Decentralized renewable energy solutions to foster economic development

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Abstract

Electricity supply and socio-economic development are closely linked. Innovative, sustainable decentralized energy solutions represent indeed the most efficient instrument to promote electricity access in remote and low load density areas.

Within this framework efficient generation technologies are crucial for the provision of electricity access and, in turn, to foster local development although not yet sufficient to directly spur sustained growth. Inclusive business models able to foster productive uses of energy are necessary, although the cycle jump-start requires many different inputs. The following study will therefore analyze the existing nexus between electrification and development, further highlighting the important role of having a holistic point of view and building strong partnerships to achieve the most efficient and sustainable business model. Finally, systematic know-how dissemination and a consistent regulatory framework for decentralized energy systems will represent key elements for an effective energy policy within emerging economies.

The fundamental role of electrification in economic development

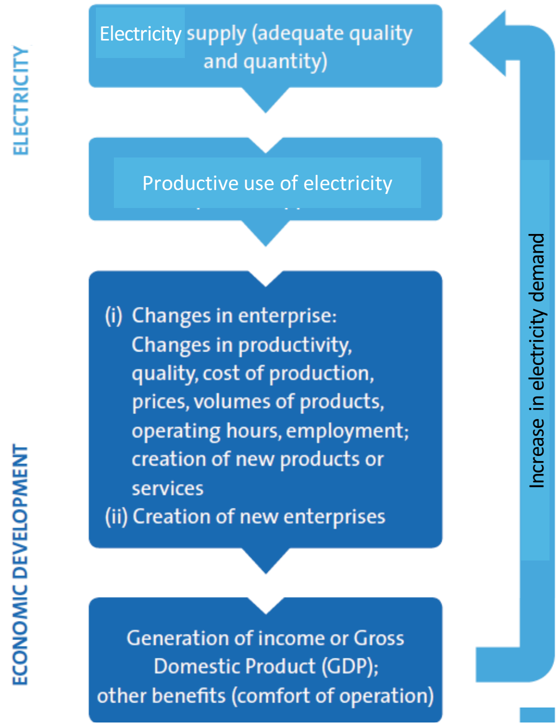
Three key arguments underpin the case for access to electricity as a critical enabler for socio-economic development:

(i) access to energy is of paramount relevance for the achievement of several of the United Nations' Sustainable Development Goals (SDGs);

(ii) "productive use of energy", as opposed to "consumptive use of energy", would enable new income-generating activities for poor populations, igniting the activation of the capital accumulation cycle; and

(iii) lack of access to energy is a direct indicator of poverty based on living standard's measurement criteria

The links between access to energy (in particular electricity supply) and poverty reduction through income generation can be presented as a step by step approach, as shown in the following figure[1]: a household/business benefiting from electricity supply is only the first step towards the user/entrepreneur's decision to make use of it. But it is only the actual use of the power supply, and the step changes that such use of power allows to the user/enterprise (mostly in the form of productivity improvements), that enables income generation and capital accumulation. The following figure is only an example of interaction between electricity supply and socio-economic development. However, it provides a useful conceptual framework for a systemic approach to investigate the benefits of access to energy.



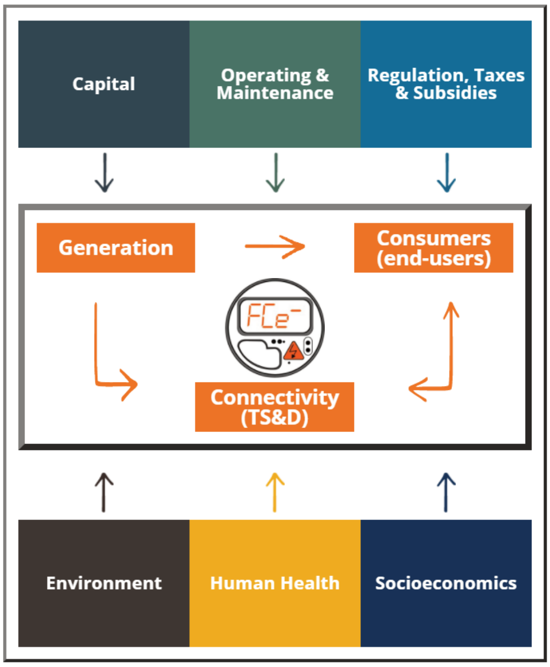
Once recognized the key role of electricity in economic development, criteria must be set out in order to comparatively assess alternative models for the design and implementation of energy systems.

- **Full Cost of Energy**

The *Full Cost of Energy* approach pursues the systematic consideration of all the elements determining the total cost of generating and delivering electricity[2] to the end users, meaning all the direct and indirect costs associated with power generation and delivery, including generation capacity, fuel costs, environmental effects, Transmission & Distribution infrastructure investments, the cost of dispatching and flexibility, the cost of redundancy as well as the *time-to-market* of the different alternatives.

[1] Adaptation from PRODUSE, The Impact of Electricity Access on Economic Development: A Literature Review, page 6.

[2] The Full Cost of Electricity, The University of Texas at Austin



• Centralized versus decentralized energy systems

Adopting the Full Cost of Energy approach enables, *inter alia*, the comparison of two general models to provide secure and sustainable access to electricity: i) centralized power generation and ii) decentralized energy systems.

The first model refers to the generation of electricity at large-scale centralized facilities, whose location is mainly determined by the efficient access to fuel and land availability. High Voltage (HV) networks need to be designed and deployed in order to efficiently transport electricity from the centralized plants to the load centres. Large conventional power stations, such as coal, gas and nuclear plants, as well as large renewable facilities, such as hydroelectric stations and utility-scale wind or solar power stations, are representative of the centralized model.

Decentralized generation refers instead to a variety of technologies to generate electricity at or near the end user(s). Decentralized energy systems are typically based on local renewable energy sources, captured via mini-hydro, biomass, biogas, solar, wind and medium-enthalpy geothermal plants. They are either connected to a single load, such as a home or a SME or, through localized bi-directional medium voltage (MV) and low voltage (LV) networks, to multiple loads in the same area, giving rise to a mini-grid. Decentralized generation systems are modular and flexible, and can include multiple generation and storage elements (in *hybrid* configurations) in order to guarantee supply 24/7.

Historically, the full cost of a *delivered* kilowatt-hour was higher in distributed than in centralized systems. However, the rapid cost digression experienced by decentralized generation, storage and energy management technologies (as well as the quantification of the environmental effects of centralized generation) have bridged such gap, particularly in areas with low initial load density. Such cost advantage, coupled with rapid and flexible delivery, points to decentralized electricity systems as the most efficient instrument to foster access to electricity in areas of low load density. Furthermore, in case of future connection to the main grid, sophisticated and resilient mini-grids can play a fundamental role for the stabilization of the wider electric system.

Distributed energy systems: the technological state-of-the-art

Decentralized energy systems are not a new concept: every day diesel and gasoline generators provide electricity to millions of people and businesses where there is no grid or where the grid is unreliable. What has changed is the emergence of a wide array of competitive, sustainable and reliable technologies for renewable energy generation and energy storage and management.

Today, decentralized energy systems comprise a variety of technological solutions for different applications and with different performances in terms of dispatchability, availability, etc. such as:

• Solar Home Systems

SHS (Solar Home Systems) are stand-alone photovoltaic systems in rural areas, not connected to the grid, designed to meet a household's basic electricity needs.

SHS consist of solar modules connected to a solar charge controller, an inverter and a battery. The energy is stored into the battery bank and supplied to the load via a DC/DC or DC/AC conversion system. They feed low-power appliances such as lights, radios and small TVs for about three to five hours a day.

SHS are a key instrument for basic access to energy (and the creation of initial loads) but not a tool for productive uses of energy, given their limited power and autonomy.

With cost as one of the biggest barriers for SHS uptake, optimizing the system size versus the energy needs is crucial.

While in 2003 only a SHS of 20 Wp was economically competitive with kerosene lamps, in 2015 this was true also for a 70-80 Wp kit. The main contributor of such cost digression has been the decrease in the cost of the photovoltaic modules. The cost of batteries has now also entered a steep descending path, while the cost of the Balance-of-System (BOS – inclusive of inverter, cabling and structure) is expected to significantly decrease with rising volumes.

Much of the challenge in the diffusion of SHS hinges on the successful optimization of battery lifetime. Battery can account for more than 50% of the total SHS costs, while having the least lifetime among the components.

The key advantages, disadvantages and relative challenges of today's two mainstream battery typologies are set forth below:

LEAD-ACID Batteries		
Advantages	**Disadvantages**	**Challenges**
– Mature technology – Low cost	– Restricted depth of discharge – Low energy density – Electrode corrosion limits useful life	– Battery file-cycle
LITHIUM-ION Batteries		
Advantages	**Disadvantages**	**Challenges**
– High energy density – Long life-cycle – High roundtrip efficiency	– High production cost (but falling) – Safety devices needed	– Cost-effective battery management system on small scale

• Single-user hybrid solutions

Single-user hybrid solutions (mostly for SMEs) combine i) one or more renewable-energy sources, ii) normally a storage system to balance the system and time shift renewable energy production, iii) conventional back-up systems (usually diesel gensets) to ensure 24/7 energy supply; iv) a BOS inclusive of inverter(s) and an energy management system to ensure stable supply and optimize power flows.

Such single-user systems can be grid-connected (if so, they can source power from the grid when economically convenient and when the grid is considered sufficiently stable), but are designed not to rely on the grid, neither for energy supply, nor for voltage and frequency stabilization. By contrast, they are thought as independent power generation systems, able to provide 24/7 energy supply.

A hybrid solution can be characterized on the basis of the ratio between the capacity of renewable energy sources and the load to feed: low, medium and high renewable penetration require different architectures, different sizing of energy storage systems and the use of different control functions.

Hybrid solutions combine the environmental benefits and short time-to-market of renewable sources with a dispatchable, guaranteed, high-quality power supply.

• Mini-grids

Mini-grids can be defined as a set of generators and loads within a limited defined area, operated in a coordinated way. Mini-grids can be run as stand-alone localized electric systems, especially in rural areas, but can also be connected to the wider electric system, in order to efficiently exchange energy, balancing capabilities and cold reserve (*capacity*), i.e. they can be integrated as single active elements in centralized power systems.

Mini-grids cluster multiple loads and distributed generation systems via MV and/or LV by-directional localized networks. The elementary building elements of the mini-grids can be pure loads (households, SMEs), prosumers (households or SMEs with their own hybrid solutions), community or commercial mini-grid-level generation and/or storage facilities. A mini-grid can be privately or community-managed, or else utility-managed.

Presently, most micro-grids adopt conventional AC grid systems. Since many renewable sources generate DC voltages, converters are required to transfer power from these energy sources to the AC grid system. For example, wind turbines require back-to-back power converters to synchronize and adjust the output frequency and voltage level with the AC grid system. In residential and rural segments, grid connected equipment such as computers and battery chargers use DC power. Thus, these devices require an AC-DC conversion stage for AC grid connection. Such multiple conversion stages reduce the overall efficiency and reliability of the systems. Hence a renewed interest in exploring DC grid systems.

Inclusive business model: Productive uses of energy

Fostering productive uses of energy is essential to ignite a virtuous circle of demand growth and increasing local availability to pay, which lays at the basis of mini-grid return on investment.

In fact, despite choosing the most efficient generation technology to provide electricity access is necessary to support local development, it is not sufficient to directly spur economic transformation and sustained growth. Indeed, a sustainable business model shall be created in order to couple electricity supply with other solutions and quality inputs to successfully unleash the community's inner capacity to develop and trigger a virtuous cycle.

Opportunities and positive impacts related to mini-grid development

Mini-grid implementation through the above mentioned sustainable business model has the potential to generate widespread and transformational benefits, such as:

- Providing critical employment opportunities, particularly in the agricultural/agro-processing industry and Small/Medium Enterprises (SMEs);
- Promoting growth of local economy and private sector, thus presenting opportunities for investors as well;
- Enabling households to achieve a better standard of living, which in turn would enable them to be more productive and generate additional income also used to buy

efficient electric equipment (e.g. fans, food processors, refrigerators etc.) that will improve their quality of life;

- Catalyzing training & development of skilled human resources as people acquire new competencies to run new businesses or to take advantage of new employment opportunities;
- Making the investment in electrification sustainable, thanks to the growing local consumption and to the increased community ability to pay.

However, the identification of the potential uses of electricity that could ignite this virtuous circle requires prior analysis and actions. In fact, local businesses development should be done during the whole lifecycle of the electrification project, since it helps both to design the infrastructure and to establish a sustainable business model, which has to be tailored to the specific socio-economic characteristics of local communities. Such characteristics vary from place to place and there is no one-size-fits-all solution that will suit all villages.

Such development should be performed in an inclusive way, building the demand bottom-up, as the involvement of local players is essential from an early stage to build trust between residents, local businesses, the mini-grid developer and operator.

The development model must consider the holistic system to be effective. For example, the identification of solutions to include productive use of electricity and electricity use needs to focus on different inputs, relationships, mechanisms, and dynamics at play, such as:

1) Supply-Demand of electricity, including aspects such as the reflectiveness of electricity tariff and the incurred costs for the electricity supply and the availability to pay for different uses of electricity
2) Competitiveness of mini-grids with existing solutions, such as kerosene, Solar Home System;
3) Desirability and attractiveness of electricity-enabled behaviors, products and services;
4) Business Acceleration, including the capability of the electricity supply to power devices for productive use (e.g. sewing machines, milling machines) and increase the economic productivity, the disposable income and the ability to pay;
5) Sustainability of the business model or all stakeholders, including local communities, investors and national governments.

Potential uses of electricity to foster socio-economic development in rural areas might include, among others: electric pumps for irrigation and increased harvests of crops; electric mills replacing more expensive existing diesel powered mills; fridges and food processors (for fish, meat, dairies..), and power for small roadside business centers providing photocopying, fax machines, and internet.

- Mini-grids have an impact on a wide range of stakeholders in rural and peri-urban areas, including:
- Rural/local community households;
- Community schools, clinics, health centers, NGO offices, local government offices and other public buildings;
- Farming/agri-food sector - for irrigation and food processing;
- Private sector and Small and Medium Enterprises (SMEs) as listed above;
- NGOs and the private sector as mini-grid developers;
- Rural electrification agencies – which may act as intermediaries between the mini-grids and consumers (or may be by- passed by them in some models).

For this reason, partnerships among organizations (private sector and NGO's) and local players with different fields of expertise are critical to address all the essential inputs concurrently and to support a sustainable growth of economic activity that drives electricity consumption and that will support the main consumption anchors. An appropriate support system could help villages to channel local resources into economic growth.

Italy, in particular, could provide a strong support with technical expertise and supply of advanced and robust machinery, which represent leading sectors of Italian economy.

Barriers to further development

Decentralized solutions can play a central role in achieving universal electricity access, and represent today a proven, effective alternative to traditional grid expansion.

Policy schemes adopting decentralized energy systems, should compare, at equivalent levels of supply reliability, with the Full Cost of Energy (also in terms of time-to-market) of serving the same loads via a centralized electric system[3] and aim to offer the investor a fair risk-adjusted remuneration.

Policy-makers have historically regarded rural electrification with off-grid technologies as a philanthropic activity, giving priority, for industrial development, to the expansion of existing grids. Even though in the past years it has become clear that the development of off-grid projects does not prevent integrating them in future centralized power systems[3], gaps in policy and regulation still persist. Therefore, it is necessary to define an enabling framework to scale up the use of decentralized systems as a proper way of addressing the electrification challenge.

The widespread assumption that rural electricity supply is to be considered a charity rather than a commercial activity is erroneous, as studies show that spending power in rural areas is high compared with the long-run marginal cost of electricity supply.

The private sector is willing to invest but their generalized involvement is still challenging, because of the lack of a regulatory framework providing enough clarity on operational rules and on key critical issues, and for the absence of de-risking mechanisms. Permitting processes are still long and not streamlined, and too many authorities are involved in the electrification activity, creating overlapping responsibilities or lack of responsibility.

We can summarize in **three** categories the main building blocks of an effective framework to foster decentralized energy systems:

1. Simplified permitting and licensing procedures

Governments should keep mini-grids permitting process streamlined, providing a land registry and a standard set of permits on application form, inclusive of right of ways, environmental impact assessment, district authorizations, etc., enabling regulators to quickly assess projects viability. Such permits should be assessed in a reasonable - and well-known in advance - processing time, through a single window support channel (one-stop shop). In addition, a combined generation, distribution and supply license with an exclusive right of supply should be provided for a determined period of time to avoid the risk of developers paying the significant cost of project preparation and then finding themselves subject to competition from other developers.
Permitting procedures should be linked to technical and safety standard requirements. Therefore, it is very important that countries

[3] The benchmarking has to consider ***cost-reflective*** electricity tariffs, ***not*** tariffs actually in place, that may be not cost reflective

develop a regulating body able to define Technical connection rules (Grid Codes), to be fulfilled also by mini-grid projects that, although initially off-grid, might be integrated into the main grid in the future.

2. Flexible tariff setting rules

Financial and economic aspects also play an important role in promoting the development and safe operation of decentralized grids by private players.

Flexible tariff setting rules and financing mechanisms have to be in place to ensure reasonable return to investors and affordable prices for consumers.

Tariffs for mini-grids need to be set independently from the tariffs applied to main grid-connected customers, that are generally highly subsidized by the Government. The tariff level should be flexible enough and based on what will be affordable and acceptable to remote users (for example, for farmers it will be easier to pay electricity after harvest than in other times of the year), balanced with the developer's need to meet operating expenses, including depreciation, and deliver a fair return on investment.

Tariffs levels are therefore expected to provide developers with a suitable financial return, while accounting for the need to deliver high quality service. Governments and development partners can support lower mini-grids tariffs by providing grant subsidies that offset the high initial capital costs and thereby reduce investment risks.

3. Clear "Exit options" in case of main grid arrival

The most critical risk in the development of decentralized solution is represented by the potential arrival of the main grid before the time needed to recover the investment.

Such risk can be mitigated by the diffusion of official Governments plan providing more certainty on grid extension in the medium/long term, that anyway should be reliable and not abruptly changed.

Moreover, clear exit options in case of main grid arrival must be set in advance, identifying duties and rights on involved parties (i.e. developer, Distributor System Operator, Regulator), in order to provide to developers fair guarantees on the return of their investment.

Government regulation can help to mitigate this risk by mandating one of the following possible options: a) the mini-grid operator could become a power generator, selling energy to the main grid, through PPA with a guaranteed tariff, and distribution assets purchased by a DSO. b) the mini-grid operator could become a DSO, that purchases electricity from main grid and resell it to customers (disposing of the legacy generation assets in the mini-grid); c) a combination of power generator and DSO, with a specific regulatory regime for *embedded* generation.

According to the preferred choice done by the mini-grid operator, the DSO must have the obligation to purchase the distribution portion of the mini-grid assets that represents the most capital intensive portion of the total investment, provided that the latter are technically compliant with the Grid Code. A crucial element therefore is represented by the determination of the compensation value for the distribution assets. That value must be based on the expected return of the investors at the time of the investment decision, and therefore on the future cash flows that he was expecting to receive for the time of operating of the projects.

Anyway, the role of the Regulator in managing smoothly the exit option is crucial in order to ensure the fairest solution in the interest of consumers and mini grid operators.

While a consistent regulatory environment is a requisite for decentralized energy systems to become a pillar of government's electrification strategies, in certain areas and applications the private sector is showing the ability to independently develop and fund the deployment of private mini-grids, mainly for captive and own consumption. Such initiatives should not be discouraged in any way: communities and businesses that autonomously mobilize capital to deploy sustainable and reliable decentralized energy systems are a valuable complement, not a threat, to centrally promoted schemes. Fostering entrepreneurship is itself a major contribution of clean energy technologies to economic development.

Conclusions and call for action

The role of electrification in economic development is fundamental. Innovative, sustainable decentralized energy solutions represent the most efficient instrument to promote access to electricity in areas of low load density or very far from existing national grid. Fostering productive uses of energy is essential to ignite a virtuous cycle of demand growth built on an inclusive business model, however, the cycle jump-start requires many different inputs.

Having a holistic point of view and strong partnerships will be important to activate all the inputs simultaneously to achieve the most efficient and sustainable business model, which will be beneficial both for local communities and investors. Systematic know-how dissemination, a consistent regulatory framework for decentralized energy systems, and an open mind towards entrepreneurship in the energy sector are fundamental elements of an effective energy policy for emerging economies.

FOCUS: The relevance of decentralized solutions for the development of Zambia's power sector

ENGIE eps

There are five fundamental factors driving the relevance of decentralized solutions for the development of the power sector in Zambia:

(i) limited potential load density outside urban centres and mining areas;

(ii) consequently, the limited reach of the transmission grid;

(iii) need to enable primary sources with a different seasonal profile than hydroelectric production;

(iv) a mismatch between the aggregated load profile, dominated by baseload demand from the mining sector, and the typical load profile of residential demand, exacerbating the challenge to cover peak demand by modulating hydro production;

(iv) abundant renewable energy potential (in particular solar and biomass, in addition to hydro).

The prevalence of the mining sector in Zambia's electricity demand has fundamentally influenced the development of its power system, through the development of high-capacity transmission backbones serving mining areas and urban centers (whose growth is in turn highly correlated to the mining sector), and a limited reach of the main grid in other regions.

Rapid urbanization is exacerbating such dynamics, further reducing potential load density in rural areas.

This fundamental asymmetry makes an obvious case for a decentralized energy approach to rural electrification, relying on affordable solar technology (possibly complemented by biomass in agricultural areas generating material residues with energy potential) as main element of the primary mix, supported by conventional back up capacity (powered by diesel or, where economically sustainable, biofuels) and storage capacity for balancing and intra-day energy management purposes.

In this framework, Solar Home Systems are synergetic with a microgrid roll-out program, by *incubating* initial load.

Potential policy framework

The key challenge to the systematic implementation of microgrids in this environment is the typical trade-off between i) the need of a cost-reflective tariff to remunerate the capital expenditure in generation and local distribution infrastructure, and ii) the depressive effect of a cost-effective tariff on initial load creation, required to ultimately justify the roll-out of a distribution infrastructure and foster network economies.

Furthermore, historically low electricity tariff in Zambia, partly justified by the need to preserve competitiveness of copper mining in a land-locked country, set a challenging price benchmark for decentralized solutions.

Accordingly, a balanced mix of policy tools is recommended to foster the deployment of decentralized energy solutions.

1. A liberal framework for spontaneous private microgrid realization: entrepreneurs able to identify economically-sustainable load pockets should not be prevented to market unregulated schemes to villages and communities;

2. A transparent framework for the deployment of regulated microgrids, along the guidelines set forth in this paper, with a clear identification of any subsidy element required to secure remuneration of network infrastructure in a low load density environment (potentially with a digression scheme for such specific tariff components as load grows).

3. Favor for Solar Home Systems as a path to load creation.