

FIGURE 15 - Micro-grid at Ban Houaypha village (Laos) electrified by Sunlabob 2013

Source: www.sunlabob.com

4.1 Introduction

Along with *Small-and-Pico-Lighting-Systems*, Mini-grids are one of the most promising emerging technologies for Universal Access to Electricity. They can provide affordable, reliable, upgradable and scalable electricity services for rural population in villages or house clusters as well as for non, or weakly, electrified urban population. Mini-grids provision ranges from basic access to light and phone charging up to community or industrial high power appliances, covering the five tiers of access to electricity defined by Sustainable Energy for All and up to the levels and quality of service required by developed societies.

In this document we will be focusing on isolated Mini-grids, not connected to the power distribution network. Connected Micro-grids will be described within the framework of network extension business models.

4.2 Technology

Mini-grids have been extensively used for electrification of villages, communities, industries and community facilities, either isolated or with the possibility of connection to the grid, for remote locations where the grid extension is not feasible, or where the weak condition of the grid supply required eventual disconnection from the network and stand alone operation of the Micro-grid based on local storage, generation and management. Thus, there is a huge variety of technological configurations in practice, from low cost DC Micro-grids for rural village electrification to large islanded grids for large numbers of residential, productive or public service customers.

Because of this diversity there is not a standard categorization of Mini-grids, nor a clear distinction between different terms used for them as isolated grids, Micro-grids, or even Pico-grids. Though most of these terms make reference to different sizes, there is also a lack of consensus in the distinctive limits between them[102], so here we will use these denominations indistinctively. For the sake of simplicity, in this document we will refer to Mini-grids as isolated systems that provide electricity generation at local level, which use distribution networks within a limited area and that are not connected to the national grid[103].

Isolated Mini-grids can be AC or DC, with a single generation set or hybrid, characterized for their peak load, generation capacity, energy or number of customers.

The analysis of the technology options requires a thorough detailed design of each system, according to the geographical layout, dispersion of the population, energy needs, user profiles and generation options so as to establish the optimal configuration in every case.

4.2.1 Distribution

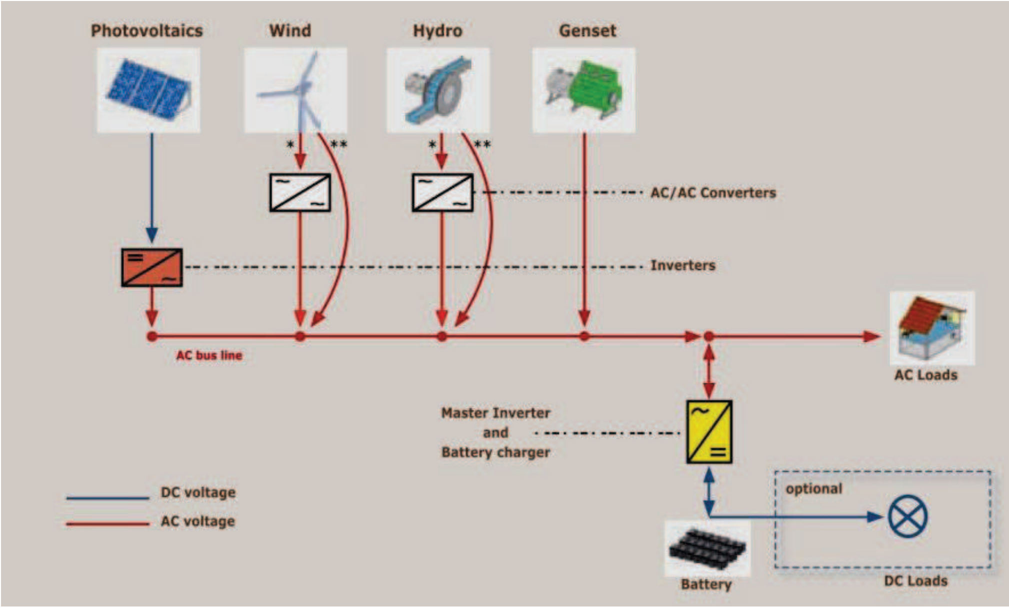
There are two major families concerning distribution technologies: AC and DC Mini-grids, though hybrid configurations can also be found.

AC mini-grids

As shown in Figure 15 bis, it consists of an AC line, which distributes the electricity from the generation to different AC loads. Different generation technologies can be coupled directly (diesel or biomass generator sets) through inverters (photovoltaic) or even AC/AC converters (wind, hydro). Storage is usually provided by batteries, which are connected through a bi-directorial master inverter and may also feed directly DC loads.

[102] The SE4All initiative, through the United Nations Foundation Micro-grid Work Group, is currently aiming at achieving a consensus classification and definition collaboration. www.worldbank.org/thread/1997 .
[103] Adapted from Alliance for Rural Electrification, 2011

FIGURE 15 bis - Generic AC coupled Mini-grid



Source: Alliance for Rural Electrification, 2008

In Mini-grids for energy access, the voltage level of the distribution system matches usually the house current (100 to 400 volts), though some medium size systems in large un-electrified clusters or villages could require setting a higher voltage (less than 2 KV) requiring the use of voltage transformers.

The wiring can be mono-phasic or tri-phasic. Mono-phasic schemes are simpler to design and install but have higher losses. Tri-phasic grids permit eventual connection to the national grid, as well as powering larger loads. They are more economical in terms of wiring costs because of the smaller losses, but require a careful design that takes into account load balance, though even in 50% unbalanced schemes tri-phasic grids can be cheaper than mono-phasic[104]. The cost of the power distribution network varies upon topology. Typical off-grid AC low-voltage distribution line cost is around 3000 $/km for the plains, and increases by 10-25% for remote hilly regions[105].

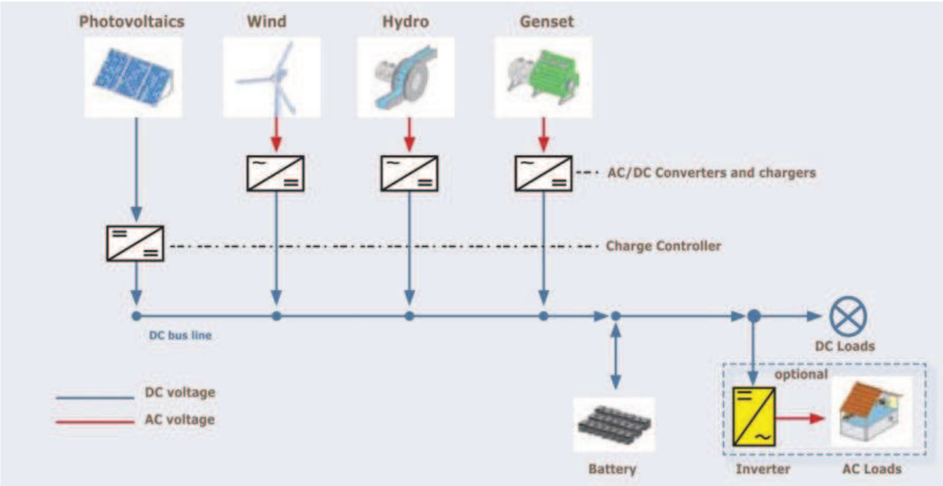
DC mini-grids

Figure 16 shows a generic DC Mini-grid scheme, which distributes the electricity with a low-voltage DC line (12 to 48 V). Different generation technologies can be coupled trough AC/DC converters (wind, hydro, diesel or biomass generator sets) or directly (photovoltaic). The

[104] Alzola et al., 2009
[105] Kishore et al., 2013

batteries are protected from over charge and discharge by a charge controller. AC loads may also be connected using load side inverters.

FIGURE 16 - Generic DC coupled Mini-grid



Source: Alliance for Rural Electrification, 2008

Though some authors consider negligible the difference in costs between AC and DC distribution[106], specific on-site design depending on grid topology, energy resources available and load profiles may lead to substantial differences. Moreover, recent studies point to future reductions in costs for the domestic and commercial appliances[107] between 2% and 21%. Inverter cost and inefficiencies would also be spared[108] in DC-only systems.

4.2.2 Generation

Solar

Off-grid PV mini/grids are usually within the range of 1 to 500 kWp. Typically they distribute three phase or single phase AC electricity, where the PV generation is connected to a low-tension independent power distribution network through a DC/AC inverter.

The capital cost of a AC PV Mini-grid system can be broken down in the cost of each component, with the PV panels accounting approximately 60% of the total cost, 25% for the power controlling unit (including the inverter, junction boxes, charge controllers and distribution boards in an appropriate room) and 15% for the battery bank[109].

[106] Alliance for Rural Electrification & USAID, 2011
[107] Thomas, Azevedo, & Morgan, 2012
[108] Brent & Rogers, 2010; Soto & Modi, 2012
[109] Kishore et al., 2013

The inverter accounts for most of the cost of the power control unit, thus explaining the increasing popularity of DC Micro-grids, as the availability of low-cost appliances and smart control DC system grows.

Concentrated Solar Power – Stirling

A CSP-Stirling system concentrates solar heat into a Stirling machine to generate electricity usually ranging from around 3 to 25 kW[110]. The use of CSP Stirling machines for off-grid electrification expands the range of off-grid technology choices. CSP-Stirling units are of the appropriate size to power small and medium range micro-grids for isolated villages, they are reliable, require low maintenance and their levelized cost of energy is in the range of other alternatives[111].

Enel Green Power, the company of the Enel Group specialized in renewable energy production, is currently testing small CSP Stirling plants for stand alone applications (to be placed on the roof of buildings). The rated power of these small plants is 3kWth + 1 kWel, for a price around 15k€ which makes them also suitable for high efficiency micro-grids of small villages in developing areas.

Wind

Power generation with small wind turbines (SWT) present higher advantages for Micro-grids than for SAS, especially in hybrid configurations as will be seen later.

Hydro

Hydro systems for Micro-grids range from very small contribution of pico-hydro (5 to 20kW), micro-hydro (up to100 kW) and mini-hydro (that could reach 1MW).

Diesel

Diesel generators provide a powerful and reliable generation for Micro-grids, especially as backup generation for other renewable sources. As explained in *Diesel* in section 0, cost of diesel is very volatile, not only because of international oil prices volatility, but because of the characteristics of isolated areas where transport, logistics and scarcity may multiply the cost of fuel.

[110] DFID, 2010
[111] Beerbaum & Weinrebe, 2000; DFID, 2010; Nouni, Mullick, & Kandpal, 2009

Biomass

As detailed in Chapter 3.2.2 section *Biomass*, biomass is also a very interesting renewable resource in many places, though it is important to guarantee a sufficient and steady supply.

Marine energy

Either in the case of wave energy or tidal energy many small pilot plants are being tested by specialized developers. This kind of plants could be used to give access to energy to micro-grids in coastal areas and isolated islands with a high potential in terms of marine energy:

Wave energy: Oceans might be an immense source of energy. Their waves, formed by powerful winds travelling over long distances, can unleash a lot of energy with their movement. The actual amount varies depending upon different factors, such as the speed of the wind, the distance covered by the wind over the ocean, the wind duration, the currents, the ocean floor which can converge or disperse the energy. The most powerful waves occur in areas where strong winds have travelled over long distances. That makes the coasts of Southern America, Africa and Asia an ideal area to exploit the waves movement, being placed at the end of long fetches (the Atlantic and Pacific oceans).

Tidal energy: Marine currents are deeply and continuously affected by the tidal. The tidal stream technologies can capture the kinetic energy of the currents moving according to the tidal, which is precisely predictable, being created by the movement of the sun and the moon. It is this predictability that makes tidal energy such a valuable resource. The ideal areas where a good tidal range exists are where the speed of the currents are channeled, affected by coastline, sea floor, in narrow straits and inlets, around headlands and between islands.

Hybrid

As also stated before, hybrid power systems are those powered by a combination of complementary generation sets, either based on renewable energies or mixed with fossil fuels[112].

The hybrid Micro-grid can include different configurations based on the availability of local energy resources (fuel provision, sun, wind, hydro, biomass). It can help existing facilities powered by diesel or LPG gen-sets to minimize their fuel consumption by adding renewable generation and limiting the use of fuel to periods of high loads or low renewable resource availability. Thus, hybrid Micro-grids improve the reliability and quality of the electric service, also optimizing the use of fuel and hedging the uncertainty of volatile fuel markets. They also

[112] Alliance for Rural Electrification & USAID, 2011; Alliance for Rural Electrification, 2008

allow the use of smaller batteries compared to 100% renewable systems, limiting battery discharge and reducing its stress, thus also extending battery lifetime.

4.2.3 Storage

Storage is considered to be the weakest part in renewable powered Mini-grid systems[113], not only technically but also organizationally, as it requires a higher level of understanding by consumers to have a longer battery life, as well as specific and costly maintenance by the operators.

Considering this socio-cultural adequacy, as well as the fact that operation and maintenance costs for off-grid systems account for a significant share of the cost of the supply[114], lower up-front costs energy storage systems (ESS) that require higher maintenance and careful operation, as lead-acid batteries, are slowly being displaced by more expensive but durable, lower maintenance and lighter batteries as lithium-ion[115].

Larger and more complex systems benefit from pumping storage[116], though today pumped storage is unlikely to be competitive for SAS or small Mini-grids[117] unless hydro generation including a high level reservoir is a priori part of the system.

As also mentioned before, ESS applications[118] can be grouped into power and energy applications. In the case of RES powered Mini-grids storage needs to accomplish both functions, as it accounts for a large share of the energy provided to users in the long-term, but it also provides for power quality and fast reserve power supply at any given time.

Table 11 and Figure 17 show different storage solutions applicable to Micro-grids. However it must be noticed that many of them are not actually installed in low-cost systems, where lead-acid batteries are the most common solution. Further studies are needed to assess the suitability of other storage options for universal access and their applicability in specific cases.

[113] Kishore et al., 2013; Ulsrud, Winther, Palit, Rohracher, & Sandgren, 2011
[114] Izquierdo et al., 2011
[115] International Renewable Energy Agency IRENA, 2012
[116] Manolakos, Papadakis, Papantonis, & Kyritsis, 2004
[117] Greacen, 2006
[118] Sigrist et al., 2013

TABLE 11 - Storage technologies capabilities

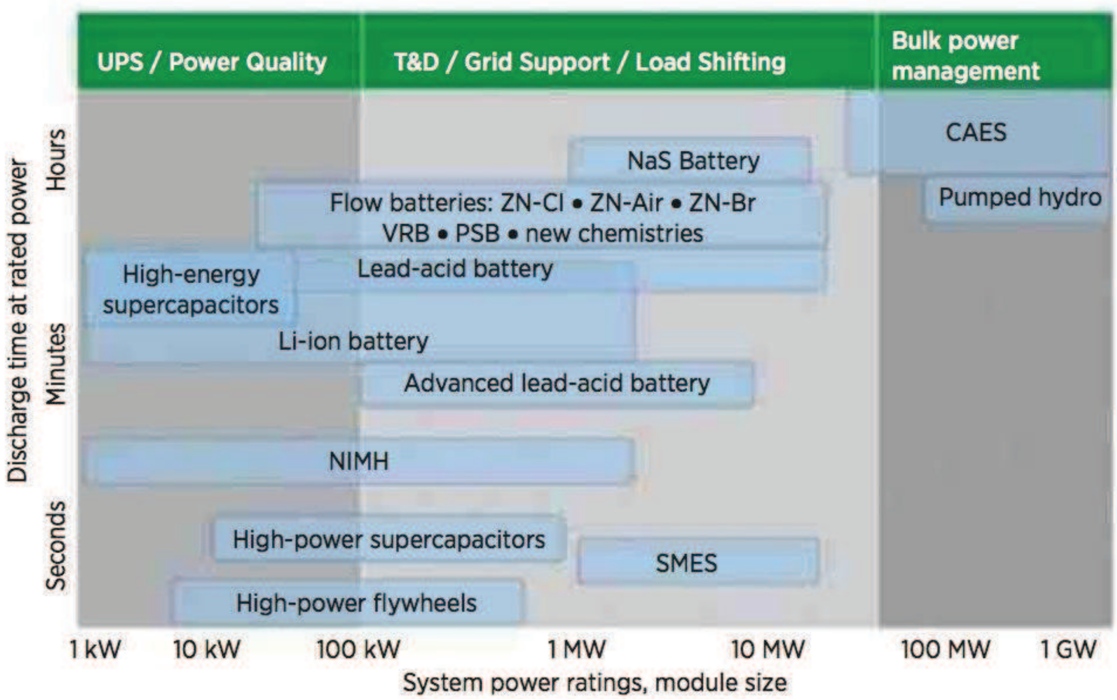
Storage Technologies	Main Advantages (relative)	Disadvantages (Relative)	Power Application	Energy Application
Pumped Storage	High Capacity, Low Cost	Special Site Requirement		●
CAES	High Capacity, Low Cost	Special Site Requirement, Need Gas Fuel		●
Flow Batteries: PSB VRB ZnBr	High Capacity, Independent Power and Energy Ratings	Low Energy Density	◐	●
Metal-Air	Very High Energy Density	Electric Charging is Difficult		●
NaS	High Power & Energy Densities, High Efficiency	Production Cost, Safety Concerns (addressed in design)	●	●
Li-ion	High Power & Energy Densities, High Efficiency	High Production Cost, Requires Special Charging Circuit	●	○
Ni-Cd	High Power & Energy Densities, Efficiency		●	◐
Other Advanced Batteries	High Power & Energy Densities, High Efficiency	High Production Cost	●	○
Lead-Acid	Low Capital Cost	Limited Cycle Life when Deeply Discharged	●	○
Flywheels	High Power	Low Energy density	●	○
SMES, DSMES	High Power	Low Energy Density, High Production Cost	●	
E.C. Capacitors	Long Cycle Life, High Efficiency	Low Energy Density	●	◐

Source: www.energystorage.org

The choice of storage technologies and the balance between generation and storage installed is largely dependent on each Mini-grid topology, number and location of users, load profiles, quality requirements and generation capacity and reliability.

Mini-grids storage must enable consumers to be generation independent for many hours. Depending on the size of the system, different options are available, as shown in Figure 17.

FIGURE 17 - Electric storage systems power and discharge time ranges



Source: International Renewable Energy Agency (IRENA), 2012

4.2.4 Smart operation

Commercial sustainability and technical performance of Mini-grid business models require a complex operation that, both for AC and DC systems, requires a higher sophistication than the previous SPLS or SAS analyzed in this Working Paper.

The Mini-grid goal is to match the resources with the demand of energy, balancing generation, storage and loads. The first decision to be taken is whether to run the energy management system automatically or manually, as shown in Table 12, but regardless of the choice made the unpredictability of human behavior and external conditions requires a deep local knowledge for the design of the system.

TABLE 12 - Advantages and disadvantages of energy management options

Energy Management System	Advantages	Disadvantages
Automatic	- Under standard conditions, optimization of life-cycle costs - Can be easily managed from a remote location	- Investment costs and need for further technological training - No anticipation of weather conditions - Not able to handle exceptional demand circumstances (one-off events) - No capacity to take into account short term cash flow problems - No capacity to take into account diesel availability (and unexceptional prices)
Semi Automatic System	- Can combine pros and cons of both systems, while leaving a margin for adaptation and unpredictability	- Leaves a margin for adaptation and unpredictability
Manual System	- Flexible management, especially under exceptional conditions (weather, supply of diesel etc.)	- Requires knowledge about long-term effects of decision - Tendency to prefer short-term gains over-long term cost optimization - Requires 24/7 availability of the technician

Source: Alliance for Rural Electrification & USAID, 2011

The second but more important technical (and social) decision to be taken in a Micro-grid design relates specifically to load management in a limited resource network, intended to avoid the "tragedy of the commons" [119] where multiple consumers acting independently will ultimately "deplete a shared limited resource even when it is clear that it is not in anyone's long-term interest for this to happen". Particularly, this is important if each connection does not include individual metering and load limiters. In this case, the arrangement of collective community management and education is critical to avoid damage of the system and failure of the business model.

The appropriate use of electricity dispensers (meters with energy limiting functions) will help avoid misusage of the system, particularly if they provide the user with meaningful information about energy use, energy expenditure and remaining reserves, so to help him take appropriate energy management decisions. Prepaid meters offer a cheap intermediate solution, as they will help avoid energy abuse, but harm consumers that run off electric supply without any previous warning. Prepaid meters also avoid the problem of reading, billing and collecting fees from customers. Collective hub meters (one to many) can also be found as an intermediate solution

[119] Garrett Hardin, 1968

for a group of users that shares one meter. In cases where the cost of meters, hub or prepaid meters is too high for very low-income customers, connections can be equipped with load limiters that will avoid overload of the system during peak demand, even if they cannot control the energy consumed in the long term.

4.2.5 Advanced technologies

On top of the innovation in generation technologies and appliances already described in previous sections of this Working Paper, specific advance is especially expected in the use of smart grids. There are already business models based on smart electronic metering, that even provide separate metering and charging for different energy uses (lighting, watching TV, phone charging, productive, etc.). Low-cost meters that provide real time energy consumption information to the user will help users control their energy expenses, and also will provide the operator of the Mini-grid with useful information for billing and collecting, as well as for the Micro-grid technical operation. The number of areas in which smart grids innovation can contribute to Micro-grid advancement are:

- Demand response: Integration of user meter data, account data, historical climate, outage patterns to compute demand and operation forecasting models.
- Distributed generation: Integration of control for different renewable and fossil energy sources, interfacing, switching and controlling energy generation assets.
- Micro-grid controller: Multi-agent framework for distributed Mini-grid control, collaborative control nodes to integrate switching, load balancing, VAR control, storage and self-healing operation.

Cloud and “smart phone” services for metering and user information, billing, electronic payments and other administrative services adapted to the needs of the developing users.

4.3 Business model alternatives

This section considers only those business models actually in place for Micro-grids and analyses them considering the criteria established by Reiche and others[120] together with Osterwalder’s business model canvas and delivery model map[121], along with the categories for successful business models proposed by Eisman[122] and Mataix[123]. Please see the introduction to this Working Paper for further information on the classification.

[120] Reiche et al., 2006
[121] Garside & Bellanca, 2013; Wilson et al., 2012
[122] Eisman et al., 2013

It is important to note that some of these business models do not only provide isolated Micro-grids services. A number of them will also be involved in other energy access modes as single user or pico-solar-systems, cook stoves or grid extension, as well as in services with existent synergies as telecommunications, water or even medical or humanitarian activities as will be seen later.

4.3.1 Private, for profit

Small, decentralized

The commercial market for isolated grids has attracted many small entrepreneurs into the arena of energy services, most of them directly as independent power producers. Sunlabob power[124], OMCpower – telecom power solutions[125] and Scatec Solar[126] are significant examples.

Sunlabob is a small enterprise established in 2001 that provides reliable and affordable power (SPLS and Mini-grids, among other services) to village residents in remote Lao. With an average household income of less than 2.5 $/day, a 6.5 kWp Micro-grid provides electricity to households, community center and street lights. They implement hybrid AC Mini-grids (hydro, solar and biofuel gensets that avoid supply problems in the dry season when the hydraulic resource is very scarce).

Their business model also counts on the establishment of Public-Private-Partnerships with international donors (as the Foundation Energies pour le Monde or Helvetas Swiss Association for International Cooperation) and public entities that fund all the civil constructions (water channels, distribution lines, generation buildings) while the enterprise invests in the equipment (hydro turbine, fuel generator, solar panels, wind turbines, control equipment).

Users capacity of payment needs to cover the cost of the operation and maintenance plus the equipment. This program targets at providing energy access to 15 solar villages, reaching 10000 rural Laotians.

The business model intends to reach sustainability involving and empowering members of the community. Sunlabob owns the generation system and finances the movable assets while public partners and donors fund the fixed assets (public infrastructure and grid) whose ownership is transferred to the village. Users are charged variable fees according to their consumption[127].

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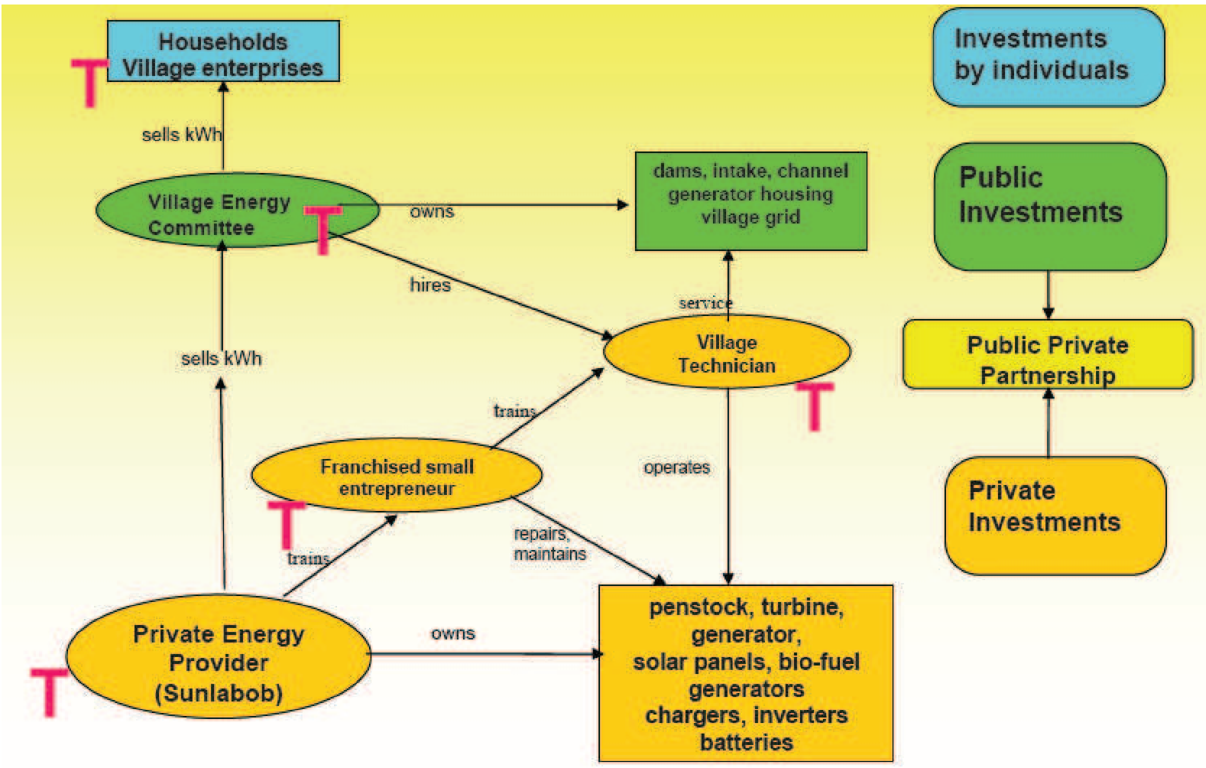
[123] Mataix et al., 2012
[124] www.sunlabob.com/hybrid-village-grids.html
[125] www.omcpower.com/telecom/power-solutions
[126] www.scatecsolar.com
[127] Thirumurthy, Harrington, Martin, D.Thomas, Takpa, & Gergan, 2012

Sunlabob relies heavily on the creation of Village Electrification Committees (VEC) which are in charge of the collection of fees and train local technicians for the operation and maintenance of the Micro-grids.

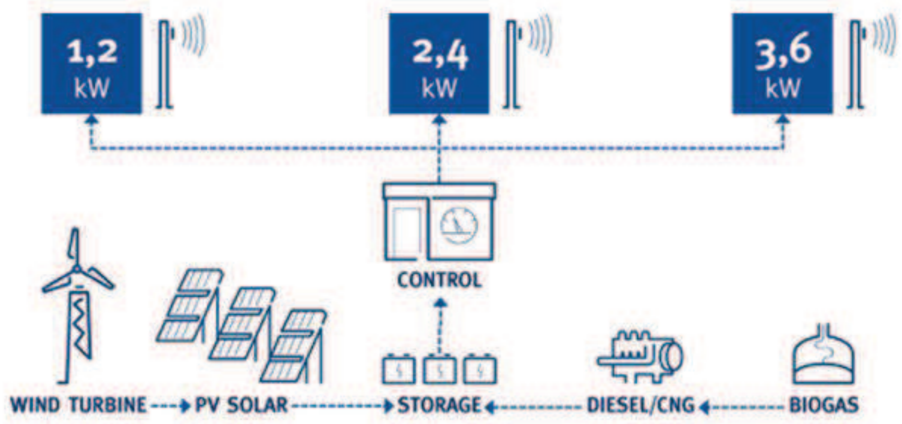
FIGURE 18 - Sunlabob hybrid Micro-grid business model



Source: www.sunlabob.com

OMCpower Micro-grids is focused on providing electricity to mobile telecommunication companies. A hybrid Micro-grid powers a cluster of communication towers, enabling scalability of the load. This example is very significant, as it emphasizes the suitability of "anchor loads" to guarantee sustainability of the Micro-grid business models. Anchor loads are specific users that because of their characteristics (income generation, public service, relatively high power consumption) provide a minimum level of consumption that enables an appropriate level and stability of income for the distribution company.

FIGURE 19 - Telecommunications scalable Micro-grid scheme



Source: www.omcpower.com/telecom/power-solutions

The third case is Scatec Solar. This is a Norwegian company devoted to project development and turnkey PV systems and also to solar production as independent power producer, managing assets directly owned by Scatec Solar. They provide service for the villages of Rampura and Gopalpura in India. According to the company "the model is relatively cheap and it is easy to operate and maintain. It can be built in three to four weeks and can easily be scaled up if the demand for electricity increases". This definition comprises three of the main technical challenges of Micro-grid projects: affordability, scalability and easy operation and maintenance. Though willingness to pay is relatively high in these villages, the model depends on subsidized infrastructure costs paid with funds collected via some sort of feed-in tariff in the donor country. The revenues from the local customers reach to cover the operation and management costs, including replacement of batteries.

Large, centralized

Schneider Electric[128], which was also present in the segment of SPLS and SAS, are also valid example of brand builder[129] in the field of Micro-grids in Africa and India, as well as other very large technology providers as ABB or Johnsons Controls.

Brand builders business model for providing energy collective solutions to the market in the base of the pyramid follow the same channels established for other electrification technologies in their portfolio as SPLS or SAS. Partnership with local distribution is cherished, supporting the national partners with training and communication services provided by the national representatives of the brand. Brand builders favor this partnership scheme, either with existing integrators and distributors and dealers or other large regional actors as social organizations, cooperatives or micro-financing institutions with a large customers base, or partnership with local technological franchises, but keeping control of their brand name, trying to avoid

[128] www.schneider-electric.com/products/ww/en/8600-access-to-energy-collective-solutions/
[129] IFC World Bank, 2012. Please see definitions at WP1a.2 Small-and-Pico-Lighting-Systems.

reputational risk brought by direct exposure to the markets. The services provided for business management guidance cover the whole business cycle from project management to human resources, accounting, sales, customer relationship management and communication advertisement. Please see *Large Centralized* in section 2.3.1 regarding SPLS system for a more detailed description of this kind of business model.

India also has launched the decentralized distribution and generation Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) program, that includes Micro-grids as a complementary measure to grid extension for village electrification, attracting companies as the Northern Power Distribution Company of Andhra Pradesh Limited [130] with a grid extension and Micro-grid concession over 5 different districts of Andhra Pradesh. This company is operating solar Micro-grids in 29 villages that are not reached by the RGGVY grid extension program.

In Brazil Guascor[131], a subsidiary branch of Dresser-Rand[132], operates an innovative Mini-grid for 250 residents in the tiny island of Ilha Grande developed jointly with the Spanish technology provider Zigor. This hybrid solar 30 kWp Mini-grid with diesel backup generation was installed under the Brazilian government "Luz para todos" program established in 2003. This isolated system is one of the 345 that the company operates across the country under regulated conditions, ensuring the reliability of supply through hybrid systems and flexible smart operation. Funding of these systems enjoys a central government subsidy of 85% for the installation.

In Chile and Peru, ENEL Green Power and ENEL Cuore are engaged in installing a hybrid PV-wind[133] and hydroelectric[134] plants respectively to provide reliable power to villages in remote off-grid locations, providing clean energy at affordable prices that can meet the household and productive demands of their population.

4.3.2 Non-governmental, non-profit

Cooperatives

The Energy Service Delivery project launched by Sri Lanka Sustainable Energy Authority targeted on the introduction of off-grid renewable energy development and has achieved the electrification of over 130,000 rural households through SAS and isolated Micro-grids[135]. Under a market approach coupled with a credit line, it promotes private and also community based. While the private sector engaged primarily in SAS, village hydro, solar and hybrid Micro-grids

[130] www.apnpdcl.in
[131] www.guascor.com.br
[132] www.dresser-rand.com
[133] www.enelgreenpower.com/en-GB/plants/ongoing_projects/chile/chile_ollague/
[134] www.enel.com/en-GB/sustainability/energy_access/projects/peru_huallin/
[135] Palit & Chaurey, 2011

have been built, owned and operated by rural communities through electricity cooperative societies. A similar scheme can also be found in Nepal also according to the same reference.

Cooperative schemes in Costa Rica have also been very successful. Coopesantos[136] is an electrification cooperative for the region of “Los Santos” that services an area of 1500 Km^2 integrated by 120 communities, with grid extension, single user and Micro-grid power services. In addition to residential services, Coopesantos has recently installed a hybrid wind-solar Micro-grid that services more than 50 isolated houses and over 2900 cooperative workers, supporting agro industrial activities developed by another partner cooperative, Coopetarrazú, where coffee drying would be powered by the wind micro-turbines. This project, in partnership with Costa Rica University, receives support from USAID for the initial investment and increases the energetic efficiency of the rural business, enabling also the financial sustainability of the energy business model. Coopesantos has also recently started also the provision of other services like cable TV and Internet to their associates, and has achieved sufficient scale as to achieve CDM.

Social enterprises

Mera Gao Power[137] has developed a ultra low-cost off-grid mobile charging and light Micro-grid model at village level in the state of Uttar Pradesh in India. Each house is equipped just with two LED lights and one mobile-charging point for 0.5 $/week plus an initial connection fee of just 0.8$, making it affordable and suitable in comparison with the actual cost of kerosene lighting and battery charging (that costs around 0.2$ per charge in a nearby town). Users just pay for the service itself, keeping up-front costs to a minimum and avoiding the need of credit that is required to buy an equivalent SPLS. The model equilibrium point is reached within 18 months, and the return of investment over three years is expected to reach 15%. The model counts on an initial investment fund from US Aid for setting 50 Micro-grids in villages of this region in 2012 and targets to install between 1000 and 2000 villages in the next five years, upgrading the systems to reach also agricultural services, healthcare, education and leisure activities.

NGOs

The Energy and Resources Institute[138] (TERI) in India has already developed and installed 36 DC Micro-grids in rural Uttar Pradesh from 10 to 100 users (households and shops). These systems are flexible to satisfy the needs of different profiles of users providing LED light for about 4 to 5 hours at nighttime. Power is distributed over a short distance from solar fed battery banks to clusters of users. This business model, supported by a 55% grant from the Norwegian Ministry of Foreign Affairs and funded by Regional Rural Banks, has transferred the

[136] www.coopesantos.com
[137] www.meragaopower.com
[138] www.teriin.org

ownership of the assets to 36 energy providers (local entrepreneurs owning and operating each Micro-grid). Cost of the assets is about 6.5 $/Wp and energy providers charge users with a 2,4 $/month for operation and maintenance. This electric charge has been agreed jointly by providers and customers according to the needs and capacity of payment of the population.

TERI is now committed to reduce the grant support required to start up the Micro-grids. They have also developed a smart Mini-grid pilot for the integration of multiple distributed energy resources and intelligent load management with the capacity to respond automatically to network problems and self healing capabilities. This smart Mini-grid design is intended not only for large scale deployment in the country for commercial and productive facilities, but also for education, health, urban residential complexes as well as remote un-electrified locations targeting maximum flexibility, reliability, efficiency and safety.

4.3.3 Governmental

Small, decentralized

Though most of the decentralized village Micro-grids business models are mostly private or cooperative, other community based models are adopted by local municipalities or village energy committees, for instance in Sri Lanka and India. These committees play the role of stand-alone power producer, distributor and merchant. In India, governmental schemes like Remote Village Electrification or Village Energy Security Program followed this approach[139]. Participation in community-based models varies greatly ranging from communities that take an active role to communities that only focus in monitoring and oversight[140]. These schemes are similar to cooperatives as in both models the community takes a leading role in the electrification process, though community based companies do not require membership by the beneficiaries, nor even in some cases there is a formal legal entity established to represent the community.

Large, centralized

Large off-grid electrification models, with a central control by governments have been very rare, especially for remote regions in developing countries where this is also a symptom of the lack of government presence in practice on the ground over these regions. Even in centrally planned China, before 1977, remote hydro Micro-grids were operated, funded and managed by rural residents and collective groups, with some support from the central state[141]. Nowadays,

[139] Palit & Chaurey, 2011
[140] Krithika & Palit, 2013
[141] Bhattacharyya, 2013

the general practice relies on active local participation, state or region wide led open bidding processes and bottom-up approaches.

5 Grid extension

This section analyses the business models for grid extension electrification for urban and rural communities without access to modern energy services. The purpose of the document is to identify the key features that may extend this model to suitable areas still without service, in pursue of universal access to electricity, and the relevant policy and governance measures for the sustainability, reproducibility and scalability of these initiatives.

FIGURE 20 - Low-cost grid extension at South Africa

Source: IFC World Bank, 2012

5.1 Introduction

Extending the electricity distribution network to each customer first in cities and towns, and then to villages and rural areas, has been the usual pathway to electrification worldwide. Nowadays, grid supply is commonly agreed as the final stage for the electrification process. Grid extension may provide electricity for almost any application with the highest quality of service available.

Network extension, where there is enough generation capacity, remains the most appreciated (and common) electrification mode, presenting significant advantages over other options[142]:

When a village (or community of houses) gets connected to the network, all the habitants (even those who cannot afford the connection at their homes) get benefits from the grid supply as street lighting, pumped or irrigation water, education or health applications, agricultural and productive uses.

[142] NRECA International, 2000

Where cross subsidies are properly (and even straightforwardly) established, electrification should also reach every habitant despite their capacity of payment.

The grid can provide enough quantity and quality of services to enable broad economic development activities (Tier 5) rather than basic access to lighting and phone charging.

Extending the grid establishes a basic infrastructure for future socioeconomic development in, often neglected, communities (rural or peri-urban).

Economies of scale coming from large generation plans also result in low-cost electricity.

Where generation is based on fossil-fuel plants, scale and centralization allows the implementation and supervision of carbon emissions and pollution mitigation measures.

Despite these facts, actual grid service presents may challenges for developing countries. Areas without electricity generally present less disposable income for energy expenditure[143] and lower population and consumption density, which come together with higher connection costs, especially for remote isolated locations; lack of appropriate generation capacity in the existing network, that leads to intermittent, weak and unstable service; electricity thefts and even sabotage are some of many hurdles that grid extension needs to address in order to achieve universal access.

In urban areas, the main challenge lays in allowing affordable connections, together with establishing suitable business and contract models for low-income population. In rural areas[144] the cost of extension of the national grid can make these projects unfeasible, especially in difficult terrains (mountainous or rain forest areas with difficult access for machinery to build the transmission lines) and where the size of the demand is small. Extension of the grid to a certain village depends on the aggregated demand, terrain, distance and also on the assessment of the national grid in terms of additional generation reinforcements required or specific national costs.

The total cost for achieving Universal Access through network extension is estimated between 47 and 62 billion $ per year[145], thus bounding the upper end by targeting universal grid connected electric supply in rural areas with the same quality of service and consumption scalability despite the location of the consumer. This amount is similar to the scale of investments proposed by Brazilian[146] for a rational access framework, and higher than the amount estimated by the International Energy Agency[147], which takes into account multiple electrification options.

[143] NRECA International, 2000
[144] Alliance for Rural Electrification & USAID, 2011
[145] Pachauri et al., 2013
[146] Brazilian et al., 2010
[147] IEA, 2010

In any case, complementarity with other electrification modes becomes a requirement in order to reach very isolated and also frequently pariah population, for which the adoption of innovative approaches for the extension of the power grid, as those enumerated in this section, becomes also a sine-qua-non condition.

As also pointed out by NRECA, "the situation calls for both a more accurate estimate of the true costs associated with grid extension and an assessment of the extent to which high costs are intrinsic to it". For this section, we will focus on the implementation of low-cost technologies and innovative approaches for grid extension. Also in this regard, models and methodologies which assess suitable reference costs of grid-extension, together with the other electrification modes, along with geographic, socio-economic and energy policy considerations, will help policy makers establish the course of action and appropriate remuneration levels to implement the electrification plans.

5.2 Technology

On this study we are going to focus the discussion on the extension of the distribution network to the final users. Other facts regarding need for capacity expansion or transmission network reinforcements will be briefly exposed as needed, as the extent of these problems exceeds the scope of energy access and must be analyzed considering the whole electricity system. Table 13 shows an estimative breakdown of the connection costs for rural electrification. The purpose of this indicative table is to evidence that distribution and then generation account for most of the connection expenses.

TABLE 13 - Estimation of costs breakdown for grid based rural electrification

Annual fixed costs/connection (US$)			annual consumption (kWh)				
			500	981	1500	2000	3000
Generation	US$	64.1					
Distribution	US$	138					
Transmission	US$	14.4					
Service connection	US$	9.5					
Total annual fixed cost	US$	226					
Fixed cost per kWh			45.2	23	15.1	11.3	7.5
Fuel cost/kWh	USct		7	7	7	7	7
Total costs/kWh	USct		52.1	30	22.1	18.3	14.5

Source: Charles Trevor Gaunt, 2003; Zomers, 2001

Despite the fact that cost is an important dissuading argument against grid extension to some rural areas, the relation between density of customers and distance to the transmission network can result, for many cases, in costs within the range of a few hundred dollars, even down to 150 $/connection in rural households in Nepal[148]. An appropriate emphasis on

[148] Inversin, 1994; NRECA International, 2000

innovative low-cost distribution technologies can lead to further improvements in budget, as will be seen later.

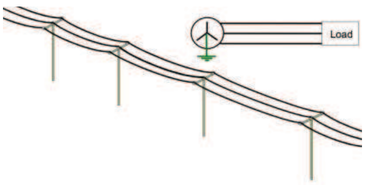
A grid distribution system can be divided into two components:

- MV Distribution network: The infrastructure required to transmit power at a medium voltage from the national grid or distributed power plant to demand centers. It includes medium voltage[149] (MV) distribution line, transformers and control systems.

- LV distribution network: The distribution system within a load center that serves each individual end customer. It includes low voltage[150] (LV) lines and meters.

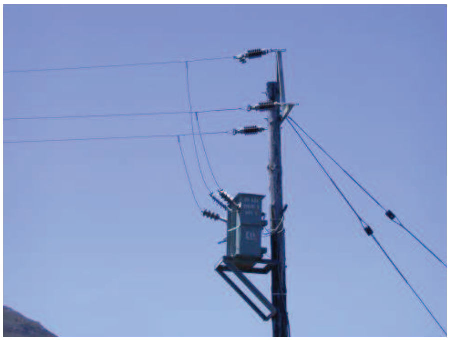
5.2.1 Distribution network extension

Three-phase



Three phase lines make the most efficient use of conductor for heavily loaded feeders, and deliver constant torque to motors. Most of the countries follow either the European or North American configurations[151]. The choice of configuration depends on the population geographical pattern, as much as on historical reasons. In the case of very small electrical loads, supplied by light feeders on which the minimum conductor size is constrained by mechanical strength, the three phase conductors are not fully utilised to carry current, so the apparent efficiency of three-phase supply is not achieved.

FIGURE 21 - Low-cost grid three-phase grid extension at South Africa (European configuration)



Source: C.T. Gaunt

[149] Medium voltage usually ranges from 1kV to about 25 kV.
[150] Low voltage range for residential consumers is usually 120V or 240 V
[151] Europe uses three phase conductors, designed for more dense populations in this continent. North American configuration uses four conductors three phase plus multi grounded neutral to serve more dispersed patterns of population in rural areas.

The cost of centralized grid extension is very variable in different countries, or in different regions within the country. Table 14 reflects indicative labor and other specific costs vs. material costs in different countries in Asia, Africa or Latin America, showing a variability of more than 300% in grid extension costs.

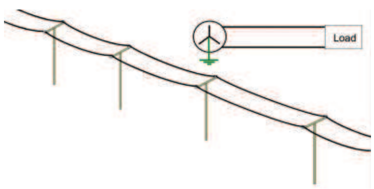
TABLE 14 - Cost of grid extension in selected countries (US$/Km)

Country	Labor & other costs	Materials	Total
Bangladesh	$ 350	$ 6,340	$ 6,690
Laos	$ 1,420	$ 7,230	$ 8,650
El Salvador	$ 2,090	$ 6,160	$ 8,250
Kenya	$ 6,590	$ 5,960	$12,550
Senegal	$ 5,150	$10,810	$15,960
Mali	$ 2,590	$15,170	$19,070

Source: Alliance for Rural Electrification & USAID, 2011; NRECA International, 2000

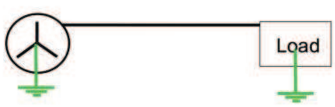
While different costs of labor can be explained due to local conditions, the variation in the cost of materials depends on the average size of conductor but also on the important share of cost of poles (about 40%) and hardware, which in some cases are manufactured locally with a substantial reduction on costs.

Monophasic



One alternative to reduce electricity delivery costs is to omit one of the three conductors, giving only a single phase supply with two phase conductors or a phase and neutral. The operation of single-phase electrical motors is not as smooth as with a three-phase supply, but the cost reduction is substantial[152]. The percentage of savings in going to single phase construction averages 30 to 40% compared to three-phase design[153].

Single Wire Earth Return (SWER)



In Brazil, New Zealand and Australia, during the 1940s, engineers went further and omitted another wire, leaving only one conductor, and using the earth as an active circuit element for the return current. With adaptations to suit local conditions, this single wire earth return, or SWER, technology was introduced in Botswana, Namibia and South Africa during the 1990s. Hardly an innovative technology, but an example of innovative design[154].

[152] Charles Trevor Gaunt, 2003
[153] NRECA International, 2000

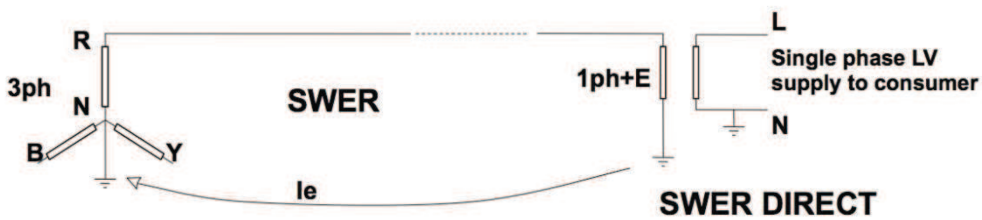
FIGURE 22 - These photographs from the first Botswana SWER system illustrate the simplicity of SWER systems: an isolating transformer with input from two phases, a load transformer connected to the line and the top of the earthing electrode that carries the current into the ground.

Source: C.T. Gaunt

SWER direct

There are various configurations for achieving the SWER part of the delivery system. The choice depends on the voltage at the source, distances, parallel telephone circuits, and other customer loads connected to the main backbone from which the SWER is supplied.

FIGURE 23 - SWER with isolating transformer scheme



Source: C.T. Gaunt.

SWER with isolating transformers

Although not always needed, isolating transformers can be used to separate a SWER sub-system from the main part of the network.

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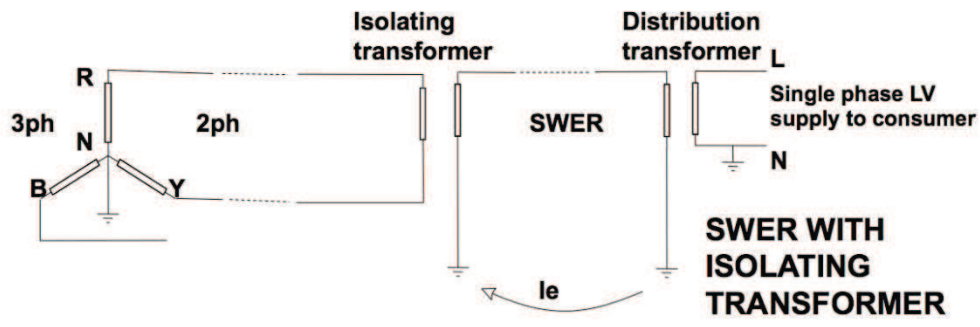
[154] Charles Trevor Gaunt, 2003

One aspect of the earth return is that the earth current effectively flows at a depth that depends on the resistivity of the soil, and affects the inductance of the overhead line. However, not all current flowing in the ground is beneficial in SWER delivery. Often, a ground current is used as an indication of a fault on the power system and to initiate automatic tripping to protect the system and the public. SWER with isolating transformers provides additional safety, also with a higher cost.

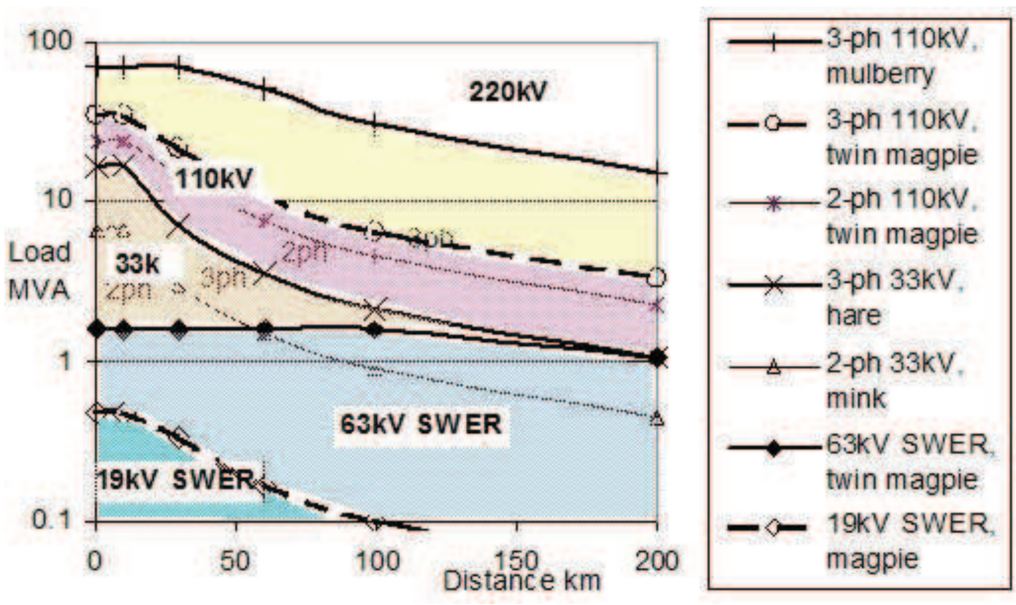
FIGURE 24 - SWER with isolating transformer scheme.



Source C.T. Gaunt.

Although most SWER schemes have been implemented at voltages of 19 to 20 kV, the technology can be used at higher voltages. Figure 25 shows the delivery capacity of lines operating at various voltages, and was used in planning the pilot project in Mozambique. It illustrates that 63kV SWER could have significant potential for delivering electricity into new, unserviced areas.

FIGURE 25 - Delivery options for grid extension to rural areas in Mozambique.



Source C.T. Gaunt.

5.2.2 Connected mini-grids

Different Mini-grids configurations, as described already in 4.2, can be connected to the bulk power system using the appropriate switches, AC/DC or AC/AC converters. These Mini-grids can function either in interconnected operation mode when the network supply is adequate, or in independent operation mode when the network quality is interrupted.

Connection to the grid may allow the exchange of energy from the network to the Mini-grid and also the transmission of the excess capacity from the Mini-grid to the bulk network. This late operation mode as generators requires a careful regulation, as will be described later.

There is a whole range of products suitable for different supply needs to avoid unreliable grid service: from single solar houses connected to the grid, which could also sell their energy surplus to the national utility provider, through large industrial and commerce centers and finally to Mini-grid utilities.

5.2.3 Advanced technologies

The main requirement to achieve an optimum extension of the network for universal access requires mainly the innovation in reducing the costs per kilometer to reach farther, and reduce the connection costs for individual customers. According to NRECA[155] the variety of options for reducing the cost of grid extension include:

- Using higher voltage for remote locations.
- Using higher quality poles to reduce life-cycle costs and consider alternative pole designs.
- Wider use of single-phase distribution and SWER.
- Properly sizing and placing transformers, and consider all their life-cycle costs.
- Standardization of materials and designs.
- Implementation of quality assurance programs.
- Technology transfer for local technicians maintenance and local ventures.

[155] NRECA International, 2000

5.3 Business model alternatives

This section considers only those business models actually in place for grid extension and analyses them considering the criteria established by Reiche and others[156] together with Osterwalder's business model canvas and delivery model map[157], along with the categories for successful business models proposed by Eisman[158] and Mataix[159]. Please see the introduction to this Working Paper for further information on the classification.

5.3.1 Private, for profit

Small, decentralized

Grid extension has not been the natural market for small and decentralized initiatives. Nonetheless very interesting examples can be found considering the contribution of extended Mini-grids and of small independent power providers (IPPs) to reinforcement of the power network with distributed generation.

Sunlabob[160] in Laos (see *Solar panels* in section 0, *Small, decentralized* in 0 and *Small, decentralized* in 0 for additional information about this business experience) also provides grid connected solar systems, linked to a feed-in grid system. These connected systems come from very small scale house systems to connected village Mini-grids, which produce their own energy and feed in the energy surplus into the collective grid, thus achieving a better and self-determined quality of service, especially in case of blackouts or intermittent service by the network.

Large, centralized

Nowadays, large utilities with distribution concessions over large regions or even whole countries play the main role for grid extension. Their role in achieving Universal Access for the population in the base of the pyramid is challenging, but experiences like North Delhi Power Limited[161], a joint venture of Tata and the government established in 2001, show the success of involving innovative companies for the rapid extension of electricity service. By the end of 2011 it doubled the connections in its area of service to 1.2 million customers, and it has regularized the connections in slum areas, attracting over 610 M$ since 2003 of private funding.

[156] Reiche et al., 2006
[157] Garside & Bellanca, 2013; Wilson et al., 2012
[158] Eisman et al., 2013
[159] Mataix et al., 2012
[160] www.sunlabob.com
[161] IFC World Bank, 2012

The program "Luz para todos" in Brazil[162] engaged large utilities like ENDESA or AMPLA, part of the ENEL Group among others, so the grid could reach the farthest regions of the country, supplying Universal Access Tier 2 electrification service. The program has connected 14,9 million people in ten years. Despite these efforts, the grid extension has not been able to reach around 2,8% of the households, located in the Amazonian rainforest, which need to be supplied with micro-grids and stand-alone-systems.

Another practical example is Union Fenosa – Gas Natural in Guatemala[163]. Since the concession in 1999 of a large area of customers, they were required to connect a zero cost every customer within 200 meters of the distribution grid, and also to extend the network to 2,633 communities with a 650 $ subsidy per connection. The combination of private management and incentive-based subsidies has led to doubling the number of connections in 10 years, reaching 810,000.

Other innovative experiences like Condensa Hogar in Colombia[164] also prove that they not only can provide connections to new customers, but they can also provide finance to low-income customers. Condensa in Bogotá established a separated financing arm (Condensa Hogar) to provide customers with financing (credit lines to a customer share, 60% of which does not have a bank account, and 25% living under the 2$/day poverty line).

These credit lines are used mainly to purchase electrical appliances that allow an increased growth of electricity demand. Condensa Hogar became more profitable than Condensa's core business. This success story proves that utilities are privileged platforms for financing low-income markets.

In addition to the role of utilities, also brand builders like Schneider Electric[165] are present in the field of grid extension and connected Micro-grids access (please see *Large, centralized* in sections 0, 0 and 0 for a more detailed description on their business model approach).

By August 2013 Schneider Electric have been able to provide connection to the grid for more than half a million households in the Base of the Pyramid through their Bip-Bop initiative, targeting to connect one million households by the end of 2014. As for the other niches, they promote training for village technicians (target is ten thousand instructed young people with BOP skills) and also micro enterprises (they have set to fund, train and support 500 entrepreneurs for electricity access).

[162] www.luzparatodos.mme.gov.br/luzparatodos/asp/
[163] IFC World Bank, 2012
[164] IFC World Bank, 2012
[165] www.schneider-electric.com

5.3.2 Non-governmental, non-profit

Cooperatives

Cooperative efforts for rural electrification by grid extension have been in place since the late first half of the XX century in countries like USA or later in developing countries where meaningful experiences can be found in Costa Rica, Bangladesh and Philippines[166].

Four large cooperatives[167] in Costa Rica have thrived under the strong political commitment for rural electrification since mid-1960s with help from USAID and other international donors. Their main focus has been on grid expansion and connected Mini-grid operation. Membership entitles individual consumers to a connection, which is paid in full by the customers unless their income falls under a certain minimum level, where the cooperative will grant them a concessionary connection fee.

Cooperatives set up a strict member qualification criteria, which together with social pressure prevents abuse of the system. In addition to connection costs, each member must also share the cost of community electrification (even if he is not connected himself). This allows rapid deployment where every member contributes from the beginning to the electrification effort and receives an incentive to get connected immediately instead of waiting for the grid to be installed for everyone and then connect at a lesser fee.

Bangladesh established in 1978, only two years after their independency, the Rural Electrification Board (REB). The REB has founded 63 rural cooperatives (Palli Bidyut Samities – PBS) since then, with funding over 900 M$ from 16 international donors and the government of Bangladesh. The growth of these cooperatives in suburban areas or nearby towns has been remarkable, but as many of them have accelerated service expansion into more remote areas, where this growth is minimal, they are failing to achieve enough operating incomes to sustain their business.

An interesting case, of a very different nature, of the role of cooperatives in electrification extension can be found in Philippines[168], where the National Electrification Administration has involved 119 rural electric cooperatives for the production of wood poles for network extension in rural areas, treated with chromated copper arsenate with a retention of 12 to 17 Kg/m^3 and full penetration of the sapwood. This production of national wooden poles is intended to replace imported poles and with a development cost of 1000 $\$/hm^2$ over 8 years, they can reach a 50-fold return of investment.

[166] Barnes, 2007
[167] Coopesantos: www.coopesantos.com, Coopelesca: www.coopelesca.co.cr, Coopeguanacaste: www.coopeguanacaste.com, Coopealfaro: www.coopealfaroruiz.com
[168] NRECA International, 2000

5.3.3 Governmental

Large, centralized

Until the emergence of electricity markets and regulatory reforms at the end of the XX century, that boosted the restructuring and privatization processes all over the world, government-owned utilities have also played a fundamental role in grid extension over the years.

In Morocco[169], a government led *Global Electrification Programme* started in 2006 with a public-private-partnership with ONE (national office of electricity), the incumbent distribution utility to establish ONE-PPP. They combined grid extension and off-grid electrification with a careful energy planning that includes GIS mapping of the non-electrified houses in 40 thousand villages. By lowering installation costs (it cut about 30% of infrastructure cost by reducing the height of poles or using post-mounted substations) it has been able to reach 96% of the population in the country.

In South Africa, between 1990 and 2007 the access has grown from 35% to 80%, mostly through grid extension incentives awarded to the single government-owned utility Eskom[170].

Another very interesting example comes from the West African Power Pool[171] (WAPP) initiative to promote grid extension from Ghana to Togo and Burkina Faso. The aim is to provide electricity for 42,500 people in Togo and 32,000 in Burkina Faso, mainly households but also companies, industries and social services. WAPP is an international organization established by African states that promotes this project in cooperation with government owned utilities in the countries of intervention (Electricity Company of Ghana, Volta River Authority in Ghana, Compagnie Energie Elecrtrique du Togo, Communaute Electrique du Benin and Societé Nationale d'Electricité du Burkina Fasso). The utilities fund 50% of this project sponsored by the European Commission in another 50%. The tariffs for the cross-border energy transfer are agreed between the partners, according to the national tariffs at each country. The customers pay no direct connection fee, as the service connection is paid for by the project budget. Since the connection is free, the beneficiaries have agreed not to claim compensation for the trees and crops damaged to make way to the distribution lines. It uses traditional meters, as pre-paid meters are considered too expensive. On top of the EC donation, also cross-subsidies are needed from peri-urban and urban areas so the public utilities break even, Slowly moving towards cost-recovery, the project is expected to be self-sustainable in the long run.

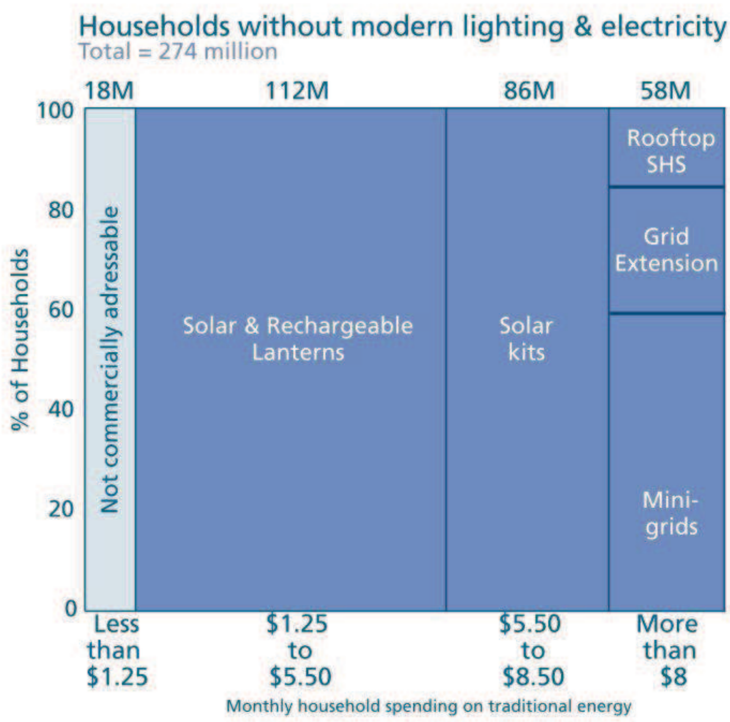
[169] IFC World Bank, 2012
[170] www.eskom.co.za
[171] Danish Energy Management, European Union Energy Initiative, & ACP-EU Energy Facility, 2007

6 Business model analysis

6.1 Market size

Figure 26 shows indicative commercial niches for the entire non-electrified world population. Each one of the technologies is analyzed according to the monthly expenditure on energy services affordable by the families/households.

FIGURE 26 - Global addressable market for Electrification according to the monthly household spending on traditional energies.



Source: IFC World Bank, 2012

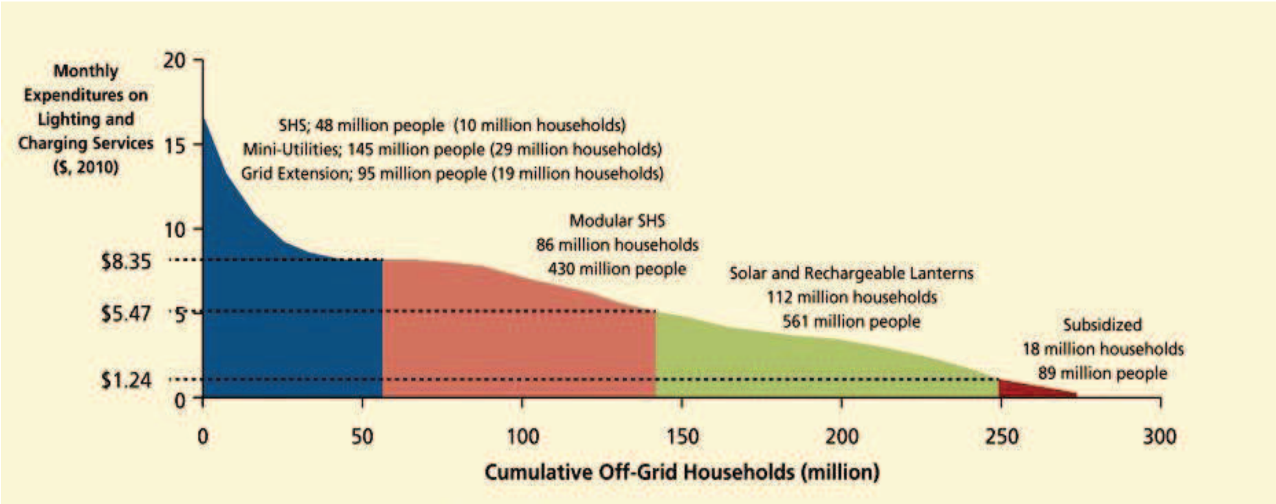
Out of a total of 274 million households without electricity the market commercially addressable (in 2010) would be:

- 58 million customers (around 290 million people) for advanced access, of which
- 10 million users (nearly 50 million people) could be served by Stand-Alone-Systems (or solar house systems - SHS), with a market around 1 billion US$ per year
- 29 million connections (145 million people) for Mini-grids, expending 4b$/year and$/
- 19 million connections (95 million people) for grid extension, 2b$/year.

- 86 million houses for solar kits (430 million people) for a market volume of 7b$/year.
- 112 million solar & rechargeable lanterns (560 million people), expending 4b$/year.

Finally, to reach the 18 million houses with the lowest income level, around 90 million people under the $1,25 line, commercial approaches would never suffice. Subsidies or other targeted actions should be made available to enable the business models required to service this last-mile and achieve Universal Access as will be discussed later.

FIGURE 27 - Addressable market for modern electricity services.



Source: IFC World Bank, 2012

This commercial market estimation does not consider that users may choose more advanced energy solutions despite their income level if there is additional support from governments, international programs, donors or other electricity customers (cross subsidies). On this regard it is important to notice that the authors base their calculations on levelized commercial costs (that includes capital costs plus a flat rate for operation and maintenance costs, all with an even distribution along the entire life of the product), simplifying the actual uneven distribution of costs (investment, fuel, maintenance, operation) through time and geography.

However, two important facts stand out from this analysis:

- if the actual expenditure of non-electrified households on traditional lighting and electricity (dry batteries and charging phones) is about $19 billion and the cost of equivalent electrification can be set to a similar figure (around $18 billion) the possibility of achieving basic electrification for all, including the nearly 90 billion poorest people, based on long term sustainable business models is real.
- Around 90% of the non-electrified population should be served with off-grid technologies. Together Solar Kits and Lanterns (SPLS) can supply affordable energy for more than one billion people in the Base of the Pyramid. Additionally, though some SHS

and Mini-grids might be connected to the grid, most of them will be built to operate in isolated mode. IEA estimations on this regard set the target for grid extension in all urban areas plus 30% of the rural population (40% of total un-electrified population), leaving off-grid solutions for 70% of the rural houses (60% of the total).

Despite the different estimations, it is clear that the bulk challenge lays in reaching isolated communities, mainly because of the specific approaches they require, demanding innovative business models out of the business as usual electrification toolkits.

Furthermore, based on the estimations by the International Energy Agency[172], the additional investment in universal access to electricity in the *Energy for All* case (compared to commitments of the *New Policies Scenario*) would amount to a total of $30,6 billion a year of additional investment, around 1.1% of the electrical tariffs in OECD countries. Paying for the up-front cost of electrification is possible, establishing the adequate mechanisms and mobilizing private sector funds, developing country utilities, government budgets, multilateral and bilateral grants and concessional loans.

One final consideration is to be aware of the fact that rural electrification programs, both in developed (several decades ago, already forgotten by most people) and developing countries, have been systematically subsidized, either by public budgets or by some sort of uplift by the already electrified consumers. It would be paradoxical that this almost universal principle might not apply to the poorest of the world.

6.2 Socio-economic and cultural context

SPLS provide very low-cost lighting, suitable for users with a very low income (may be combined with geographical isolation), either off-grid or for those who receive a very poor quality of service from the network and require some back up, or for portable uses of light such as mobile businesses. Therefore, we can find Small-and-Pico-Lighting-Systems both in urban and rural areas. They can serve users both within the range of expensive or weak and unreliable power networks, as well as off-grid population in isolated rural areas.

The main characteristic of this population without access (including here both people with no access at all and those receiving an insufficient service) is their low capacity of payment. A second feature of these users can be their need for very lightweight and portable lighting devices. This is the case of rechargeable lanterns used by students walking their way to their schools or by travelling peddlers lighting up their merchandises to extend their sales hours.

But this is also the case of population living in very remote areas who need reliable and durable devices easy to transport by themselves and that, if required, can be easily carried back to any supplier for spare parts or repairs.

[172] IEA, 2011

The next step of rural population without electricity falls into the range of Stand-Alone-Systems. The challenges of technologies for development within this context are described in depth by the study coordinated by Pérez-Arriaga and Moreno [173] and also portrayed by Izquierdo and Eisman[174] that have been detailed before in the introduction to this Working Paper. Most of their conclusions apply not only to SAS, but to SPLS and isolated Mini-grids but we want to emphasize here that the diversity of different isolated rural communities regarding their socio-cultural characteristics, economic and institutional structure, resources, education, traditions and habits determine the need of diverse business models adapted to these particular circumstances.

Regarding urban customers, we have seen above that the International Energy Agency considers their natural connection mode to be network extension. Grid electricity, being the most common electrification mode, is present in greater variety of social environments from urban and sub-urban neighborhoods to rural villages. Nonetheless, as we have seen along this Working Paper, many urban customers are now adopting newly arrived low-cost off-grid solutions, especially SPLS. This choice is usually driven by their low capacity of payment compared to supply costs of grid connection, and by the portability of these systems, but the other factors commented in the Introduction must also be taken into account, such as the prevalence of informal economy where users lack bank accounts, and even a proper legal status in their neighborhood. In many of the suburbs of great metropolis in developing countries, the lack of law enforcement and even minimum government presence hinders the possibility of establishing adequate network connection contracts. Thus, the use of simple and innovative pay-as-you-go SPLS or SAS emerges as a solution adapted to their basic needs, but as we have seen in the case of network extension, innovative approaches for these cases are also being put in place by utilities willing to provide access in these difficult locations.

Again, the main common concerns to be taken into account when approaching urban and rural communities for their transition from traditional to modern energy sources can be summarized as: adaptation to meaningful values and concepts of the local cultures[175], raising awareness, multifaceted impacts on poverty; lack of access to other basic infrastructures (running water, telecommunications, sanitation, health, education and cultural services), resilient community organization, political isolation and exclusion from the decision making process and low capacity of payment. Isolated communities add to this set the increased logistic costs of providing on-site services, equipment, fuel and replacements.

A very interesting perspective relates also to the complex socio-economic effects of rural electrification[176]. A significant growth in access to electricity fosters a considerable raise in female employment within five years. It also appears to increase the number of labor hours per day for men and women, increasing male earnings but reducing female wages. It releases women from home production and enables micro-enterprises, and evidence suggests that the migration behavior is also affected.

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[173] Arraiza & Conde Zurita, 2011; Izquierdo et al., 2011
[174] Izquierdo & Eisman, 2009
[175] Wilson et al., 2012
[176] Dinkelman, 2011

We must emphasize once more that it is required a wider perspective that considers electrification as a factor within a set of development issues to be addressed in order to achieve Universal Access targets, but that starts from a user-centric approach [177] that guarantees the *affordability, reliability* and *local embeddedness* of the business model and requires innovative business solutions that overcome the cultural barriers, in terms of distribution channels, customer relationships, risk aversion, raising awareness of customers and gaining their trust.

6.3 Energy uses and contribution to development targets

Electrification programs and planning is usually evaluated on their economic growth contribution and socio economic performance. Authors like Trevor Gaunt[178] point out that only a social approach (as described in 6.11.1) will allow universal access for population that has not enough capacity of payment to purchase electrification services. Considering the case of South Africa where the initial electrification was established to meet economic targets, with the later adoption of socio-economic goals and now targeting social objectives, the author evidences that usual assessment methods frequently result in the non-viability of rural and social urban electrification. According to the author, "*adopting a specification for social electrification allows suitable tariffs for electrification to be identified, indicates how capital investment decisions might be modified for social electrification, and identifies implications for electricity industry restructuring*" in developing countries.

As we have described in more detail in section 1.1, different electrification modes can provide suitable electricity solutions to the different tiers of service, as defined by the Sustainable Energy for All energy initiative[179]. In this section we are going to sum up the different types of energy services that can be obtained from different electrification options.

6.3.1 Residential uses

The main use of these technologies is domestic, as illumination has been their primary objective. They replace the use of kerosene, candles, batteries and diesel lighters.

Despite their limitations, SPLS systems satisfy most of the user requirements for lighting devices: affordability, portability, sufficient light intensity, safety, durability and long run time, easy maintenance, chargeable, easy to protect from theft, multi-purpose, familiar design and supplied by known brands[180].

[177] Schillebeeckx et al., 2012
[178] C.T. Gaunt, 2005
[179] ESMAP et al., 2013; Practical Action, 2010, 2012, 2013
[180] Lighting Africa, 2011

Family households with 1 to 4 rooms would benefit from clean lighting and phone charger using a single SPLS for a 4 to 6 hours service or a lower-end SAS for enhanced or continuous supply. This lighting allows the family to carry out nighttime activities as reading or studying, cooking or cleaning. Additional services available at this low end for SPLS and SAS would include cooling (air fans or small fridges) or even low consumption DC radio or high-efficiency TV.

The main advantages perceived by the new users are better lighting and lesser home pollution[181]. Solar lanterns are preferred for outside use and provide a weightless, safe and reliable source of light for moving around.

SAS can provide more advanced power solutions for home use, as refrigeration, individual water pumping or powering computers and home appliances. Mini-grids can by themselves cover all the range of applications from Tier 1 to Tier 5 and beyond.

FIGURE 28 - Stand-alone solar refrigerator.

Source: Energy Alternatives India. www.eai.in

[181] Eisman et al., 2013

6.3.2 Commercial uses

The range of applications starts with lighting provided by lanterns and solar kits for local and mobile micro-business, helping the users build a high share of the customer base of the business model, as shown by the Grameen Shakti experience[182]. They would also create opportunities for local entrepreneurs as retailers and providers of maintenance and charging stations.

FIGURE 29 - Commercial mobile SPLS.

Source: Grameen Shakti

More advanced applications, as cooling for conservation of food and drinks, can be provided by a new generation of stand-alone refrigeration PV equipment, as seen above, where a significant reduction of costs is being achieved by innovation in materials and batteries.

The main impact of these technologies for productive uses would be in the productivity gain coming from their combined use with information and communication technologies. Low cost mobile devices charged with SPLS would enable remote payments and banking, communications with customers and even use of modern management tools for microenterprises.

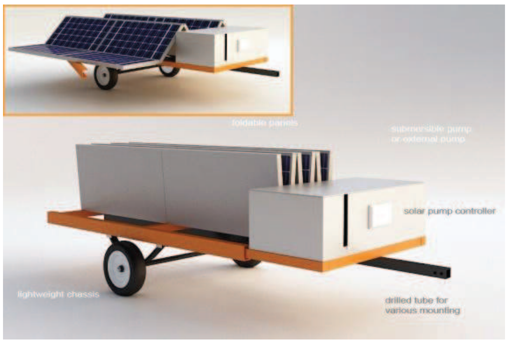
The use of micro-grids for village markets or more sophisticated shopping centers is also an important anchor for mini-utilities. Commerce is one of the sectors that gets more direct benefits from electric lighting. By extending their commercial hours after the normal working period of the population, they get a direct increment in their activity, also reflected later in the growth of their power demand as they start offering new services. Being able to address the need of commercial customers will help the mini-utilities reach a stable source of income with better growth rate than residential customers in the area, helping also the sustainability of the overall financial model.

[182] Wimmer, 2012

6.3.3 Industrial and productive uses

Emerging low-cost applications for productive uses in developing environments are becoming available, especially for isolated areas and even for SPLS. Uses of SPLS are very limited in the agricultural sector. Agro-processing transforms of products (milling, food processing, textiles, paper) require much higher amounts of power, mostly powered by SAS and mini-grids. SAS are used to power needed for pumping clear water for crops and livestock. Surface and gravity fed irrigation has low energy requirements and may benefit from small pumping at certain points of the system.

FIGURE 30 - Portable solar water pump with foldable panels.



Source: http://greenpeacechallenge.jovoto.com

Other low power appliances as small solar tools for crafting, low-power sewing machines, or even small rechargeable chainsaws can also increase the earnings of this population.

Small industries also tend to have higher energy needs, even in the BoP, as vehicle repairs, tailoring, woodwork, laundry, ironing, small manufacturing. When setting up electrification technologies for productive uses, it is very important to consider the demand growth in time, especially as electrification itself will be a factor for increasing the productivity. The system should also meet the main aspects required by enterprises regarding energy services: reliability, quality, affordability and adequacy of supply.

FIGURE 31 - Electric solar powered sewing machine.

Source: www.selco-india.com

6.3.4 Community uses

Energy services for community uses also start from SPLS. Health services can extend their labor hours and use portable lights for their visits to patients at home. Their main impact comes from lighting communitarian activities and from charging information and communication technologies in health (more than 1 billion people are served by health facilities without electricity most of them in South Asia), education, community meetings or street lighting.

FIGURE 32 - SPLS lanterns uses for health center

Source: http://inhabitat.com

From portable lighting to SAS powered refrigerators for vaccination campaigns and mini-grids and field hospitals, the applications and the potential for development of off-grid electricity systems are huge.

Regarding education, though optimal school lighting would require higher amounts of energy, isolated schools in remote and low-income regions are using Small-and-Pico-Lighting-Systems for lighting. Students use portable lanterns both for lighting their desks at school and in their way home. 66.000 isolated schools in Latin America are in the process of getting both electricity, communications and information technology services through the OEI program "Luces para Aprender"[183]. This program is carried out by a public-private-partnership promoted by the Organization of Ibero-American States with the participation of the governments of the beneficiary countries, private companies and technical support by Energy Without Borders Foundation. Its goals are to provide with lighting to enable the use of ICT for learning and information alphabetization, thus improving the availability of educative resources in remote regions, and reducing the digital divide.

Community lighting on streets can benefit from modularity and low cost of these systems, as much as government offices, police stations, leisure, sports, community, and religious buildings. Even the use of portable lanterns improves the opportunities for community organization.

[183] www.lucesparaaprender.org

FIGURE 33 - Street and community lighting by Philips

Source: www.philipsafricaroadshow.com

At the end of the electrification ladder, Micro and Mini-grids do not only provide power solutions to villages and house clusters. They have been used for long as a priori transitory power sources for emergency and humanitarian activities. Self sustaining field hospitals and refugee camps require a massive logistical effort that must be performed on a tight deadline, providing basic energy, water and sanitation infrastructure. Tons of equipment must be transported across long distances to an area with poor infrastructure. The traditional preference for turnkey solutions with redundant diesel generation trailers [184] is recently changing towards less fuel dependent hybrid power systems where solar panels, batteries, power conditioning and control electronics are integrated into a mobile package[185] in many cases designed first for military use. These solutions may also integrate gen-sets and wind turbines, providing scalable and flexible power to meet evolving missions of the end user.

6.4 Prices, tariffs and income

There is a whole range of prices, fees and tariffs for the different electrification modes and appliances, from low-cost solar lanterns to mini-grids for isolated extractive exploitations. There are three main challenges in the determination of adequate service fees.

- Cost analysis of service in the long term. In addition to the traditional determination of investment costs, operation and maintenance, reposition, commercial, capital or indirect costs, the risk for these kind of business requires a very careful consideration.

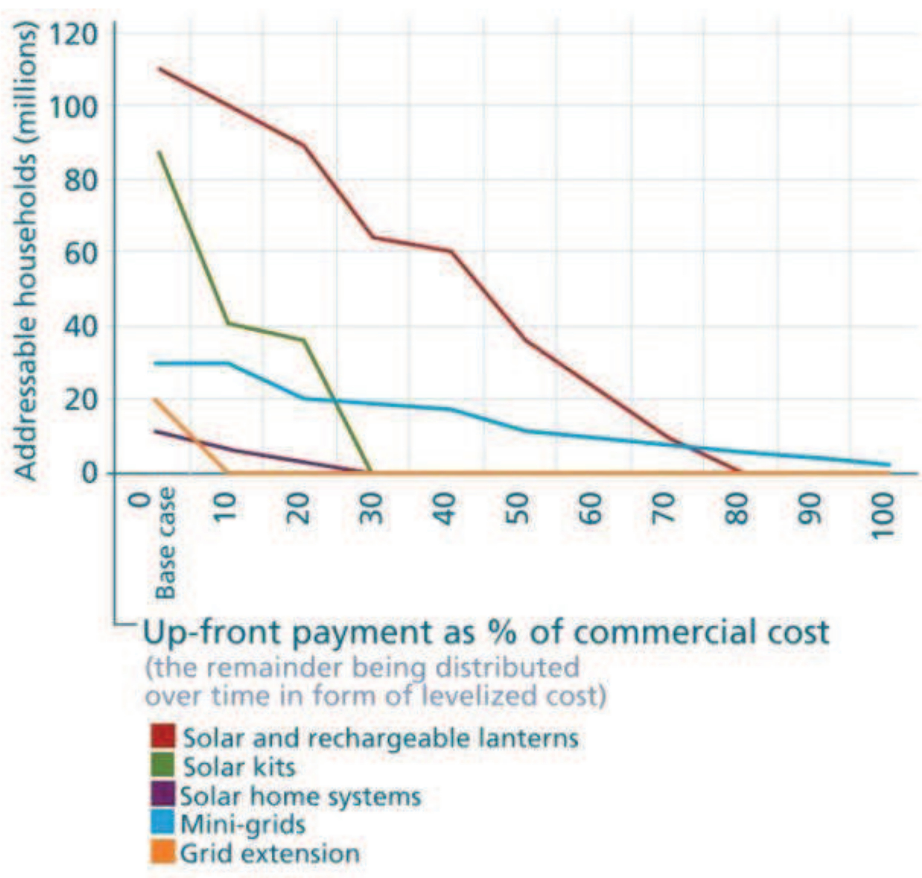
- Payment schedule. Sensitivity of customers towards up-front and connection costs is very high in the base of the pyramid.

[184] www.reevesems.com/userfiles/File/WhitePaper/White%20Paper-6_14_10.pdf
[185] www.raytheon.com/newsroom/technology_today/2011_i1/regenerator.html

- Capacity of payment and willingness to pay. They are based not only in the economical situation of the customer and surrounding community, but on customer awareness, expectations and on the value perception of the electricity service.

For the different electrification modes, customers are sensitive to the amount of up-front or connection costs to be paid, related to the monthly payments for the specific electricity service[186]. Figure 34 shows the different sensitivities for different technologies considering their potential market share and how it changes considering different amounts of up-front or connection costs. For instance, if we require a down payment of 20% for a solar lantern (costs from $20 to $50) our potential market will be reduced in a similar amount. For solar kits the sensitivity is drastic, since the first 10% halves the addressable market. SAS and Mini-grids follow a more steady path, but any down payment for grid extension infrastructure virtually eliminates it. To address this up-front payment sensitivity, companies are turning to fee-for-service, leasing and renting options, or sell their products through micro-credit mechanisms and other customer credits.

FIGURE 34 - Sensitivity of the addressable market to up-front cost.



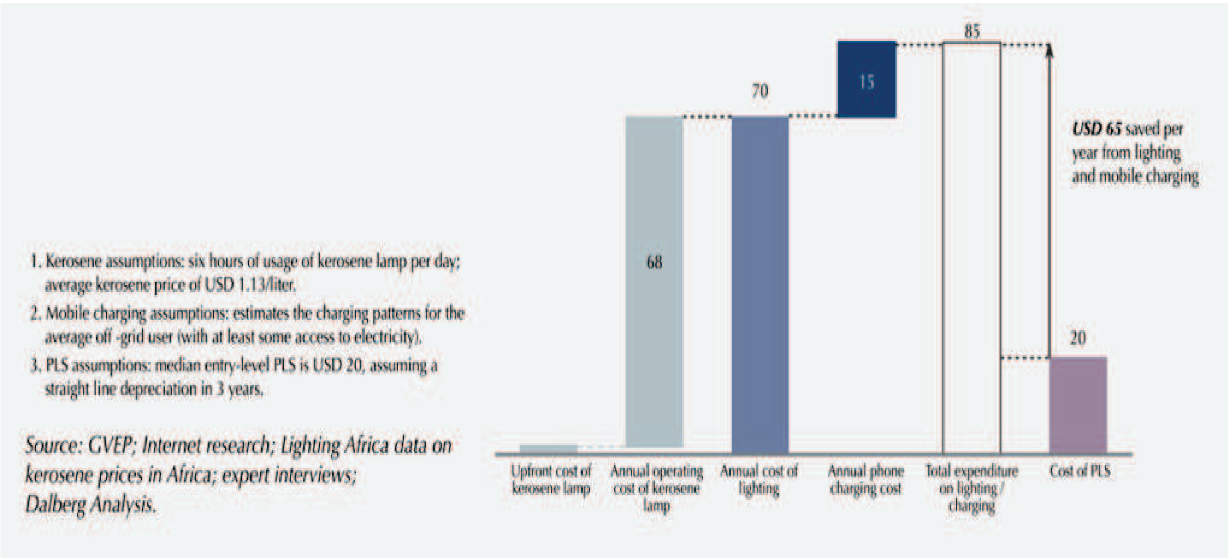
Source: IFC 2012

[186] IFC World Bank, 2012

The third difficulty any price or tariff strategy faces is understanding the capacity of payment and willingness to pay of final customers. This is especially challenging for users in the base of the pyramid.

The capacity of payment is obviously related with the income level of the families, but when the monthly cost of the electricity solution goes below the previous expenditure in traditional energy sources, the families are willing to purchase the system. Costs of these solutions may be cheaper than the traditional candle, diesel or kerosene lights, depending on the technology used and on the local fuel and battery costs, which in very remote regions can be very high. But the growth of the mobile phone markets in the BoP proves that poor people can find the way to pay for something they perceive as valuable. In fact, as stated later, there are suitable electricity solutions for different income levels that fall below the level of expenditure in traditional energies. For instance, Figure 35 shows the average annual household expenditure on kerosene and mobile charging compared to the expenditure in a pico-lighting-system in USD per year, showing savings over 75% with a solar lantern, and around 25% for a solar kit.

FIGURE 35 - Annual household expenditure on kerosene and mobile charging vs. expenditure on PLS



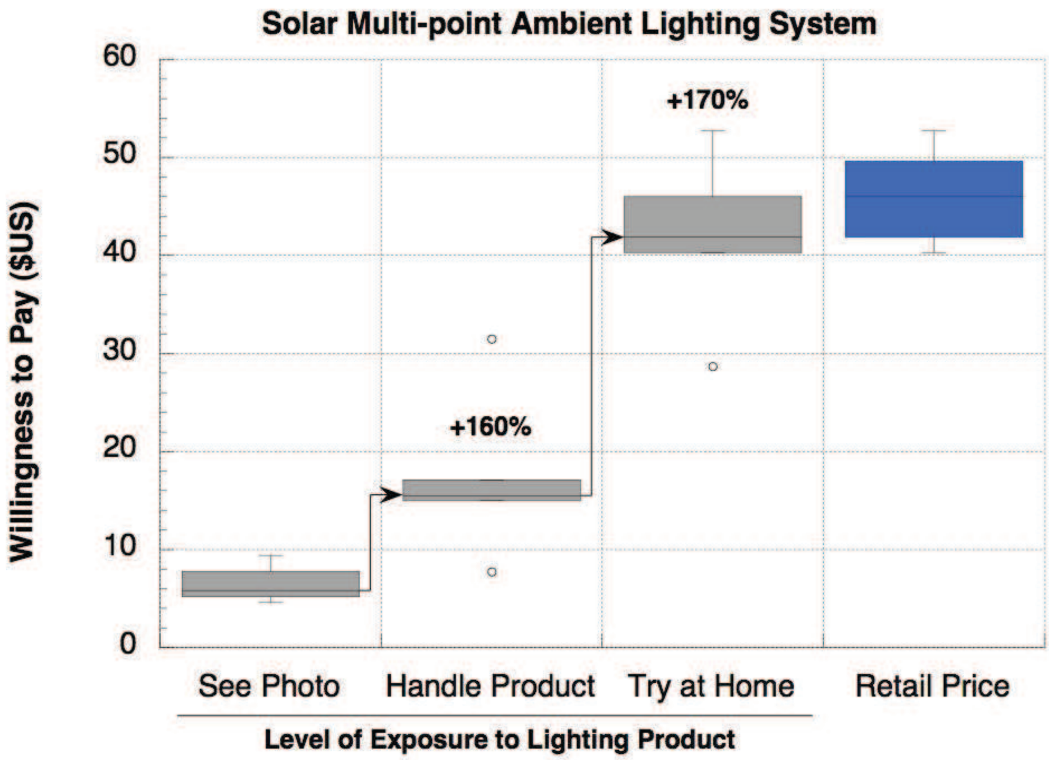
Source: IFC World Bank, 2012

As compared to capacity of payment, willingness to pay in regions un-familiar with electric devices depends heavily on the exposure to lighting products either through demonstrations or by the ear to mouth effect of early adopters[187]. Customer education, social recognition, product guarantees and familiarity, valued associated activities (as charging cell phones) also increase the value perceived by customers[188]. These markets are skeptical of the benefits of new technology they fail to understand, so a successful entry in the market requires good quality

[187] Lighting Africa, 2011; Wimmer, 2012
[188] IFC World Bank, 2012

products and a close perception of product value, which may bring up the willingness to pay to a similar level compared to the retail price.

FIGURE 36 - Evolution of potential buyers' willingness to pay for a solar multi-point ambient lighting system at different levels of exposure

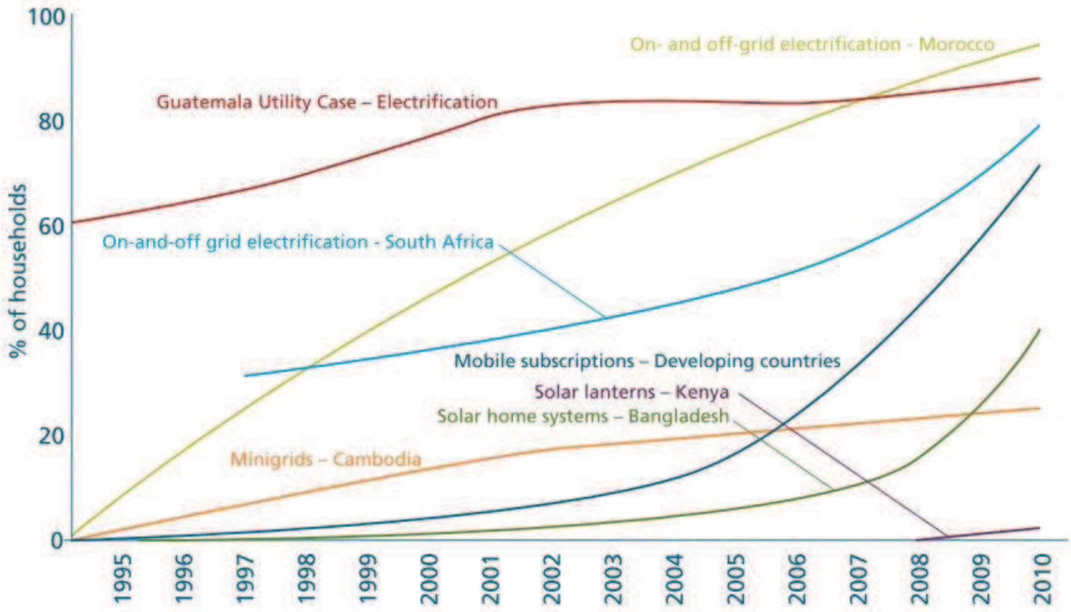


Source: Lighting Africa, 2011

The difference between addressable market and actual market growth in the base of the pyramid is virtually impossible to assess, given the complex drivers involved. Nonetheless, though the growth of access to mobile phones cannot be taken as a benchmark for electricity services, it shows that isolated areas and low-income customers can be served even through capital intensive infrastructures.

The following figure shows the growth of different electrification experiences as compared to mobile subscriptions in developing countries.

FIGURE 37 - Penetration rates of energy and mobile phone services in developing markets



Source: IFC World Bank, 2012

As for the payment methods, the following approaches are found in different business models:

- Pay as you go: The high up-front cost of SPLS and small SAS purchased on a turnkey basis, compared with the monthly capacity of payment of the targeted population in the Base of the Pyramid requires micro-financing these payments in micro-credits for the final users.

- Renting or leasing of equipment, especially for those that need recharging in a service center because they lack a power source, defers the customer payments in terms of hourly, daily or monthly fees for service. The need for credit is transferred from the users to the intermediaries, who need to defer the investment costs of the service center and charging stations.

- Fee-for-service: Some business cases report that this is becoming the most popular choice by customers, as the user pays for the electricity service received.

Payment and commercial credit schemes that take into account periodicity of income (mainly in rural agricultural areas) also help the adoption of service by low-income customers.

6.5 Distribution

Reaching these BoP customers, either because of their geographical isolation – if this is the case – or their social or economic marginalization, requires a set of different approaches depending on the characteristics of the market, distribution costs, transport and service times, population dispersion, customer heterogeneity and user skepticism.

As we have seen from the different examples of business models for each electrification mode, different technologies result in very different approaches for serving the markets. The diffusion of new technologies typically starts in urban areas and then they reach rural customers[189]. In this case many of the technologies are especially designed for isolated rural areas, so specific efforts must be devoted to reach and adapt existing distribution channels (strategy usually adopted by brand builders as mentioned before, through franchises or partnerships), or create new ones. Small international independent actors find this more difficult to achieve, and usually partner with social organizations with a wide base of associates or beneficiaries in order to spread their products. For a detailed description of these models, please see sections 2.3.1, 3.3.1 and *Small, decentralized* in 4.3.1.

Lightning Africa analyzes distribution channels for SPLS according to the relationship with manufacturers to reach BoP customers:

TABLE 15 - Overview of different distribution channels and relationships between manufacturers, retailers and distributors

Distribution model	Product range	Distributor gross margin	PLS marketing	PLS distribution / logistics	PLS last-mile sales and after sales support
Distributor-dealer network	Broad range of complimentary, competitive and sometimes unrelated products	10-40%	Materials: distributor Cost: last-mile dealer	Logistics: distributor Cost: distributor	• Final sales: handled by dealer • Product financing: informal after-sales support: distributor
Own distribution / direct-to-consumer	Exclusive to company	20-50%	Materials: distributor Cost: distributor	Logistics: distibutor Cost: distributor	• Final sales: handled by sales team • Product financing: rarely formalized • After-sales support: sales team
Institutional partnership (e.g., with MFI, SACCO, NGO)	Typically exclusive or limited to other value-added products	10-30%	Materials: distributor Cost: shared	Logistics: distributor Cost: distributor only or shared	• Final sales: handled by partner • Product financing: if partner is a financing institution (MFI SHG network, etc); rental/ charging kiosk model is optional • After-sales support: partner
Franchise	Exclusive to distributor/ manufacturer	10-30%	Materials: distributor Cost: shared with franchisee	Logistics: distributor Cost: shared with franchisee	• Final sales: handled by franchisee • Product financing: rarely formalized • After-sales support: franchisee
Rental /leasing system to micro-entrepreneurs	Typically exclusive or limited to other value-added products	10-30%	Materials: distributor Cost: shared with leaser	Logistics: distributor Cost: shared with leaser	• Final sales: handled by leaser • Product financing: rental model enables small cash payments • After-sales support: leaser

Source: Lighting Africa, 2013

[189] IFC World Bank, 2012

6.6 After-sales, operation and maintenance

After sales service is especially important for low-income customers, given the fragility of these markets. Market spoilage due to low-quality products and lack of maintenance has been addressed before in this Working Paper. Offering after-sales guarantees through service agreements or maintenance contracts helps overcome hesitation from poor customers[190].

The present stage of the electricity market in the base of the pyramid limits the capability of the agents to provide cost-effective after-sales services. Manufacturers and other agents are becoming increasingly engaged in after-sales activities involving repairs and replacement based on warranty agreements.

Operation and maintenance must be guaranteed along the whole life of the systems[191], in order to guarantee the sustainability of the electrification goal. These operations must be performed at local level, so continuous on-site service must be guaranteed. To do so, training of local technicians, either hired as utility personnel, sub-contracted or through a franchise formula, becomes a necessity for the sustainability of these business models.

O&M costs can be very significant, and reach up to 100% of the investment costs of lighting systems in isolated and remote areas (more if cost of fuel transport is considered). Thus, cost-cutting these activities becomes a priority for electrification business models.

Repairs and maintenance: Basic maintenance of this equipment can be performed by the users themselves, but this requires an specific training that should be given according to the needs and capacities of these users. Good practices[192] involve also training individuals of the electrified communities as technicians for O&M services (either on behalf of the equipment suppliers or independently) thus lowering the cost derived from assisting population in remote and isolated areas.

Replacement: Customers may receive on-site service or take light-weight faulty products to their service centers for full or partial replacement of the electric system. Companies are providing replacements either based on warranty or after-sales agreements. After-sales agreements are established for off-warranty equipment, if required by the users, as the life of the system usually exceeds the warranty period by the manufacturers.

This method is cheaper than deploying a network of technicians for maintenance, and allows electrification of isolated areas out of reach of the service centers. For SPLS, transport is usually managed by users on their own, but organized means for sending and retrieving faulty equipment are also in place.

[190] IFC World Bank, 2012
[191] Izquierdo & Eisman, 2009
[192] González-García, Montes Ponce de León, & Pérez-Arriaga, 2009

6.7 Capacitation and awareness rising

New users of electricity systems are often unaware of their rights as customers, both regarding tariffs or purchase of equipment and warranty. "This leads them to simply write off faulty product as a bad investment without seeking repair or maintenance services"[193]. In fact, most of the complaints do not report faulty systems, but arise from difficulties in using the equipment.

At an initial stage awareness raising, demonstrations, prescription by famous or popular individuals in the community, or even head teachers in schools as we have described above is critical for breaking the cultural barrier between traditional technologies and modern electrification systems. For centralized systems and micro-grids, the awareness campaigns must promote the achievement of community interest and consensus, usually involving the local and regional authorities.

Training and awareness rising are a constant across all the business models examined in section 2. Training of users, sales force, technicians, intermediaries and micro-entrepreneurs requires a huge effort focused on the appropriation of the necessary knowledge for the long-term sustainability of each business model.

6.8 Synergies and competition

The main synergies of electric energy systems come from the obvious connection with the mobile industry because of the need of charging the batteries of the cell phones. This synergy works in a double way. Mobile industry needs the development of electricity services in the base of the pyramid in order for their devices to work, so they will be interested in helping the scale up of this market. On this regard, dealers and franchises might be interested in a combined business model, providing both energy and phone services.

On the other hand, telecom towers will provide a steady anchor consumer that facilitates electrification in isolated areas, as has been further explained in section 4 devoted to isolated Micro-grids.

6.9 Scalability and replicability

Scaling up delivery models from hundreds to thousands and millions of customers, required to achieve Universal Access, is a major issue that the most successful initiatives shall have to deal with. For Grameen Shakti[194] the main challenges of scalability are:

[193] Lighting Africa, 2013
[194] Wimmer, 2012

- Personnel: Multiplying the staff to cover sales, operation and maintenance for millions of users in the BoP requires tens of thousands of technicians, given the close nature of this market (Grameen Shakti proposes a ratio of one hundred lighting systems per technician). The creation of these jobs is in fact very positive for the development of the region.

- Capacitation: Universal access needs the successful training of users, local technicians, micro-financers, entrepreneurs and, in general, of all the work force needed for the expansion and provision of the energy services. Large training initiatives, scholarship programs involvement of the community and of specialized institutions will be required.

- Capital: Small-and-Pico-Lighting-Systems are usually bought on credit, as some SAS. But mini-utilities setting mini-grids or servicing large numbers of SAS require large investments in equipment and operative capacity. The capital required to scale up credit needs also to be multiplied. The sources and uses of this capital, as further discussed in 7.2, to the scale needed for Universal Access require a national plan that involves the effective cooperation of the government, financial corporations, international institutions, aid agencies, financial intermediaries and the participation of the local communities.

- Expansion and diversification of supply: Not only technology availability might be a bottleneck for large electrification programs, but also dependency from scarce international supply sources. For instance, Grameen Technology Centers have evolved into manufacturing hubs, providing decentralized production for accessories, PV panels assembling, and other technical services.

- Synergies: Electrification must be accompanied by other development activities, especially supporting community and productive uses of electricity. In the case of Grameen, synergies with telecommunications and micro-financing and even commercial activities come directly from the interrelation with other corporate branches as Grameen Phone, Grameen Shakti or Grameen Danon.

Scalability of electricity supply with off-grid technologies may benefit from the actual success of distributed business models, where multiple and more diverse agents can enter the market with fewer entry barriers (lower economies of scale) as compared to the other electrification approaches with more demanding infrastructural needs.

The second key issue is replicability of successful business models. But replication of positive experiences can be problematic[195], because what succeeds in some countries may well suffer problems in others. Barnes even concludes that the business model design might not be the critical element in successful rural electrification, as the model is part of the social, cultural, economic and political fabric of a society. Successful private initiative can bring remarkable benefits in some countries[196] but the perception that it would lift the burden of electrification

[195] Barnes, 2007
[196] Barnes, 2007; Besant-Jones, 2006

from governments has not proved to be true either[197]. So, as also stated before, a complex assessment of public, private and social factors is needed to successfully replicate any given experience in different contexts.

6.10 Long term sustainability

A successful business model guarantees the sustainability of the electrification service for as long as required by the users, which in the case of SPLS ends by the transition to other electrification modes up the electrification ladder as shown in 6.11. Sustainability must be considered along the three pillars: economic, socio-cultural and environmental.

6.10.1 Economic

The long term economic sustainability[198] of a business model results from the interaction of different complex socio cultural factors (awareness raising, training, community involvement), need of support services and an enabling environment (stable, light and suitable regulation for energy services and energy resources, subsidies and innovative financial instruments, development and energy planning), together with a sound and innovative energy delivery model (product quality, price compared to traditional alternatives, value proposition, cost structure, revenue streams, partnerships), so to overcome specific existing market barriers to starting and scaling up operations. In summary, with subsidies or not (most likely yes, for deployment of the initial infrastructure for intermediate to high tiers, at least) there has to be business for a private investor.

Low-cost electrification technologies are closer to the capacity of payment of the users in the base of the pyramid, but the availability of grants, subsidies or financial guarantees from the government or international donors helps hedging the market risk that agents assume servicing this emerging market in the base of the pyramid.

6.10.2 Socio-cultural

One of the main obstacles[199] to players in energy access is market spoilage and regression to kerosene-based technologies because of a faulty initial experience with solar lighting. Poor performance and short life of some solutions feed the skepticism of users towards the energy transition to modern lighting. Providing adequate equipment and quality of service from the early stages is especially important to overcome cultural prejudices. The main marketing channel in the BoP is mouth to ear, so a faulty entrance will easily lead to market spoilage.

[197] Barnes, 2007; Eberhard & Tenenbaum, 2005
[198] Wilson et al., 2012
[199] Lighting Africa, 2013

Good practices show the importance of increasing the level of awareness of customers as to distinguish between quality and non-quality systems.

6.10.3 Environmental

The main environmental problem caused by traditional energies is related to black carbon in-house pollution, which results in 15 million premature deaths per year. The value proposition of these business models includes the transition from traditional fuel based energies into renewable electric technologies, with the associated reduction in not only carbon emissions, but also in-house pollution. This reduction results in immediate and direct improvements in the healthy environment of the customers, significantly reducing their risk of respiratory illness. Other benefits come from forest protection and improvements in agricultural technologies.

6.11 Upgradability

One of the main decisions for electrification planning, not only network extension but also for off-grid electrification modes, is deciding whether to implement access according to the actual needs and capacity of payment of the customers to be connected (selective electrification), or to prepare the planning for all the potential customers and load growth expected in the area (blanket approach)[200].

In grid extension, the cost of upgrading the capacity of transmission lines overlaps or is lower than the typical cost of new construction[201]. Therefore a conservative approach for sizing distribution capacity would be advisable, either if the incumbent follows a blanket approach to address a minimum access level for all the population, or a selective electrification for users with a minimum consumption level.

6.11.1 Blanket or area electrification approach

The advantages of the blanket approach are "that no-one is without electricity, that the supply authority can plan on a long-term rather than an ad hoc basis, and that no cumbersome quoting or payment procedures are involved (as for example in the case of a new consumer on a line paid for by someone else)"[202].

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[200] Charles Trevor Gaunt, 2003
[201] Baldick & O'Neill, 2009
[202] Dingley, 1988

The blanket approach is usually associated to a political logic frame for social electrification, that according to Gaunt[203] presents the following characteristics:

- Impact focus is on poverty alleviation and on the political demonstration of service delivery benefits as education lighting or less indoor pollution.
- Targets are basic use of electricity for all households (including poor customers), environmental improvement, adequate quality and social performance.
- Government intends sustainability of the business models, cost of service retribution within budget with a minimum capital investment and subsidies.
- Blanket electrification requires later specific planning and budget allocation for any reinforcements or upgrading of the systems.

6.11.2 Selective electrification

This alternative approach is described in three phases: connection, densification and reinforcement. Lower costs and commercial approach allow small positive financial returns and higher sustainability, but poor households are electrified last (or not at all) and it is needed to continuous revisit areas to identify population that is excluded from the electricity service.

Selective electrification approach is associated to a political logic frame for socio-economic electrification[204]:

- Impact focus is on improved regional economy and quality of life for households in modern energy economy.
- Targets are lower supply energy costs, stimulation of business development and increasing economic activities so health and education also improve.
- Government intends cost reflective tariffs based on economic viability and acceptable fees by residential, commercial, productive and community customers.

Selective electrification also allows better revenue allocation and efficiency of the system, allowing progressive upgrades as the demands grows, and can also benefit from targeted subsidies for low-income population that enable the achievement of universal access.

[203] Charles Trevor Gaunt, 2003
[204] Charles Trevor Gaunt, 2003

6.12 Electrification mode evolution

Small-and-Pico-Lighting-Systems are suitable for the lowest step in the energy ladder towards modern energy services. They serve not only as a first stage for most of non-electrified population, and they also service users that are connected to weak unreliable networks and need small portable backup or complementary systems.

The average user of this equipment will complete their whole payment in less than 4 years, though the useful life may be several times that period. The arrival of new more powerful electrification modes will allow resale of this very light and portable equipment to new users, or also its recycling into other uses for the same customer, again as backup or ancillary services.

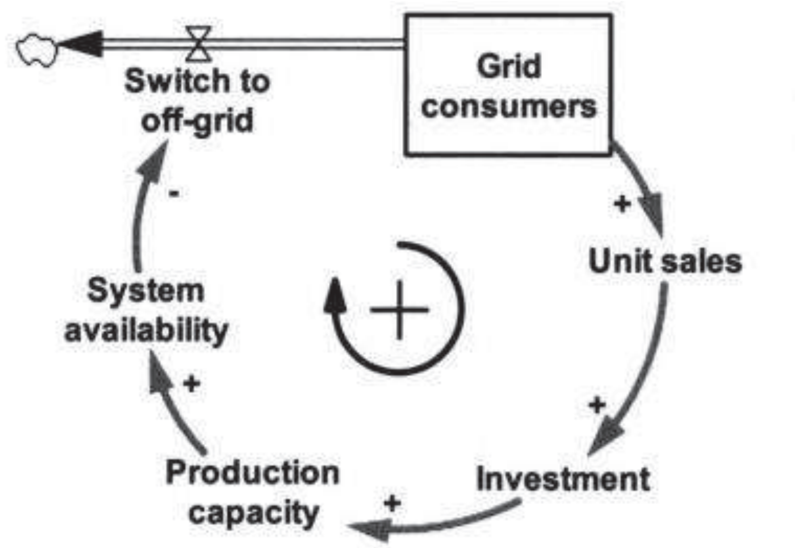
Off-grid isolated population can evolve into Stand-Alone-Systems or Mini-Grids from SPLS as their demand for energy services grows, as well as their capacity of payment. Most of SAS technologies and almost every mini-grids allow a modular approach that enables the installation of more generation and storage capacity as the requirements grow. We have seen also that these systems can be connected to the network but disinvestment strategies for companies should be anticipated in the event of arrival of the network.

As for network extension, it is important to emphasize here, as it has also been done before in other sections of this Working Paper, that grid service is sometimes not the final stage of the electrification history of a community. Involution to other stages can happen, caused by market spoilage because of low quality, intermittent or inadequate power service. Usually most of the switches happen between both grid extension modalities included in this section: network supply and connected Micro-grids (that can address the intermittencies and capacity deficiencies of the grid).

There are cases where network quality, capacity and costs are completely inadequate, therefore when users can afford a suitable independent supply for their own activities, residential communities, schools, hospitals or productive facilities, they may even choose to completely disconnect their Mini-grid from the power network (thus also avoiding any connection fees associated).

Involution to Stand-Alone-Systems or even Pico and Small Solar Systems may also happen for similar reasons, and when these are much cheaper alternatives than grid supply. Deaton-Steel has analyzed the dynamic of grid-based electrification compared to off-grid choices in Kenya, identifying capacity constraints, unreliability and load shedding as shown in Figure 38.

FIGURE 38 - Reinforcing feedback from customers to system availability



Source: Deaton-Steel, 2008

7 Enabling environment

"*When innovative companies, frontier financiers and enlightened policy makers come together, business can play an important role in helping to close the energy access gap.*"

IFC World Bank, 2012

According to the WB strategy for energy, the success of energy business models requires the articulation of an enabling environment that includes a stable and appropriate energy policy, regulation and government framework, effective financial instruments and adequate funding mechanisms, and a coherent alignment with international policies and scenarios[205]. Together with this institutional framework, universal access to modern energy services requires significant innovation at different levels of the value chain.

7.1 Energy policy, regulation and governance

7.1.1 Energy policy, regulation and planning

The first question we should address is: why regulate? why shall the government establish a specific institutional framework for universal access to electricity?

"*The traditional justification for any kind of economic regulation is to protect consumers against monopoly abuse*"[206]. On-grid power supply is a natural monopoly that has been regulated by governments using different means in the past.

Additionally, access to modern forms of energy should be a constitutional right, making the government responsible for the fulfillment of this right[207]. To achieve this goal, a specific financial, institutional and technological framework is required[208] to scale up access, setting the ground for successful involvement of private companies and other actors, as mentioned in many of the successful business cases included in this Working Paper.

The regulatory framework required for the electrification of isolated rural areas is highly dependent on the country and the different regions within it. Countries have succeeded in their electrification efforts using diverse institutional approaches including different technical, economic and financial designs[209]. The variety of approaches for successful electrification has also been shown in this WP.

[205] World Bank, 2009
[206] Reiche et al., 2006
[207] Dietrich, López-Peña, & Linares, 2011
[208] IEA, 2010
[209] World Bank, 2010

A successful regulatory and governance framework for grid extension and off-grid electrification in a given country can only be achieved by applying different key lessons learned from other success stories, but including the necessary adaptations and innovations required for a specific setting. For the WB a key element is the "*definition and enforcement of an institutional framework consistent with the country's strengths and the nature of the problems faced, so as to use the limited resources in an efficient manner*".

The components of the agenda for energy system planning for developing countries could be[210]:

- Consideration of traditional energy services, including in informal sector activities.
- Attention to the whole transition process, in its energy and social dimensions, from traditional to modern energy and traditional to modern economies and societies. For instance urbanization processes also manifest in the form of migration, increased demand for employment in the modern sector, increased consumption pattern and rising energy intensity.
- Characterization of rural-urban divide, and consumers by income groups and spatial distribution for a clearer understanding of energy sector developments and planning of network extension as well as off-grid electrification, including supply modes.
- Focus on structural changes and competition in the emerging markets and the uncertain and changing patterns of business environment.
- Careful analysis of technological changes and technology diffusion and capturing uncertainties about long-term economic growth in the future.

One has to acknowledge that this list may be considered as an ideal target and that, in reality, all of these factors are only implicitly accounted for by the system planner or the politician in the best of all cases.

The application of these principles to the regulatory framework requires a series of tasks by the regulator on the different policy topics that are shown in Table 16.

[210] Bhattacharyya & Timilsina, 2010

TABLE 16 - Regulation and Policy for Grid and Off-Grid electrification

	FUNCTIONS			
	REGULATION		POLICY	
TASKS	Price regulation	Service quality regulation	New Connections	Subsidies
Gather information and data	• Get information on current and projected tariff revenues and costs. • Get information on willingness-to-pay for alternative service levels.	• Obtain information on current service levels. • Carry out technical studies on the feasibility and cost of different service standards (technical and commercial).	• Gather information on existing coverage. • Define the meaning of new connections.	• Determine the magnitude of subsidy funds that will be available. • Decide which communities and/or entities will have priority to limited subsidy funds.
Establish rules	• Set tariff levels and structures in the absence of competition, with provisions to link some parameters to inflation. • Establish procedures for adjusting tariffs for unexpected events or at the end of a specified tariff period.	• Define quality standards for different types of technologies and providers and for different customer categories. • Specify the date by which standards must be achieved. • Specify penalties for failure to achieve standards. • Determine how compliance will be measured and monitored. • Specify events that excuse compliance.	• Establish connection targets. • Specify the dates by which connection targets must be achieved. • Determine how compliance will be measured and monitored. • Specify events that excuse compliance.	• Decide on the levels of capital and operating cost subsidies for eligible entities. • Decide on how and when the subsidies will be disbursed. • Decide on the actions (for example, connections, maintenance visits) that will trigger disbursement.
Monitor the implementation of existing rules	• Audit financial accounts, if necessary or feasible. • Ensure that tariffs comply with rules.	• Monitor service to ensure that mandated levels of service quality are being achieved.	• Monitor connections to ensure that connection targets are met.	• Monitor performance to verify that recipient has performed the actions that qualify for subsidies.
Enforce decisions	Enforce decisions • Define tariff adjustments on basis of performance. • Apply sanctions if tariff rules are violated.	Enforce decisions • Apply sanctions if the operator has failed to achieve the standards. • Specify events that excuse compliance.	Enforce decisions • Apply sanctions if the operator fails to meet coverage targets. • Specify events that excuse compliance.	Enforce decisions • Withhold subsidies for nonperformance, or apply penalty or refund requirements.

Source: Reiche et al., 2006

The subsequent question would be who should perform the regulation?[211] "Although it may be legally necessary for the national or regional regulatory to have final formal responsibility over all entities within a country that provide electrical services to consumers, it does not logically follow that the regulator should be required to perform all the tasks". The authors propose the delegation or contracting out of traditional regulatory functions to entities that provide the off-grid service, or even "not to regulate at all" when the law enables actors to perform their duties instead of prescribing the actions. In any case they specify that delegation is especially desirable with a functioning rural electrification agency or rural electrification fund.

[211] Reiche et al., 2006

Some kind of regulation will always be required (at least an "enabling" one) especially when the actors must receive subsidies to provide a sustainable long term supply, and also to avoid malpractices and guarantee electricity as a public right.

As seen along this Working Paper, the different electrification modes allow the establishment of different types of business models, whereas some of them are more likely to develop natural oligopolistic structures that increase the risk of market power abuse. This is particularly the case of Micro-grids, where mini-utilities operate and own both the generation and the network which grant them a de-facto monopoly because, once installed, it is very difficult for any other agent to enter the same system and offer its services.

In these cases the establishment of a regulatory control is needed. Some countries in Africa and India have set controls to manage customer claims against abusive prices charged by the mini-utilities. When a minimum share of users files a claim, the regulator launches an inspection to determine if any kind of market power abuse is taking place. Another more sophisticated approach implies that Micro-grid owners should allow the connection to their network of any new agent that intends to provide power services to the connected customers.

When lacking a higher law for rural electrification, the electrification agency or fund would be a *de facto* regulator, because of the conditions and requirements imposed to the agents as quid pro quo for receiving subsidies, but it is always desirable to convert the *de facto* regulator to a *de jure* regulator because they will have closer, better knowledge and appreciation of the technical conditions, cost implications, socioeconomic specificities of the communities, coordination of off-grid subsidies and tariffs, and avoid duplicity and overregulation in comparison to having a single regulator for the power system. For the regulatory reforms of the energy sector in Africa[212], many countries established independent off-grid agencies and funds where regulators contract-off traditional regulatory services.

Encouraged by international initiatives and donor agencies, many countries are nowadays integrating explicitly off-grid solutions as a complement to grid extension in their electrification planning policies[213].

Promotion of SPLS is a suitable alternative for very poor and very isolated population. The first energy policy goal should be to provide the whole population of the country with access to modern energy services as a right. As we have already seen, in countries with large low-income or isolated population, the use of Small-and-Pico-Lighting-Systems would be suitable as a first step towards this goal, thus enabling the realistic and affordable assumption towards universal access commitments by the policymakers, but keeping in mind that the contribution of these systems to development is limited, and universal access should finally reach an enabling level of service for raising the standard of living and improved quality of life that modern energy access can get[214].

[212] Eberhard & Tenenbaum, 2005
[213] Eisman et al., 2013; Eisman, 2011; González-García et al., 2013; Lighting Africa, 2013
[214] Brazilian & Pielke, 2013

Countries should be able to determine the suitable access level for all their population, where all the electrification modes should be integrated in the national energy roadmap as different options for this low-income population, from grid extension to Mini-grids, Stand-Alone Systems and Small-and-Pico-Lighting-Systems, thus establishing the optimum strategy towards universal access combining all the existing options.

7.1.2 Regulatory barriers and measures

It is important to highlight that these models require government regulation, and in many cases direct support. The role of the government is not only natural but still key in these cases[215], where the magnitude of the challenge requires different roles from funding and executing rural electrification to promote co-investments with the private sector.

Quality of service standards

Quality of electricity service in poor households is also of the essence. We have already seen that market spoilage because of frustrated expectations is one of the main obstacles to universal energy access. Codes, standards and certification are important elements to address poor quality products, poor installations and maintenance, or poor service[216] and to reduce risks both for the users and the companies.

On this regard, definition of adequate off-grid quality-of-service standards, as well as adapting grid extension standards to low costs technologies is a basic requirement for universal access.

[215] NRECA International, 2001
[216] Martinot & Reiche, 2000

Table 17 - Quality of service standards for solar home systems in Bolivia IDTR programmed

	STANDARD	PENALTY OR INCENTIVE
PRODUCT QUALITY	• Components and system must meet technical input specifications. For instance, PV module output must be at least 90% of name plate. • Standards are measured (a) for the prototype of each system size and (b) in random in situ samples.	Operator needs to fix or exchange all systems that do not meet minimum requirements, and pay a penalty to the user.
SERVICE QUALITY	• Minimum energy (defined as Ah at given voltage level) provided by the system must meet minimum specified for each system size. This translates into minimum hours of appliance use. • Must make the mandated annual visit to customers during years 1–4, including user training.	17% of total subsidies will be paid (a) upon completion of each of the 4 visits (3% per visit) and (b) in a final payment upon satisfactory service up to year 4 (5%).
COMMERCIAL QUALITY	Must respond within 30 days to a request for new service.	Will be fined US$2 for each day of delay.
	Must respond to customer complaints within 10 days if reachable by road and 15 days if not reachable by road.	Will be fined the number of days without service times the equivalent daily tariff times a penalty factor (about one US$1 per day). No penalty if it was the customer's fault; customer pays visit.
	Must employ one local technician with spare parts for every 300 users.	Payment of subsidies will require the establishment and training of independent and certified local technicians with spare part shops.
	Source: IDTR 2004.	

Source: Reiche et al., 2006

For instance[217], electrification by isolated Mini-grids sets flexible connection criteria and low standard quality in many cases where Mini-grids and Stand-Alone Systems are installed spontaneously outside any regulatory or service framework, according to particular interests. On the other hand it is also damaging to enforce an unachievable quality of service. The equilibrium is always a source of conflicts that must be addressed:

- quality of service issues that are important for the clients must be regulated, controlled and measurable with a reasonable cost;
- quality of service does not need to be uniform through all client categories;

[217] Reiche et al., 2006

- commercial and technical quality must be measured and standardized. Cost of lack of quality must be established proportionally to the penalties that can be imposed on the concessions;
- the total cost of penalties should not weight more than 2% to 4% of the supplier turnover.

Particularly, implementation of quality of service standards for off-grid rural electrification depends critically on the determination of the responsibility of the failure of the system. If the customer is responsible, then no penalty is due. When the electrification assets are sited at the customer's premises it is difficult to determine whether the problems are because of misuse or wrong operation or maintenance by the consumer, or because of lack of service or faulty equipment provided by the retailer.

Reiche et al. show that three alternatives can be considered. For Micro-grids the generation, batteries and other sensible parts can be installed out of reach of the consumers, but then metering and power regulation technical issues arise. Another option both for Micro-grids and SAS is to assign the ownership of batteries to the consumers themselves, who will then be responsible for their proper maintenance and replacement in case of failure. A third option would be to set incentives for good operation and maintenance of the system, as bonus programs.

As explained before, especially for the case of Small-and-Pico-Lighting-Systems, one of the main reasons for market spoilage comes from poor quality non-tested products[218]. On top of any manufacturers standards and labeling policy, governments may help in sending the customers a clear signal on quality, durability and performance by establishing national standards and control programs[219].

Lighting Africa proposes a 5-step product quality program to support market development, provide technical assistance to companies and represent the interests of low-income costumers:

- standardized product testing method;
- product verification enforcement;
- test laboratory capacity building;
- technical advisory services for innovation according to the needs and expectations of the users;
- outstanding product awards to further support improvements in products and services.

[218] Lighting Africa, 2013
[219] Kilian Reiche et al., 2010

Tariffs and subsidies

One of the main issues is how to assign tariffs, which subsidies to establish, and how or when should tariffs and subsidies be reviewed and renegotiated[220]. For the lower income segments of rural population, tariffs are usually agreed in terms of capacity and feasibility of payment, taking as a reference the cost of alternative traditional energy sources such as biomass, liquid fuel as kerosene, candle lights and other.

Tariffs a priori should cover the net present value of investment plus operation and maintenance costs, including replacement, structured in a connection fee plus periodical service fees. Subsidized tariffs are reduced in the amount set by the public grant, both for investment and supply service, as determined by the subsidy scheme. Many authors prefer to focus subsidies in the investment phase of the electrification (connection subsidies, grants for installation or purchase of equipment) so operation and maintenance should be in any case paid for by commercial tariffs, guaranteeing long term sustainability of the business models without dependency on public budget for tariffs. On the other hand, provision of subsidies to the investment would be preferable if the operation and maintenance of the project is financially sustainable with the tariffs, since it avoids dependency from the subsidies in the long run, lowering the risk for the investors.

Even in these cases, the investment subsidy should better be paid to investors during the lifetime of the electricity services[221] to avoid "build and run" behaviors, but helping companies with access to capital funding to pay for the up-front costs of investment.

It is interesting to consider targeted subsidies according to the different levels of income of users, so that there can be a gradual adjustment of subsidies according to the need for service and capacity of payment of beneficiaries. Different levels of consumption in the different steps meant also a different distribution of investment costs and service, and therefore the differentiation of subsidies would depend not only of the income level but also of the installed capacity.

Tariffs and service need to be adapted to the circumstances and capacity of payment of the customers, respecting some flexibility within certain regulatory guarantees, but to allow simplicity and fairness for the customers some authors recommend setting a maximum common tariff of reference for all the operators[222], regardless of the different actual costs of service of each distribution operator or situation. One option for grid extension and isolated Mini-grids, is to publish public tariff tables that specify a maximum allowed retail prices for operators under certain circumstances, but allow flexibility to the operators to offer prices under that maximum[227], also allowing proper planning of business models that know both tariff and subsidy levels before making investment decisions.

[220] Martinot & Reiche, 2000
[221] Dietrich et al., 2011
[222] Reiche et al., 2006

Then, different levels of subsidy can be established according to different cost categories that must be carefully analyzed. Regulators should consider that cost service in more isolated areas will be higher both because of higher investment and costs of service, lesser number of consumers and higher dispersion of the population.

The possibility of cross subsidies between users should be accompanied by a tariff impact study[223] to determine the consumer segments and how to assign them the cost of funding the off-grid or extension electrification programs. Thus, electrification costs can be charged preferably to those segments with a lower payment default rate and higher income level, so that the impact of the electrification fee in the tariff will not be relevant. It is important to consider on this regard that ill determined tariffs might result in the actual bankruptcy of the whole system, unable to recover the present cost of electrification.

In any case, the payment of the subsidies must be subject to the verification of the continuity and quality of the electricity service.

Regarding subsidies for basic services as water and electricity, the World Bank[224] assumes that subsidies are effective mechanisms for the redistribution of national wealth, service rate expansion and access assurance for impoverished population, and therefore are an important social policy instrument. Thus, the contribution of rural electrification to the reduction of poverty must be carefully assessed, as a benchmark with other alternative strategies as education, health or water in order to design an equilibrated subsidy system.

An interesting conclusion of this study is that the common subsidies established in steps, as those described above, are basically regressive in terms of redistribution of income, as they benefit the population with lower income in a higher degree.

On the other hand, it also confirms that connection subsidies are more attractive than consumer subsidies especially when the electrification rate is very low, but their effectiveness must be measured in terms of new connections resulting from these programs. Unfortunately, there are very few studies that analyze and discriminate the impact of different subsidy schemes in terms of achievement of electrification targets, development objectives or reduction of poverty.

Table 18 shows the classification of subsidies that can be funded directly by governments, by donor agencies and international programs, by other users cross subsidies and unfortunately in many actual cases, not funded at all after an initial period.

[223] Bravo, 2001
[224] Komives, Foster, Halpern, & Wodon, 2005

TABLE 18 -Typology of Consumer Utility Subsidies

		Targeted subsidies			
			Explicit targeting		
	Untargeted subsidies	*Implicit targeting*	*Self-selection: quantity targeting (See chapter 5)*	*Self-selection: service-level targeting (See chapter 6)*	*Administrative selection (See chapter 6)*
Consumption subsidies	*Across-the-board price subsidies* ⇒ all consumers *Charging for variable but not fixed costs* ⇒ all consumers	*Low collection rate with no disconnection policy* ⇒ all consumers who do not pay their bills *Illegal connections* ⇒ those with illegal connections *Flat fees for unmetered connections* ⇒ high-volume consumers with unmetered connections *Combined water and sewer tariffs* ⇒ households with water and sewer connections *Single volumetric charge* (when costs vary by customer or time of use) ⇒ high-cost customers	*Increasing block tariffs* ⇒ low-volume consumers with meters *Volume-differentiated tariffs* ⇒ households with metered private connections who consume less than x units per month	*Free water at public water taps* ⇒ households using public taps *Low rates for low-voltage electricity service* ⇒ households with connections to low-voltage electricity services	*Geographically differentiated tariff* ⇒ customers who live in certain areas *"Social tariffs"* ⇒ customers classified as poor *Merit discounts and discounts for pensioners* ⇒ qualifying customers *Burden limit cash transfers* ⇒ households whose utility bills and housing expenditure exceed a defined burden limit
Connection subsidies (*See chapter 7*)	*No connection fee* ⇒ all new customers *Subsidized interest rate for financing connections* ⇒ all new customers	*Flat connection fee* ⇒ new customers who are more costly than average to connect		*Reduced connection fee for households providing labor or materials* ⇒ households that choose to provide labor *Reduced connection fee for lower service level* ⇒ households that chose this service level	*"Social connections"* ⇒ households classified as poor

Source: Komives et al., 2005

Government funding of subsidies can be paid directly to the users, to the concession according to the service provided to every client, or as a flat sum to the concession, that then distributes this benefits among the clients.

Government subsidies prevent the distortion in the price structure caused by cross subsidies, but otherwise they distort the economy as a whole, and sometimes may overburden the weak public budgets of some developing countries.

Cross subsidies pose risks as they affect economic areas that might be sensitive to the higher costs incurred for the funding of the subsidy.

When the subsidy scheme is unable to provide funding, the concessions accumulate financial losses and are forced to reduce costs, by cutting off the investment and lowering the quality of service. This deterioration of service might lead the users to go back to their traditional energy sources, or search for alternative solutions as the pico or micro PV standalone systems.

The World Bank states that subsidies distort the behavior of the concessionary distributors. In some cases it is estimated that 40% of the subsidies are spent in inefficiencies of the utilities and overprices.

Thus, the subsidy scheme must also incorporate incentives for the continuous improvement of quality and efficiency of the concession.

Because of the negative effects described above, governments should not establish permanent subsidy schemes to energy consumption[225]. There are several advantages in concession auctions and calls, as the incentives to the participation of the private sector and the competence established between the applicants. However, it is not always easy to attract bidders because of the risk scenarios associated to rural electrification in developing countries with weak political and economical structures. Other possible scheme proposed is a joint venture with public investment and private management. This lowers the uncertainty for the concession, but still requires the support from the government. A third proposal requires the private sector to assume both the investment and operation of the electrification, but with the prior constitution of a rural electrification fund that will support the program. This rural electrification fund will receive its financial resources from private investors, international energy or environmental programs, and from the concessionary companies themselves, without excluding the possible participation of the government also. The success of the program depends of the long-term sustainability of the fund, which must be refinanced by the tariffs themselves, as return from the investment.

Direct sale electrification technologies, as SPLS or some SAS, are not within the natural scope of public tariffs, but they can benefit from subsidies to the investment and fiscal policies may foster the scalability[226].

To help customers pay the high up front costs of SPLS and SAS, some governments have implemented subsidies on all solar equipment as Uganda (45% subsidy as part of its *Energy for Rural Transformation* program) or Peru (50% subsidy to investment in Small Lighting Systems).

An important barrier in some developing countries for penetration of electrification equipment is high duties and taxes on solar lighting products reaching nearly 50% over price in some countries. Exemption to customs duty and/or VAT is in place in many countries, mostly for the whole SPLS, though some times the exemption covers the PV equipment but not the DC lights.

Finally, governments should reduce and finally eliminate other conflicting incentives with other competitive technologies, as grants to kerosene consumption, which effectively slow down the growth of modern lighting systems.

In the case of grid extension, the establishment of the appropriate tariff and subsidies framework not only enables the extension of the grid to the population in an affordable and economically sustainable way. It also sends the right signals to operators to implement complex and appropriate solutions suited to different situations[227]. For instance, distributors may perceive the extension through Mini-grids connected to the national grid as a threat if it takes clients from them, or as an opportunity if the regulation caters to feed-in solutions and tariffs commercially interesting. From the point of view of the independent power providers in connected Mini-grids, most of them lack experience with the regulatory framework, which

[225] Bravo, 2001

[226] Eisman et al., 2013; Lighting Africa, 2010, 2013

[227] Alliance for Rural Electrification & USAID, 2011

might prevent them from launching their business and makes necessary a balance between regulation and flexibility: providing the IPPs with clear rules for the energy transfer from and towards the national network, respecting as well their ability to address their Mini-grid users and members in an appropriate local-handled way with a minimum but effective supervision[228].

Competition and selection of operators

The World Bank[229] proposed a series of key issues for the regulation of public concessions.

Integration of the rural electrification services. High costs of service in rural areas and economies of scale in activities such as communication and information, tariff collection and pre and post sale commercial services justify the integration of electricity services with others as water, telecommunications and microfinances, among others. In fact they assert that microfinance activity has the highest synergies with energy access.

Terms and mechanisms of concession. Design of incentives and risk allocation (to suppliers, consumers or government) affect the intensity of competition and the long term sustainability.

Bid attraction. One of the main challenges is the attraction of capable agents to a given auction. Lack of experience might be a barrier for local or international bidders, as well as regulatory and financial uncertainty or transparent information about costs and benefits. Subsidies might be an incentive but the regulatory framework might be a more decisive factor in the long term. Parameters for the bid would be tariff levels, customer connection charges, minimum required subsidies and/or number of new connections and customers

Design of process for offers, competition, negotiation. From auctions or competitive calls to direct allocation of contracts, the structure of the concession process is a key factor.

Participation of the beneficiaries. This is a critic success factor for the program. The users of the electrification technologies must participate in the choice and design of technologies and management processes.

Selection of equipment. Leasing and purchasing. The concession can be free to choose any kind of equipment according to the specifications, but in other cases the government can own the assets and lease them to the distributors, thus achieving economies of scale for the purchases.

Regulatory agenda. Regulation of rural concessions is very different to traditional regulation, and requires different views. The main challenges are achieving political independence and hedging of the funding.

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[228] Reiche et al., 2006
[229] Martinot & Reiche, 2000

The goal for promotion of private initiative and competition should be to get "good fits", rather than simply assuming international best practices[230]. The authors classify the contract choices in two major traditions with different characteristics for long-term electrification concessions in sub-Saharan Africa: French "*affermage*" model and Anglo model of independent regulators. For the "*affermage*" contract private operators assume only operative duties and are paid for each unit sold. The operator is so paid to run the system, with incentives on meeting some performance targets. Thus, commercial risk is shifted to the operator. In the Anglo model, the contractor gets a full concession both with operational and investment responsibility.

Coming back to the categorization of models[231] described in section 1.2, the different electrification models give pace to different implementation agents. In application of the principles proposed by the World Bank the participation of the communities must be promoted in all of them[232]. Local ventures and communities are incentivized to participate in the tenders and in the maintenance of the installation given their crucial role in the sustainability of the project. Hybrids of private, public and community responsibilities favor the service management, reducing rogue behaviors by integrating the beneficiaries in the decision making.

Each electrification initiative should be analyzed individually to decide the optimal approach to involve the private investors[233] including the following issues:

- identification of electrification agents, and allocation of incentives, subsidies and funding;
- establishment of template contracts for owners, suppliers, operators, consumers and government;
- definition of the coordination level for agents of electrification;
- implementation of a *Electrification Information System* useful for the coordination of agents, monitoring of the implementation and information for investors.

As for the specific mechanisms for selection of operators, many can be chosen according to the nature of the initiative and the business model approach to be promoted[234]:

- competition in the market;
- competition for the market;
- by project;

[230] Eberhard & Tenenbaum, 2005
[231] Reiche et al., 2006
[232] Dietrich et al., 2011
[233] NRECA International, 2001
[234] Reiche et al., 2006

- by cluster;
- by yardstick;

Beginning with the SPLS electrification mode, it does not rely on regulators for the selection of operators. The government role, on top of establishing the appropriate market structure and incentives for sustainable business models in SPLS, governments can play a role in raising awareness among the population towards the energy transition, establishing innovation and capacitation incentives for agents and intermediaries, helping entrepreneurs and other stakeholders build capacity and scale up[235].

In the case of SAS there is a much wider variety and diversity of management models that can be grouped in down payment, credit payment and service fee. The first two options require the transference of the ownership while the model of service fee retains the ownership in the distributor, but offers continued service to the customers.

As for mini-grids[236], we must consider a variety of roles that can be played by different actors:

Promoter: the organization that conceives and develops the electrification program, analyzing its technical and economical viability and achieving the necessary funds. This role is paradigmatic of an entrepreneur that can be the owner, an enterprise, an NGO or any other actor with the will, imagination and capacity for that.

Owner of the installation: this is the organization that owns the assets of the electrification systems. It can be private or municipal, or even a cooperative with the necessary capacity to gather the required funding for the initiative.

Operator: this is the agent in charge of the operation and maintenance of the initiative. It is hired by the owner to administer the assets. The operator is required to have capacity for the efficient and effective management of the facilities.

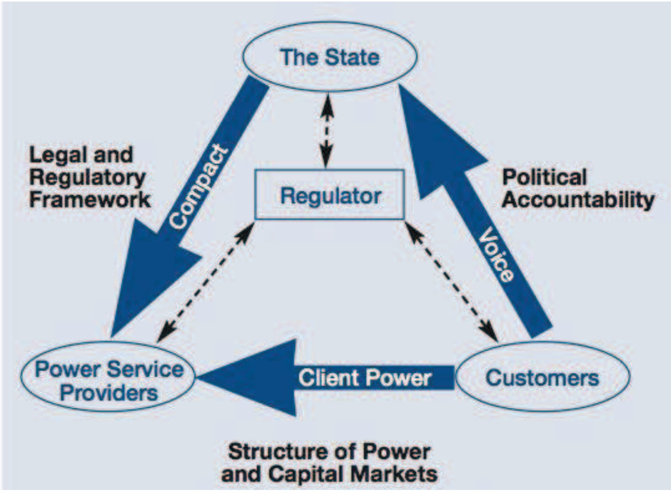
7.1.3 Government control and institutional framework

Governance relationships in any power market are fundamental to engage in a power sector reform for Universal Access[237]. Figure 39 shows an analytical framework for the chains of accountability from customers to service providers. The first direct route goes directly through the market, considering the competition of the agents for market share and capital and the users power of choice. The indirect route goes through the government or regulatory institutions that can intercede between both parties and secure the public interest. Low-income population has in general a very weak political voice and also very little power to choose a

[235] Lighting Africa, 2013
[236] Izquierdo et al., 2011
[237] Besant-Jones, 2006

different service provider. Thus, the regulatory long route is critical for the governance framework.

FIGURE 39 - Power market governance framework



Source: Besant-Jones, 2006; Reiche, Covarrubias, & Martinot, 2000

7.1.4 Stakeholder ecosystem

The market as usual approach in the Base of the Pyramid will not solve on its own the challenge of universal service for poor communities. London, Stuart [238] and Prahalad [239], emphasize the need for the creation of "organizational ecosystems" where actors of different nature can interact in a collaborative environment using network structures.

It is required the creation of the conditions and incentives for alliances of many actors with an innovative approach to create the disruptive innovations needed to achieve Universal Access[240]. The experience of Acciona Microenergía shows that

- an appropriate regulatory framework for electrification,
- an active participation of the communities through their Village Electrification Committees, and
- a committed promoter willing to supply funding means, technology and management

may launch sustainable and affordable electrification initiatives. The example of Grameen Shakti in Bangladesh where an institution of reference in micro credit financing builds the

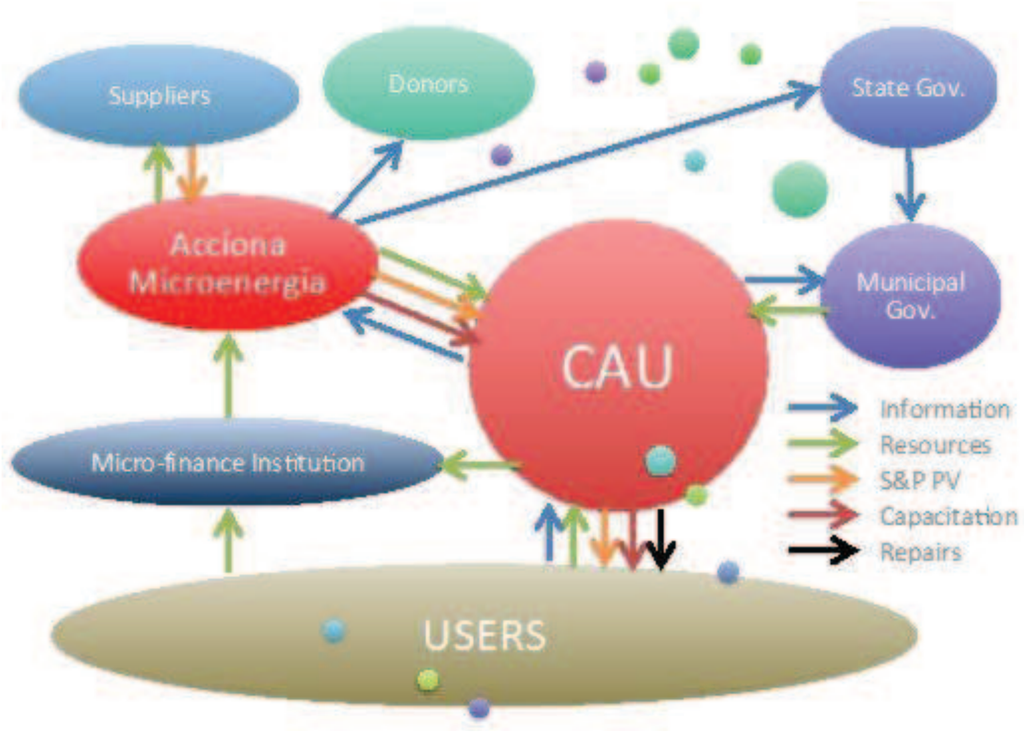
[238] Janssen et al., 2011
[239] Prahalad, 2006
[240] Mataix et al., 2012

electrification initiative close to the users and taking advantage of the institutional opportunities is also an example of these three key success factors.

As seen in many cases, the existence of institutional anchors greatly enhances the success chances of any business initiative. Anchors can be of a very different nature, as financial institutions (Grameen Bank for Grameen Shakti), large utilities and technology partners (Acciona for Acciona Microenergy Peru or Mexico), international agencies (USAID for Mera Gao Power) and large partnerships and international programs as Lighting Africa or EnDev.

As an example, Figure 40 shows the institutional ecosystem for the Acciona ME business model for small PV systems in Peru and Mexico.

FIGURE 40 - Actors for the Acciona ME social enterprise business model



Source: Eisman et al., 2013

This model shows the main actors and key relationships between them, with the main role given to the center for assistance to users (CAU). CAUs repair and replace damaged equipment, sell 12Vcc appliances compatible with small PV systems, inform and support the users, and also can sell new systems or exchange used ones. At the promotion state, the CAU is key to inform the new users, implement the installation of systems and follow up the electrification projects.

At a later stage it is the key element for the maintenance of the systems and the long-term sustainability of the electrification. CAUs are located in reference villages for any supply regions, so users can reach them from their houses, for repairs, information and purchases. The managers of the CAU are usually local people, which receive the necessary training to provide for the user needs along the life cycle of the PV system.

The central offices of Acciona ME in the country back up the CAU for any logistical, technical or administrative issue beyond their responsibilities, supervising and accompanying their administration. Initially, commitment from the local authorities is preferred for the growth of CAUs, but the possibility of licensing CAUs to local entrepreneurs with the support from Acciona is also considered.

Sometimes, the ecosystem is partially formalized in Public-Private-Partnerships, like *Lighting Lives* in Liberia, which brings together efforts from the Rural and Renewable Energy Agency with the World Bank Group, high quality manufacturers of pico-voltaic equipment and six local retail partners (including NGOs and micro financing institutions) to facilitate the creation of a viable commercial market for these lighting products.

7.2 Funding and financing

According to the World Energy Outlook[241] financing the amount needed to provide universal access in 2030 requires the contribution of all available sources and funding mechanisms, with the main contribution by the private sector facilitated by a supportive investment climate by public authorities implementing strong governance and regulatory reforms.

Actually, energy access funds are mainly directed towards large-scale electricity infrastructure. As we have seen in this report, off-grid distributed business models are nowadays the most appropriated electrification mode for most of the population without access. Table 19 shows different financing instruments provided by different universal access stakeholders.

[241] IEA, 2011

TABLE 19 - Sources of financing and the financing instruments they provide

	Grants / credits	Concessionary loans	Market-rate loans	Credit line for on-lending	Partial credit guarantees	Political risk insurance	Equity	Quasi-equity	Carbon financing	Subsidy / cross-subsidy	Feed-in tariff	Technical assistance
Multilateral development banks	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
Bilateral development agencies	✓	✓	✓	✓					✓			✓
Export-import banks / guarantee agencies			✓			✓						✓
Developing country governments	✓	✓					✓	✓		✓	✓	
State-owned utilities							✓			✓	✓	
National development banks		✓	✓	✓	✓							✓
Rural energy agencies/funds	✓									✓		✓
Foundations	✓						✓		✓			
Microfinance			✓									
Local banks			✓									
International banks			✓					✓	✓			
Investment funds							✓		✓			
Private investors							✓		✓			✓

Source: IEA, 2011

There are three kinds of business models according to their revenue model[242]:

- commercially profitable;
- not profitable, but economically viable;

[242] NRECA International, 2001

- nor profitable nor viable, but mandatory for social reasons.

The governments should never support the first type, except for the provision of access to capital and funding sources in countries where capital markets are scarce or inaccessible for rural electrification programs. As for the other two, NRECA acknowledges four courses of action for governments.

- The government develops the electrification, but organizes a bid for the operation and maintenance of the programs. The electrification assets remain state owned.

- The government develops the electrification and auctions not only the operation and maintenance but also the assets, which become private.

- The government plans the electrification program, and accepts bids for its development (implementation, operation and maintenance) transferring the ownership to the concessionary.

- The government does not manage the program, but elaborates an indicative planning for different concessions and responsibilities of the private actors.

Despite being commercially profitable, still many business initiatives will need support to access funding at different levels. This is the case of pico and small solar systems, where the main barrier is the upfront prices of the technology, which are much higher than traditional fuel based lighting. Micro-credits and financing mechanisms defer this payment in installments, thus making these technologies affordable by users in the BoP[243].

But not only customers need innovative financing instruments. Making funding available up to speed for the value chain of Universal Access requires to focus on the needs of manufacturers, distributors, retailers on top of end users, as shown in Table 20.

[243] Lighting Africa, 2011

TABLE 20 - Financing needs across the value chain for the case of Small-and-Pico-Lighting-Systems

	Manufacturers	Distributors	Retailers	End-users
Financing required	• USD 250K – 3m	• USD 25K – 1m	• USD 300 – 10K	• USD 20-150
Timeline of financing	• 90-120 days	• 90-120 days	• 30 days	• 6 months- 1 year
User financing	• Initial capital for R&D and production assets • Working capital • Trade finance for inputs	• Trade finance for PLS imports • Working capital for growing distribution network • Credit to the last-mile dealers or end-users	• Working capital to purchase PLS for sale or rental models • Capital to extend credit to end-users	
Key challenges	• Substantial capital required for scaling up production for international players • Smaller scale, African manufacturers are largely new entrepreneurs and are underserved by financial institutions	• Inadequate credit from manufacturers • Long lead time translates into high opportunity costs • SME financing is underdeveloped with no focus on renewable energy sector • Firms lack credit history which is a pre-requisite for working capital loans • High interest rates on existing SME products	• Neither MFIs nor commercial banks are natural providers of capital • Few financial institutions focus on renewable energy-related micro-enterprise loans	• Upfront costs of lantern too high (cannot pay more then 10-20% of monthly income upfront due to low income levels and limited savings) • No scaled examples of MFI lending for PLS purchases in Africa or globally

Source: Interviews with industry stakeholders; Dalberg research and analysis

Source: Lighting Africa, 2013

Providing access to the necessary funding requires the mobilization of private, national and international sources focused on energy access at the Base of the Pyramid. Lighting Africa[244] analyzed the potential solution to finance challenges from the point of view of the agents.

Manufacturers: commitment in equity from private capital, but also from donors and social funds; commercial bank loans and risk guarantees; social enterprise challenge funds and concessionary financing by governments.

Distributors: manufacturer-funder partnerships for working capital or trade financing; commercial bank loan-loss partnerships or guarantee scheme for working capital, social enterprise challenge funds and corporate co-financing for their last-mile dealers.

Retailers: commercial bank loan-loss partnerships or guarantee facility so distributors can extend credit to dealers; risk sharing facilities and micro-financing for lending to micro-entrepreneurs, corporate co-financing.

End-users: micro-financing for PLS and SLS; funding for the establishment of rotating savings and or credit union organizations (informal sector); product-linked micro-credits or rental/pay-per-use models; payroll financing.

To achieve Universal Access and overcome the financial and funding barriers analyzed, regulators can establish a dedicated trust for co-funding off-grid and network extension electrification to the BoP. Funding for this trust should be guaranteed, establishing the

[244] Lighting Africa, 2010, 2013

appropriate sources of income, fenced against any possible misuse. A remarkable example of this kind of trust has been established by Liberia, funded by the benefits of their program *Lighting Lives* and also along this Working Paper we have seen the cases of Costa Rica or Laos.

Making this funding available would need the establishment of partnerships between financers, governments, multinational corporations and international programs to provide capital and incentives that reach both conventional and base of the pyramid institutions.

7.3 Innovation, technology transfer and appropriation

Technologies for the base of the pyramid, especially for very low cost lighting systems, are experiencing a tremendous impetus in terms of improvements in quality, performance and durability, but also a sustained decline in prices.

Innovation in low cost technologies for electrification, especially on DC appliances for SPLS and SAS, productive and community uses in the base of the pyramid is a major challenge that requires the participation of users and local electrification agents for the definition of the user needs. Cross innovations from other sectors may benefit also the electrification modes as for instance the improvements in battery technologies from the cell phone and automobile industry.

Innovation in business models adapted to these markets, diffusion of successful experiences and specific regulatory and financial instruments will be required to achieve universal access and development in the BoP. The promotion of national and international knowledge hubs, or clusters that gather practitioners, governments, community representatives and international institutions, will support the replicability, scalability and dissemination of good practices. Lighting Africa[245] also identifies some key innovation areas for distribution models:

- reducing the number of intermediaries between the manufacturer and the local dealer;
- develop distribution partnerships with institutional market aggregators, such as micro-financing institutions, saving and credit cooperatives and unions or other synergic cooperatives;
- partner with mobile operators, taking advantage of the great need for off-grid mobile phone charging;
- regarding appropriation and technology transfer, it has already been stated the importance of raising awareness and training the population and agents for the technology shift from traditional to modern technologies. Energy access technologies (from SPLS to low-cost connections) should be user-friendly, but still require a basic

[245] Lighting Africa, 2010

training for proper use and maintenance, which will extend the life of these systems. Identifying possible causes of malfunction and training users and local technicians for elemental repairs will help foster this transition and prevent market spoilage.

A few companies like in Bangladesh[246] and Africa[247] have started to assemble locally their lighting systems, taking advantage of the low labor cost in their countries and also as a mean to transfer valuable skills and job opportunities to their population. This also helps to better adapt the product to the local needs and uses, and may lower taxation over the final product. This technology transfer also helps building up a network of expert technicians that may also repair and maintain the equipment in place.

An innovative and very interesting approach to training in rural electrification techniques is the Barefoot College[248] in India. With support from the Indian government, this NGO takes women from the poorest of villages and teaches them skills such as building, installing and repairing solar lamps, without requiring them to read or write. The participating villages create a committee, agree on the amount to pay for the solar installations and choose the women who will go to the school for the six month training program. When they return home, they install and maintain the systems. The approach has been described as “de-mystifying high technology”.

[246] Wimmer, 2012
[247] Lighting Africa, 2010
[248] www.barefootcollege.org

8 Conclusions

8.1 Pico and small lighting systems

Pico and Small Lighting systems make available a clean, affordable, portable and reliable technology for basic energy services, especially for in and outdoor lighting, charging of communication devices as cell phones, powering radios or even small TVs as well as low power community and productive uses.

The contribution of these systems to development is limited by their low storage capacity and power, but still represents an important leap from candle or kerosene lighting, home wood fires and dependency from disposable batteries.

Customers would usually prefer higher electrification modes that allow them to watch color TV, wash and iron their clothes or use power productive equipment, but for the majority of the population without access to electricity, PSLSs is the affordable option to provide basic energy systems. But this basic electrification level, though desirable, should not be the final step for the consideration of this population as "electrified".

Nevertheless, this transition to modern energy services from well-known traditional technologies requires a very important demonstration and awareness raising effort.

The low cost of SPLS allows the emergence of new business models for provision of energy services, similar to the retailing of IT and other mobile technologies, radically different from traditional grid supply.

The nature of these business models makes them more robust in weak regulatory frameworks in many developing countries. Nevertheless, they would benefit from appropriated regulatory measures in terms of quality of service, and technical standards.

The high up-front costs of these technologies, compared to traditional energy sources, requires the establishment of appropriate financing mechanisms especially designed both for the users in the base of the pyramid, and also for the service providers along the value chain, reducing the risk of the intermediaries to attain their economic sustainability in the long term.

Energy policies for universal access should consider these solutions as an initial step for the electrification process, as it would enable un-electrified population to experience hands-on convenience, benefits and uses of electricity.

Despite these benefits, this stage should always be considered as previous to other electrification modes, because of its limited capability to enable further development opportunities.

8.2 Stand-Alone Systems

Stand-Alone Systems are probably the most successful and flexible off-grid electrification mode for the achievement of multi-tier universal access. They can provide basic low-cost service to households with 4 hours of energy to power 4 LED lights, phone charger, small fan, radio and high efficiency TV systems. But they can also reach up to provide enough energy for 24 hour advanced supply including space heating and electric cooking, energizing high power electric pumps, mills or saws.

SAS present also a variety of energy supply options, from solar to hydro, wind, biomass or diesel power, favoring hybrid configurations for higher efficiency and system performance.

The multiplicity of business models matches also this large set of user service levels and appliances, from pay-as-you-go systems at the low-end to rental, community or cooperative exploitation and fee for service tariffs.

Investment costs are higher than SPLS, therefore increasing the need for appropriate financing mechanisms for customers, retailers, distributors and manufacturers, in order to provide suitable and innovative solutions for the base of the pyramid market.

Continuous operation and maintenance is necessary for long-term sustainability of SAS systems. Most of these activities can be performed by the users themselves or by local technicians. This has favored the creation of ancillary jobs and auxiliary businesses at local level, with especially high incidence in the empowerment of female entrepreneurs. To achieve this virtuous cycle, a previous careful capacitation, training and technology transfer effort is required, as well as continuous support and life-long uprating of skills, which need to be implemented at a higher scale.

Stand-Alone-Systems can be the most appropriate solution for very isolated customers, but in many other cases they are an intermediate step before the arrival of the grid connections.

8.3 Isolated mini-grids

Isolated Mini-grids provide a suitable low-cost solution for villages and other clusters of customers and appliances, also ranging from very basic access levels for a limited number of hours a day to large high quality power systems. Mini-grids may serve from a limited group of a few customers, to large populations of thousands.

Mini-grids present many techno-economical advantages for off-grid electrification. Economies of scale are achieved because of the aggregation of customers, both from the point of view of the size of the systems and regarding management and operation. They also have a higher quality of service both because improved generation and storage efficiency, especially in hybrid configurations, and the because of the possibility of smart grid operation and active demand management.

Mini-grids have a higher technical complexity, thus requiring a higher effort in maintenance and operation activities at a mini-utility level, requiring the participation of more skilled technicians.

User education is critical to prevent overconsumption, but innovative low-cost metering and energy controls may be set in place to provide for a smooth system performance, also giving the customers appropriate signals about their energy consumption.

8.4 Grid extension

Connection to the national grid includes well-known advantages as reliability, economies of scale, scalability and equitability of energy supply.

However close attention must be paid to the costs. Equitable network access assumes the same tariff for all the national users of the network, despite the costs of urban, rural and isolated users are dramatically different[249]. Cost of grid extension increases the overall price of electricity for both urban and rural users, establishing de-facto cross subsidies between users.

Grid extension increases the demand of energy generation in countries where there is usually a lack of capacity, especially to satisfy peak demand periods. Many users receive grid service only a limited number of hours each day during the demand valley, and will be disconnected in favor of users with a higher priority at peak time every day. Blackouts and brownouts are also common. Therefore, grid extension must be accompanied by an investment in generation capacity or otherwise it will reduce further the quality of service.

Grid extension in populated areas receives usually higher attention from companies and policy makers, because of its higher impact and faster results. Nevertheless, specific governmental planning that considers both grid and off-grid complementary approaches is needed so that agents and consumers outside the scope of grid-extension plans know that alternative approaches should be implemented.

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