# New regulatory and business model approaches to achieving universal electricity access*

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Abstract

Universal access to electricity should be achievable by 2030, the deadline proposed by the UN in its Access for all initiative. However, progress so far has been too slow. The International Energy Agency estimates that by 2030 still more than half billion people, mostly in Sub-Saharan Africa and South Asia, will lack electricity access. Technology and sufficient funding exist, yet other key components of the solution are clearly missing. This paper argues that an essential lacking component is a regulatory and associated business model package that is well adapted to the specific characteristics of electrification in the least developed countries, and that can be supported by sound quantitative analysis of the costs and benefits of every considered option.

Keywords: Electricity access, off-grid, rural electrification, power sector regulation.

## INTRODUCTION

A large number of people lack electricity access or have access of very poor quality. Progress in improving the situation is slow and estimates for the future –like the recent ones issued by the International Energy Agency (IEA, 2016)– are pessimistic about achieving universal access by 2030, and even in 2040.[2]

Despite the grim outlook, there are multiple positive signals. The level of global awareness has grown substantially over the last decade, as indicated by a slew of

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2 The International Energy Agency estimates that by 2040 still half billion people (down from 1.2 billion today), mostly in Sub-Saharan Africa and also in South Asia, will lack electricity access. In addition, an undetermined and probably larger number of people have very poor quality electricity service, which hardly can be considered as "access".

new electrification initiatives announced by many of the concerned governments and the increasing level of available international funding.[3] Substantial –albeit insufficient– progress has been made in most countries. New regulatory approaches and business models have been proposed and some have also been tested, see for instance (Bhattacharyya, 2013; Tenenbaum *et al.*, 2014; Palit and Bandyopadhyay, 2015; Africa GreenCo, 2010; Maithani and Gupta, 2015; Barnes, 2007; Wimmer, 2012). There are numerous studies and experiences upon which one can draw and the social sciences have made important contributions in understanding the many dimensions of the problem. The technology to provide universal access is available and the investment necessary to do it –the IEA estimates a total amount of $48 billion per year until 2030– is certainly significant, but it can be raised.[4] It is therefore clear that the answer to the lack of progress has to be found elsewhere.

This paper argues that sound regulation and an ensemble of compliant, contest-relevant business models are essential missing components to achieving universal access to electricity in the least developed countries. Such regulation and the business models that fit within it must be well adapted to the specific characteristics of electrification in each country and must be informed by rigorous quantitative analysis of the costs and benefits of every option, as well as the concomitant social, political, cultural and administrative factors. Since sound regulations and business models can only succeed fully if they happen in a stable country context (where legal security is guaranteed by independent institutions and a good track record of governance) the task at hand acquires even greater proportions in the context of politically unstable countries.

## *The key role of regulation for electrification*

Essential features of the power sector that are taken for granted in the regulation of electricity in industrialized countries simply do not hold in the least developed ones. As a consequence, many customary regulatory approaches in more developed countries have to be reinvented in the context of electrification access.

3 See http://www.se4all.org for instance.

4 These $48 billion per year are less than 2% of the annual cost of electricity in OECD countries.

Two indispensable elements are thoughtful, context-specific regulatory guidelines that enable viable business models in each country, and credible institutions that have the autonomy to implement and enforce this regulation. Without these, firms will not even consider investing in electrification in a given country,[5] given the estimated magnitude of the required outlays. For instance, according to the International Energy Agency, only Sub-Saharan Africa will require more than $300 billion of investment to achieve universal electricity access by 2030. Reasonably sound regulations and institutions are required to give private investors confidence that the financial risk is manageable.

Regulation must clearly assign the responsibility to provide reliable, efficient and affordable electricity, establish the procedures to identify and resolve conflicts, and mitigate avoidable risks that may arise from the coexistence of different types of suppliers. In general, regulation must establish the supply tariffs and any necessary compensation mechanisms –either directly allocated or via cross-subsidies between consumer categories– to achieve economic viability of the supplying companies. Regulation must also make compatible centralized and distributed approaches, as well as the joint presence of the incumbent companies, large corporations, and small developers.

## *Viable business models*

The objective of an ambitious electrification program that is commensurate with the needs of the least developing countries is to develop an implementable and scalable business model for universal energy access that can attract large-scale private investment, both from a multiplicity of entrepreneurs and from

5 Practically all countries in the world have an institution in charge of regulating network energy services, *i.e.* electricity and natural gas. Such institutions belong in the area of public administration –many of them are in fact departments of a ministry–, and in most industrialized countries they are set up as authorities or commissions endowed with diverse levels of independence with respect to the government. The rationale for such arrangements is to protect the technical activity of the regulator from being subject to political instability or excessive interference with electoral concerns or with pressures by lobbyists. Such institutions are known under the term "energy regulators". There are more than 200 in the world, organized in 12 regional associations that are members of the International Confederation of Energy Regulators.

the leading large energy companies that so far have had very limited exposure to electrification activities in these emerging markets. The focus must be on both off-grid and on-grid markets across generation, distribution, transmission and customers –both households and businesses– in those least developed countries that have a minimum set of institutional and regulatory conditions as to be able to attract serious investment funds.

Most of the existing off-grid solutions, whilst having a very positive impact in delivering basic energy services, are not focused on productive uses – the main driver of job creation and economic growth. It is therefore necessary to upscale the ambition of off-grid electrification efforts. This could be helped by the ongoing trend of cost reduction and performance improvement of the technologies for electricity supply and demand, which now allow for addressing electrification in different ways. In addition, innovative financing schemes could combine the diverse payment capabilities of residential consumers with specific electricity tariffs for the commercial and industrial customers, so that new electrification becomes as economically viable as possible.

Electrification efforts must be aware and take advantage of technology improvements, both from the demand side –efficient appliances, and demand management and communication technologies– as well as from the supply side –on grid/off-grid generation technologies, storage, and grid control devices, both for utilization in microgrids or in grid extension–. The new technical capabilities and reduced costs of off-grid supply technologies make possible business models that could not have been imagined some years ago. Leapfrogging opportunities might avoid or minimize the use or extension of unnecessary legacy investments.

After this introduction, section 2 presents the assumptions underlying the regulatory compact that is prevalent in more developed countries. A different set of assumptions is needed in least developed countries, as shown in section 3. The open issues that the new assumptions raise are discussed in section 4. Finally, section 5 closes with the broad guidelines that must inspire the regulation and business models that could enable universal electricity access by 2030.

## ASSUMPTIONS IN THE TRADITIONAL REGULATORY COMPACT FOR ELECTRICITY SUPPLY IN MORE DEVELOPED COUNTRIES

There is a well-established theory and practice of power sector regulation in the developed world –with different versions ranging from a traditional cost of service framework with vertically integrated utilities to liberalized wholesale and retail markets with full unbundling of activities– that has served many countries well for several decades (Pérez-Arriaga, 2013; PURC, 2017).

This regulatory compendium is presently being challenged from several overlapping directions, including the drive towards a decarbonized power sector, the increasingly strong presence of distributed energy resources, the operation of power systems with large amounts of intermittent renewables, and the growing interest in cross-border trade in regional markets of increasing geographical scope.

These trends require adaptations of the regulations of the different activities and the rules of the wholesale and retail markets. However, the fundamentals of the regulatory approach remain stable in more developed countries, despite the need for improvements. The main reason for this is the permanence of some core assumptions about the supply of electricity that are taken for granted, but strongly influence the regulatory framework. The focus of this discussion will be on the activity of distribution, which is closest to the provision of electricity access, although the bulk power system is affected by grid extension electrification and will be also considered. What are these assumptions?

- *Supply to consumers is provided by grid connection.* All consumers are supplied by connection to the main grid, which is typically part of a large national or even regional interconnected system. This grid provides high reliability and a very stable frequency of the supplied AC power. New technologies are not disruptive enough to change this paradigm.

- *The utility is the accepted business model.* The perpetual supply of electricity is guaranteed by a "regulated monopoly with a territorial franchise" or "utility model", *i.e.* a network company with a business model based on guaranteed economic viability.

- *The regulator is in charge of those consumers connected to the grid, which, in practice, are all the consumers.* Except for the very special cases of a few places with highly remote access that have their own autonomous electrical supply, everybody is connected to the grid. Therefore, power sector regulation is implicitly designed for grid-connected consumers. The issue of how to deal with consumers that disconnect from the grid has only recently become relevant, as grid defection has started to be considered a possibility.

- *Sufficiency of upstream supply.* Connecting new consumers does not imply major changes at a bulk power system level, since demand growth happens gradually, in small increments and with the benefit of a fully developed network and generation infrastructure.

- *Electricity is an indispensable component of everybody's life.* Electricity access has become indispensable for customary household, community and productive activities. For decades, reliable and adequate electricity supply has been a fundamental component of our infrastructure and a core tenant of the functioning of our society.

- *Almost perfect continuity of supply.* The distribution network basically always maintains the connection between the transmission substations and the final customers connected to the distribution network. The continuous upstream supply of electricity is taken for granted and permanent continuity of supply is basically guaranteed. In this context, discussion about reliability or quality of supply refers to the efforts to reduce even more the few hours or minutes per year when the supply is interrupted or to decrease distortions in the almost perfect waveform of the voltage that is supplied.

- *The grid provides AC power and a full range of AC appliances is available for purchase.* All kinds of appliances are available at the standard voltage (220 V or 110 V, depending on the country) even though many of them actually function in DC (computers, TV, phones, LED lights, and all kinds of electronic devices).

- *The level of demand that the distributor is committed to supply has no external limits and aggregated demand can be accurately estimated.* The infrastructure of electricity supply is designed so that it does not limit or constrain the demand that the end customer may require, except for the self-imposed limits that the customer may voluntarily accept when contracting the supply (in some countries). The reliability level on the point of supply does not have an impact on the level of demand, since this reliability level is basically the same everywhere and close to 100%. Typically the future demand is estimated with a small error margin.

- *Regulated tariffs cover the cost of supply, and the distribution network costs in particular.* Customers are charged for the cost of the distribution service and this is included in their final tariffs, which are established by the regulatory authority.

- *Theft and non-payments are under control.* Failure to collect the tariffs and theft are generally minor problems in developed countries. If cases occur, they are promptly investigated and can be considered to be under control.

- *Energy poverty affects a minority of consumers.* Most customers can pay for the cost of electricity and it is a not a substantial component of their household budget. Nevertheless, in most industrialized countries, a significant part of the population –about 10% in the EU, for instance– are "energy poor", meaning that they live in households that pay for the cost of energy supply using more than 10% of their budget.

- *Cross-subsidization is implicit and socially is a non-issue, except sometimes for social tariffs.* In addition to social tariffs (whose extra costs are typically charged as an uplift on all the other tariffs), in industrialized countries there is a great deal of cross-subsidization of distribution costs, between those consumers living in densely populated urban areas, and the consumers living in the countryside, where the density of demand is much lower. Cross-subsidization is considered to be normal and most people are not even aware of its existence.

The next section will examine the status of these assumptions in the power sectors of least developing countries where a high percentage of the population lives without electricity access.

## WHAT IS DIFFERENT IN COUNTRIES WITH A SUBSTANTIAL LACK OF ACCESS?

Electrification in least developing countries –and more specifically in rural areas, where the majority of people lacking access live– has to start with a different set of assumptions, which should determine condition the regulatory approach. Therefore, the customary regulatory approaches adopted in more developed countries and assumed to be universally valid, in particular regarding distribution and the design of tariffs, have to be questioned when dealing with electrification in developing countries. The assumptions in the last section will be examined now one by one.

### *Supply to consumers is provided by grid connection*

It is important to realize that lack of access to electricity happens in very diverse situations. Many people without access are located in remote areas that will not be reached by expansion of the grid for a long time, maybe never, thus, other viable off-grid solutions have to be implemented. On the other hand, many people live close to the existing power grid ("under the grid", as opposed to "far from the grid"), but they lack an electricity connection, because the connection and/or monthly fee are too expensive or because the incumbent distribution utility is disinterested in providing the connection.[6] Off-grid technologies could provide an alternative or at least a temporal bridge to a future grid connection for these customers. Therefore, off-grid systems can be a solution not only for extremely remote locations that will never see the centralized grid, but also for communities that will not receive reliable centralized electricity for many years, and they could create a basic level of infrastructure that could potentially facilitate the integration with the main grid, if later deemed to be the best option.[7]

6 When we mention areas where electricity grids exist, we must specify that we refer to medium (e.g. 11 kV) and low-voltage (220 or 110 V, depending on the country) distribution grids, because people living near a high-voltage line built for long-distance transmission of electricity cannot technically connect to it, so they are in the same position of people living far from any network.

7 An interesting topic to be explored is a better understanding of why there is widespread perception that off-grid electricity is not "real" electricity and what may shift people's beliefs toward accepting it as a real, alternative form of power.

Therefore, although reliability, stable frequency, and lower cost of centralized generation because of economies of scale have made grid connection the indisputable best option for electricity supply worldwide meeting the increase in demand and universal access to energy will, in general, require a combination of grid extension and off-grid solutions in the short (and maybe even longer) term. The strong on-going cost declines in solar photovoltaic and storage technologies, combined with innovative business-models, can further enhance the viability of off-grid options.

## *The utility is the accepted business model*

In most least-developed countries the incumbent distribution utilities have failed to provide universal access. The causes are diverse. Frequently the distribution company is in dire financial straits and therefore unable to invest in electrification. The origin of this situation might be heavily subsidized tariffs that are unable to pay for the supply costs of both the extension of the grid and the purchase of the bulk power to be distributed. Most of these distribution companies are publicly owned and the corresponding national or provincial governments often cannot cover the deficit, thus augmenting the financial difficulties of these companies. Trying to connect more customers would, thus, only increase their losses.

However, the bottom line is the "viability gap", *i.e.*, the difference between the actual cost of providing the service and the revenues from the regulated tariffs or what the consumers can pay (this concept will be explained in more detail later). Distribution of electricity is expensive in rural zones with low, dispersed demand, which is a common situation in least developed countries. The cost per connection typically can be several times more expensive than it is in densely populated urban zones. Since many of the people living in these rural areas are poor, they cannot cover these high supply costs and need some kind of subsidy, which the government may not be able (or willing) to provide. In developed countries that have reached complete electricity access, the most frequently adopted practice is to apply a uniform tariff to all low voltage residential consumers in the country –or to all being supplied by the same distribution company– regardless of whether they are located in an urban, semi-urban or rural area. Unfortunately, this simple cross-subsidization approach cannot be used in least developed countries, where the average level of income is much lower, and the percentage of rural households without access is large.

Therefore, the regulator is trapped in an unsolvable dilemma: (i) either charge higher tariffs to rural consumers, which most could not pay and which violates the commonly established rule of uniform tariffs regardless of the location on the grid, or (ii) charge the existing lower tariff that applies to on-grid consumers also in rural areas, knowing that this would deteriorate the financial situation of the distribution companies.[8]

In reaction to this situation, entrepreneurs have started to occupy the empty space left by the incumbent distributors in many countries (Tenenbaum *et al*., 2014; Palit and Bandyopadhyay, 2015). These developers offer a diversity of off-grid solutions to people without electricity access or with access of such poor quality that they need an alternative electricity supply. This shatters the traditional paradigm of the traditional utility, as a regulated monopoly with a territorial franchise.[9] Depending on the country, these entrepreneurs could be unregulated and only subject to some basic industrial safety rules and organized as cooperatives, franchisees of the incumbent distributor, or new utilities specialized in off-grid supply (Bhattacharyya, 2013; Tenenbaum *et al*., 2014; Palit and Bandyopadhyay, 2015; Wimmer, 2012 and Box 1).

In the last few years, a new alternative approach has emerged; that deviates even more from the traditional utility-based paradigm; solar kits. These kits weigh about 4 Kg, with a modest solar panel of about 15 W and a lithium-ion battery of 20 Ah at 12V with a charge controller. They can supply four 2.5 W LED lights (one a portable solar lantern) and a phone charger for the typical needs of one day. These solar kits are easy to install, fully plug-and-play, have several USB ports, and are grid compatible in case the grid eventually arrives. Their unique combination of functionalities means they are *categorized as appliances*,

8 This is further complicated by the widespread issue of an "entitlement mind" or "attitude" held by many in the poorer communities (especially in agriculture) that they should not have to pay. See Maithani and Gupta, 2015: 122.

9 A similar phenomenon –known as "grid defection"– has started to take place also in more developed countries, at individual or even communal level, see (MIT, 2016).

since they can be sold by a commercial outlet without the involvement of an off-grid developer company or a utility. The users can bring the kit to the shop for repairs or enhancements with additional modules. This is a technology change that results in a radical transformation of the associated business model. Home solar kits are experiencing a notable rate of penetration (Bloomberg, 2016) but are largely unaffordable for the bottom of the non-electrified pyramid and some kind of subsidy, or a well-adapted financial approach,[10] are needed so that most households can afford these solar kits, see (Bensch *et al.*, 2016; Grimm *et al.*, 2016).

Off-grid technologies for households (beyond solar lanterns) can be economically viable: i) for the wealthier fraction of the non-electrified population, ii) when some donor institution or some governmental subsidy can make up the difference between the consumers' willingness to pay and the actual supply cost, or iii) when the service is so basic and is provided with such rudimentary means (*e.g.* no meters, non-standard poles –just using trees, rooftops and bamboo canes–, no charge controllers) that the poorest people can afford the most basic –one light and one phone charge– and unreliable service. Also, perhaps (depending on the affordability level), when a clever payment scheme is designed to accommodate the liquidity constraints of the beneficiaries, see M-KOPA, for instance.[11]

## *The regulator is in charge of those consumers connected to the grid, which in practice are all the consumers*

Regulation in least developed countries has been frequently written thinking only of consumers that are connected to the national grid, to a large regional grid or to the power system supplying an island. Access to energy amongst the population living in areas not served by existing networks has been frequently ignored in the regulators' mandate. Yet regulators can help accelerate access to electricity by establishing sound regulation supportive of viable business models, and they should be always included among the actors of the worldwide struggle to reach universal access to energy. Coinciding with the growing global awareness

10 Approaches that account for the low cash flows of the poor –for instance pay-as-you-go or pay-to-own systems, sometimes integrated with the mobile banking sector– have been implemented in Kenya, Tanzania and Uganda. See M-KOPA, for instance (http://www.m-kopa.com/products/).

11 Ibid.

about widespread lack of electricity access, during the last decade most countries have enacted pieces of legislation finally addressing the electrification problem. As a consequence, few countries have long-standing experience implementing regulations that address electricity access and, in particular, off-grid electricity supply and the coexistence of on- and off-grid technologies (Tenenbaum *et al.*, 2014; UPERC, 2016).

### *Sufficiency of upstream supply*

Shortage of available generation to meet demand is a rare occurrence in more developed countries, as they typically have a sufficient margin of generation capacity and energy, and demand typically grows slowly and predictably. This is not the case in low energy access countries, where grid-connected consumers' demand typically grows briskly, and the demand growth of those not connected depends on the ambition and implementation success of the electrification plan, if there is one. When more than 50% of people in a country live without electricity access (as is the case in many sub-Saharan countries and in some states in India) an electrification plan that aims for universal access necessarily has to account for sizeable investments in generation and a thorough redesign of the transmission and sub-transmission (also called high-voltage distribution) grids (MININFRA, 2016).

### *Electricity is an indispensable component of everybody's life*

In more developed countries, electricity access, in any amount that might be needed, is taken for granted. On the contrary, moving from a life without electrical supply to using some basic electric home appliances and electricity-powered productive devices leads to significant changes in the wellbeing of individuals and communities across several dimensions: comfort, education, health, leisure, entertainment, and economic productivity. A quantitative estimate of the magnitude of the global social return on the investment in electricity supply is necessary to establish priorities of governments, international aid organizations and financial institutions when deciding how and when to allocate financial resources among different recipients and objectives. This is an open research area, so estimates vary widely (Burlig and Preonas, 2016; Lenz *et al.*, 2015; Bhattacharyya, 2013). It is well known that electricity is an essential enabling factor of human development, but by far not the only one, therefore outcomes are highly dependent on conditions.[12]

## *Almost perfect continuity of supply*

The situation of continuity of supply is very different in least developed countries.[13] At the most basic level, the matter of concern is whether some levels of quality of supply are worth paying for, and if other alternative sources of electricity supply should be considered instead, including returning to the traditional candles and kerosene lamps. A very important practical topic for regulators and electrification planners is the relationship between the expected or actual reliability levels, the actual or expected consumer demand, and their willingness to pay for some quantity of demand at some level of quality of supply, as the three factors are closely interrelated.

The most immediate concern is how to communicate the concept of "reliability" in a context with a diversity of supply technologies and business models, a substantial number of people without access, and many others with significant curtailments that vary in frequency, duration, and intensity. A precise definition of reliability is needed by regulators to set targets, incentives, and penalties to the distribution companies; by developers to negotiate with potential customers and communities; and by consumers to understand the product that they are purchasing and the relationship between how much they pay and the reliability level that they get.

12 See the paper "The economic lives of the poor", http://economics.mit.edu/files/530, to understand the trade-offs and choices made by people in the lowest income brackets between food vs. education vs. water vs. energy vs. entertainment.

13 A recent survey revealed the dismal state of electricity supply in rural India. In the six study states: Bihar, Jharkhand, Madhya Pradesh, Uttar Pradesh, West Bengal, and Odisha, the average electrified household reported receiving only 12.5 hours of electricity per day; in Bihar and Jharkhand, only 9 hours were available. Households also reported 3.6 days of blackouts (no supply for continuous 24 hours) per month. On a 0-2 scale, electrified households reported an average satisfaction with their electricity access of only 0.95. See more at http://www.ideasforindia.in/Article.aspx?article_id=1757#sthash.yMRULgOK.dpuf

The use of a single metric for reliability is complicated because reliability is multidimensional (curtailments vary in frequency, duration and intensity) and because of the different nature of the supply in each case.[14] Individual off-grid solutions that are only based on solar PV and batteries typically provide reliable power for a limited and somewhat variable number of hours per day, every day. Since the limiting factor is the amount of energy that can be consumed daily, energy intensive appliances are mostly out of question. The reliability can be improved by being connected to a microgrid (although it may depend on the adopted demand management scheme, as each consumer now shares a scarce resource with others) and by adding a non-intermittent generation source, such as a diesel or biomass generator. Micro-grids and stand-alone systems with storage can be designed and managed so that at least essential loads are supplied with reasonably good continuity of service. In contrast, grid-connection offers a basically unlimited power capacity, allowing the use of all kinds of appliances, but it is the experience in many developing countries that grid power is unreliable, with quality of supply being worse in remote rural areas, so that in many cases electricity supply systematically fails at those periods of time when it is most needed, with uncertain patterns. Another typical difference in a developing setting is the lack of a strong infrastructure for grievance redressal mechanisms and repair services, which can further foster lack of trust in the quality of service that is provided.

## *The grid provides AC power and there is a full range of AC appliances*

Supply in DC can be an interesting option for off-grid approaches when grid connection is not expected in the mid-term or ever. Most basic appliances operate in DC (*e.g.* LED lights, phones, radios, TV sets, computers) and transformation from AC to DC is avoided, with the associated expense in power electronics and losses. Other efficient DC appliances are becoming gradually available (Phadke *et al.*, 2015). DC grids operate at lower voltage levels than AC grids and voltage constraints and losses limit the use of DC to networks of a certain size.

14 For instance, the percentage of energy demand that is served over a period of one year does not provide information about how often essential demands have to be curtailed or about how poor the service is for off-grid solar-based systems during the wet season when solar radiation is low, or for grid-connected systems at the time of the annual peak demand.

Compatibility with the AC grid, if it becomes necessary, is an issue and increases the risk of stranded generation and network assets, as well as the complexity of establishing safety and quality of service standards.

### *The level of demand that the distributor is committed to supply has no external limits and it can be accurately estimated in an aggregated value*

In least developed countries with a serious electricity access problem, there is much uncertainty about the demand level of future consumers that have never used electricity, or that are supplied with a very low reliability level. Despite this, electricity regulatory agencies, electrification planners and private developers must assume some demand level that must be met, now and in the future.

Perhaps the simplest choice is to estimate the demand (and its rate of growth) based on knowledge of other consumers in the region who live under similar conditions. The estimation may include, in addition to basic residential demand, productive or community electricity uses. In other cases, if the available budget is very tight or the affordability of the consumers to purchase additional appliances is severely limited, it might be necessary to define a demand level that is considered to be compatible with a minimum reasonable living standard.[15]

It is important to note the difference between "supply capability" (how much power can be drawn from an outlet) and "affordable consumption" (how much electricity the household can pay for and use with the appliances that can be afforded). Perhaps the ideal target in electrification planning is a level of supply capacity and energy that does not limit the level of electricity demand for services that the household could afford. The number, type and level of service of the appliances in a household –and particularly in households that have recently

15 This minimum standard will depend on the specific region, among other factors. However, it has been proposed that a minimum standard of living requires an electricity access that could provide:

- 300 lux of lighting during at least 4 night hours,
- utilization of radio, TV, cell phone and computer,
- and extension of the life of perishable food by 50% longer than at ambient temperature.

In addition, electricity supply must be affordable and have a minimum level of reliability (electricity is available when needed) and quality of service (voltage level stays within a prescribed range). (Source: Julio Eisman, Acciona Microenergía; personal communication).

received electricity access– mostly depend on the affordability level, rather than on the capacity of the electrical supply.

Another important consideration is that the demand level should be specified in terms of services –*i.e.* lighting, communication, entertainment, space conditioning, power for productive activities or cooking– and not in terms of electrical energy consumption or power. An important reason for that is that the efficiency of the appliances is evolving rapidly and, for instance, it is now possible to provide the same quality of lighting than five or ten years ago with an order of magnitude less of consumption (Phadke *et al.*, 2015).

### *Regulated tariffs cover the cost of supply and, in particular, the distribution network costs*

Perhaps the most important barrier to an orthodox and simple approach to the provision of full electricity access in many least developed countries is the existence of regulated subsidized tariffs, *i.e.* tariffs that cannot recover the total cost of supply. The typical reason for this (in principle absurd) situation is political interference in the process of tariff setting, usually motivated by fear of losing political support if electricity tariffs increase, and the fact that many households are incapable of paying the actual costs or just refuse to do it, even if they can afford to pay. Subsidized tariffs can only be sustained if the distribution companies are publicly owned and the deficit in revenues is somehow compensated with internal transfers of funds from the provincial, state, or national budget. Frequently these distribution companies are highly indebted, which makes it difficult for them to borrow money to extend the service to more consumers. The more consumers they connect, the more money they lose. Paradoxically, these distribution companies are not interested in augmenting their business, as this would only worsen their dire financial situation.

This creates a new regulatory dilemma: Should off-grid supply tariffs charged by independent developers be regulated and, if so, how to establish the off-grid tariffs? Note that the customary rule of a uniform tariff for all households connected in low voltage has to be abandoned here, since the cost of off-grid electrification is typically higher than the average cost of supply, especially if the uniform tariff is subsidized. Developers would only accept the application of a uniform tariff if: i) the initial investment is subsidized so that the regulated uniform tariff is sufficient to meet the operation and maintenance costs permanently; ii) the deficit in income is permanently covered by some guaranteed external fund, either from a donor or some official source, which is a solution fraught with problems.

A component of the tariff –regulated or not– that deserves to be mentioned here is the connection fee, since it constitutes an important deterrent for some potential consumers with very low affordability. The connection fee happens only once, when the new consumer is connected to the main grid or to a microgrid for the first time. The fee charged by distribution companies for connection to the main grid ranges from zero to $400, depending on the country. This amount is often insurmountable for many consumers, who, being close to a low voltage distribution network have to desist from being connected, because they cannot afford the connection fee, see (Maithani and Gupta, 2015: 62). It has been argued that high values of connection fees might be a discouraging measure adopted by distribution companies that do not want to connect more consumers, for the reasons that have been presented already (Tenenbaum *et al.*, 2014: chapter 5).

## *Theft and non-payments are under control*

Illegal connections to the existing grid are very frequent in deprived areas in developing countries. The ensuing loss of revenue, plus the high rate of unpaid bills and technical energy losses in lines and transformers, all contribute to the difficult financial situation that characterizes many distribution companies in developing countries.[16] To these effects one has to add the fact that the residential and agricultural tariffs in many developing countries are established below the actual total incurred cost of electricity supply, as indicated before. The obvious consequence is a disastrous financial situation of the distribution companies.[17]

16 For instance, the state of Bihar, India, reported losses of about 50% for the three concepts together. Typical values in more developed countries could range between 6 and 10%.

17 Absorption of illegal connections into a legal and safe system can be promoted by combining an accurate monitoring of the area, easier bureaucratic procedures, repression of illegality, and affordable service contracts, as shown in Ahmedabad, India, see http://www.wame2015.org/case-study/990/ahmedabad-slum-electrification-project

## *Energy poverty affects a minority of consumers*

Least developed countries exhibit the lowest indicators of socioeconomic development, and they meet three criteria: i) poverty level (measured by the gross national income per capita), ii) economic vulnerability and iii) low level of human development (measured by indicators of nutrition, health, education and adult literacy in the Human Development Index). Most of the population without electricity access live in these countries, with India being an exception, with its significant differences between segments of the population.

The unfortunate implication of having a large fraction of the population without electricity access is that it is not viable to cross-subsidize whatever electrification remains to be done with an uplift in the tariffs of those with access. This is what, in one form or another, was done some decades ago in every country in the world that today is considered to be "more developed". This is also the case today in some countries with a small fraction of population without electricity access, see Box 1, for instance. But it is not possible when the fraction of people to be subsidized is large, since this would pose an unacceptable burden on the remaining consumers. The subsidies have to come from other sources.

## *Cross-subsidization is implicit and socially is a non-issue, except sometimes for social tariffs*

Although cross-subsidization cannot be the solution to the financial gridlock of electrification in countries with a large percentage of potential consumers without access, it can be very helpful in other occasions. For instance, the company Acciona Microenergía provides stand-alone solar systems to about 3,000 households in the mountainous area of Cajamarca, Peru. The company owns the facilities and is responsible for the quality of service indefinitely, as a regular utility. They charge their consumers the same social tariff that applies to the analogous category of grid connected consumers. The deficit in revenues is collected via a small regulated uplift in the general tariff, see Box 1.

Another example is cross-subsidization at local level. Some villages or clusters of population include some loads –such as schools, health centers, small industries, shops, banking outlets or telecommunication towers– that may be willing to pay some extra fee so that a microgrid would be viable for the entire cluster. The entrepreneur could then use some sort of price discrimination: i) poor households would pay a fixed monthly small fee to be able to connect a couple of lights, charge a phone, and perhaps use an efficient radio or TV,[18] with a limiter in the connection point to verify that no excessive consumption takes place; ii) wealthier consumers would have meters and would pay in proportion to their consumption; iii) the "anchor loads" would pay according to a tariff that would make the microgrid economically viable. If such a tariff design is agreed to by all the consumers and achieves the financial viability of the microgrid, the objective has been met. Most villages and clusters of households, though, will probably not meet the requirements, and most of the electrification financial problem will remain unsolved.

## DISCUSSION

The two previous sections have shown that the regulation of electrification to achieve universal access in least developed countries cannot be based on the same assumptions that have enabled the prevalent regulatory compact in the more developed countries. Instead, it is clear that a number of open issues exist that must be understood and examined carefully. This section discusses these topics and some preliminary recommendations will emerge from the discussion, which are later outlined in the final section of the paper. The following list of topics will be discussed:

- How to deal with the viability gap?
- Are there viable business models for off-grid supply?
- Should off-grid supply be regulated?

18 Note that, although the monthly fee might be small (*e.g.* $2/month) for poor households, the price per kWh consumed by this segment of the population is the highest for all types of consumers, off –and on– grid. This is correct although counterintuitive, as the charge for the scarce consumption of kWh has to include not only energy, but also other necessary infrastructure investment costs.

- Should off-grid solutions be grid-compatible?

- How to engage the beneficiaries?

- How can electrification be made sustainable?

One more topic is added, to emphasize the need to consider the power system in its totality, beyond the distribution network level, where most of the electrification activity usually concentrates.

Key references are provided, acknowledging the important conceptual contributions that have been made in each one of these topics, but also the huge task remaining of turning them into implementable electrification approaches.

## How to deal with the viability gap?

There is an unavoidable iron law of rural electrification and its statement is simple: *Rural electrification needs subsidies.* This is true for every rural distribution network in any country, developed or developing, but the effect is more pronounced when the distribution network has to supply a dispersed, small demand, as is systematically the case in rural areas of least developing countries with scarce or no electricity access (World Bank, 2010).

The cost of building a distribution network from scratch heavily depends on the demand density. If demand is low at each connection point, and the points are widely dispersed, the network cost is much higher (several times more, typically) than the cost of supplying a dense neighborhood in a town. This fact applies both in developed and developing countries. Since in virtually every country in the world the tariffs for consumers connected to low voltage are uniform,[19] regardless of whether the consumer is connected in a rural or urban area, urban consumers

19 In some countries, tariffs are uniform for a given voltage level throughout the country. Other times tariffs are uniform only within the territory that is supplied by the same distribution company. Sometimes the consumers connected at a given voltage level are divided into groups, depending on the level of consumption or the type of meter and the tariff is uniform for all the members of each group.

substantially subsidize rural consumers. This effect becomes even larger for off-grid solutions, since the cost of supply with small off-grid generators that rely on solar, diesel, mini-hydro or biomass technologies, are typically significantly higher than those of centralized power plants.

Basically every country has had to implement some rural electrification program to provide electricity access to some less accessible and poorer areas. In addition, these programs have been subsidized with public funds or by adding an uplift to the tariff charges to already connected consumers (the majority). Once the rural electrification infrastructure has been built and its cost recovery has been guaranteed, the beneficiaries of the program have paid the standard tariff or, sometimes, they have benefited from some social tariff that also applies to those who meet some low income or other requirements. The obvious problem with developing countries with a large percentage of non-electrified population is that the volume of required subsidy to achieve universal electricity access is large, even for the public budget, and it is also too great a burden to be shouldered by the reduced percentage of electrified consumers.

The viability gap can be moderated by trimming the costs, which might be accomplished in different ways: improvements in performance and lower costs of key technologies, like solar panels and batteries for off-grid solutions; reduction of operation, maintenance, or management costs by increasing the size of the company or using automation enabled by ICT technologies; more efficient power system operation, also applicable to microgrids; and lowering technical standards –*i.e.* application of a simplified grid code to rural electrification due to the low density of demand–.

The latter method deserves special attention, since a grid code is very specific to each power system and its application is the outcome of a regulatory decision. An important boost to rural electrification can be achieved if regulators would allow less-rigorous grid standards for grid extension into rural areas with low demand density, as well as for microgrids. Demanding the same electrical and safety standards required for the central grid can be overkill in rural areas. Brazil, for example, has significantly reduced the costs of its rural electrification by establishing standards for rural electrification that maintain system safety but are less onerous and less costly than those in urban areas.[20] The state of Uttar Pradesh in India has established lighter standards in the grid code for rural electrification. While it is important that safety and the integrity of the electrical system be maintained, regulators should specify the least onerous way that this can be accomplished in rural settings.

In general, it is to be expected that these cost reduction methods will not be able to eliminate the viability gap. Therefore, in general, electrification has a serious financial problem that cannot be ignored. There are some shortcuts, but they are not a solution for the general problem:

- Donors –ranging from NGOs to governments or companies of any size– may give away funds in sufficient volume as to cover the financial gap of specific pilots or small projects. This is useful, but insufficient to meet the needs of more than a billion people without electricity access.[21]

- Small private entrepreneurs, acting outside regulation, can interact directly with villages or individual potential consumers and offer them a basic electricity service (the typical two lights and a telephone charger) at some agreed price. Subsidies might be available in some cases –for instance subsidies for the use of solar PV technologies– but, in general, we refer here to the case where subsidies are not used. This type of business model is mushrooming in the poorer regions of India and Sub-Saharan Africa. How is this possible without subsidies? Even very poor potential consumers are willing to pay for electricity at least up to the amount that they are presently paying for lighting of low quality with kerosene lamps and candles, which have negative impacts on health and safety. This amount is enough to obtain a minimum electrification level.[22] The problem

20 The case of grid extension with lower technical standards in agricultural areas in Brazil, by the initiative of the engineer Fabio Rosa, is well known. It is also remarkable that these standards became officially accepted years later in the national grid code for rural electrification once their technical soundness and cost reduction potential had been amply shown, see (Bornstein, 2007).

21 Even the funds pledged to be made available by large programs like Power Africa ($7 billion total) or the European Union, fell very short of the financial needs estimated by the IEA ($48 billion per year until 2030).

22 These households at the bottom of the pyramid happen to be paying per kWh of electricity much more than what everybody else that is connected to the grid is paying, in developing and developed countries. However, these are the most precious first kWh, whose value for the user is higher than any further consumption.

is that the affordability of these consumers is exhausted with this basic service and this minimalist technical solution cannot be scaled to meet higher demand levels, including community and productive uses. Therefore, this is not the approach that will solve the global problem, even if it is providing a much-needed improvement in the quality of life to its beneficiaries.

- Internal local cross-subsidization, in those villages or clusters with enough presence of anchor loads, may achieve financial viability of an off-grid option. Depending on the consumers' mix, the viability gap might in some cases be reduced to zero, but this requires a significant amount of non-residential demand that can afford the cross-subsidy, which is probably uncommon in the considered countries in rural areas.

- An uplift in the tariffs of already connected consumers, once the volume of consumers with access is clearly dominant such that the uplift is politically and socially acceptable.

- Massive subsidies coming from the concerned governments or from strong international cooperation funds if universal access is to be achieved. Note that this is not smart financing (which is always welcome); it is a subsidy (*i.e.* giving money away).

Finally, it must be realized that the investment cost in an electrification project strongly depends on its level of risk, *i.e.*, on the uncertain factors that determine the costs and the revenues of the project. In general, uncertainty raises the cost of capital and blocks investment decisions that would be profitable at lower levels of risk. Uncertainty may arise if the duration of concessions is too short, if there are unexpected changes in tariff levels or other regulations, or if the political environment shifts –for example, possible political decisions such as nationalization could change the ownership of industrial assets–. Uncertainty and risk are an integral part of basically any business project and some risks are unavoidable, but a stable, professional and independent regulator makes investment more attractive, while protecting consumers.

In the following sections some of these risk factors will be discussed, as well as some regulatory practices and other measures to reduce the risk, and therefore the project cost.

## Are there viable business models for off-grid supply?

The need for subsidies for rural electrification has been discussed in the preceding subsection on the viability gap. This need is even more acute for off-grid technologies. This has to be explicitly taken into account when trying to define economically viable business models for off-grid electricity supply.

Assuming a source for the subsidy exists, three major sources of risk can be identified for the off-grid solution providers: i) the subsidy fails to reach its beneficiary; ii) the grid arrives; iii) competition from solar kits.

### *Failure of the subsidy*

Investment in electrification should necessarily be a long-term activity, since the physical and economic lifetimes of network-related assets easily reach 40 years or more and they are never or very rarely dismantled.

Firstly, it is unreasonable think that a subsidy will last for that long. Moreover, given the difficult financial situation of many of the distribution companies, it is also difficult to think that the subsidy itself is not at risk from the outset, with the governments deviating the subsidy to their own distribution utilities, instead of respecting the original destiny of these funds. If the investors do not trust that the subsidy will arrive to them on time with whatever established periodicity, and they are subject to some regulated tariff, they probably will decide not to invest. On the other hand, if they have some degree of freedom to set or to negotiate the tariff, they will try to recover their investment with an acceptable rate of return in a short period of time, for instance 4 or 5 years, resulting in high tariffs to be paid by the consumers.

### *The grid arrives*

Most least developed countries have a "two-pronged approach" to electrification: grid extension for most people and microgrids or stand alone systems for remote areas or for those areas where the incumbent distributor does not plan to invest in the near future.

In the absence of specific regulation, micro-grid developers face substantial risk if the central grid reaches the area before the investment costs have been recovered, since they will most likely go out of business as they will lose customers to the lower cost (and typically subsidized) central utility service. This added risk can make power from micro grids costly and unviable, since the financial risk of the project is high and the developers will try to recover the investment costs in a few years, fearing that the arrival of the grid.

The uncertainty for any off-grid investor and the associated risk will be reduced if the country has a set of regulations ready to be applied when the two modes of electrification meet. Regulation should provide an explicit path for isolated microgrids to interact and connect with the central grid (Tenenbaum *et al.*, 2014; OKAPI, 2017; World Bank, 2010).

### *The competition of the home solar kits*

Due to their high performance and low cost, solar kits may successfully compete with the other standalone solar systems as well as with microgrids that only provide basic service. The business model for solar kits is radically different from both the classical utility approach and the approach taken by most off-grid developers, since solar kits do not need a "utility-like" or a centralized firm in charge of operation, maintenance and billing. With solar kits, household electrification is based on an appliance that is bought in a store, easily installed at home, and brought back to the store to be fixed, replaced or expanded. Solar kits, like phones, tablets, or electric shavers, are fully compatible with the AC grid without any adaptation.

## Should off-grid supply be regulated?

In countries with low levels of electricity access, off-grid technologies are becoming more commonplace, however they are rarely subject to regulation, except for, perhaps, broad industrial safety codes.

It is long past time to answer a key question: Is lack of regulation an acceptable option for off-grid solutions? Some argue that non-regulated tariffs or other forms of light-handed regulation can promote a more active off-grid sector. No doubt the lack of regulation lowers barriers to entry by removing red tape and technical requirements. Yet, there are also serious drawbacks in some situations and it is important to distinguish where regulation does more good than harm.

On one extreme end, there is the case of stand-alone residential systems, including solar lanterns, light-weight home solar kits, and the standard solar panels with lead acid batteries, occasionally backed up by a small diesel generator for schools, health centers, or medium-size commercial or industrial facilities.

The sale of solar lanterns or solar kits should only be subject to standards that guarantee a minimum level of quality and transparent information to the customer about the expected performance, to avoid that poor people without any technical training or experience buy low quality products for such an essential service unknowingly. Residential solar systems that require some expert installation and maintenance –a utility-like service such as the one provided by Acciona Microenergía in Peru (see Box 1)– may need to be either fully regulated or they can be strictly unregulated and commercially-based, like the one offered by Grameen Shakti in Bangladesh (Wimmer, 2012).

The case of microgrids is different, since the provider can find itself in monopolistic conditions once they are well established in a village or a territory, and unregulated monopolies should be avoided. In this case, some tariff and quality of service regulation are recommendable to ensure that consumers are adequately protected, as a local microgrid does not experience sufficient competition to prevent it from exerting monopolistic power.

However, this regulation does not solve the problem of the viability gap of microgrids. As indicated before, rural electrification, on-grid and especially off-grid, is substantially more expensive than electrification in urban areas with much higher demand density. As previously explained, cross subsidization of rural electrification by existing grid-connected consumers is not viable in countries with a high proportion of the population without electricity access. Some additional regulation is needed in those cases where internal cross-subsidization is not enough to achieve economic viability of off-grid solutions that try to offer a reliable service beyond an extreme basic level.

Sound regulation should establish the means by which the viability gap could be filled, with an acceptable level of risk for the private investors of not being able to obtain a reasonable rate of return. Regulation for off-grid electricity supply should not be a significant barrier to entry for off-grid operators and should not create an unnecessary burden on electricity regulators. In particular, when the supply companies are small, regulation that is time-consuming and costly to comply with could make off-grid electricity businesses unprofitable. Transparent, quick and standardized procedures should be adopted.

## Should off-grid solutions be grid-compatible?

A major shortcoming of leaving microgrids unregulated is that the supply technology is typically of such low quality that it is not grid compatible. In those places where connection to the grid is a possibility, this exacerbates the risk for private developers (who will have to remove the assets if grid-connection happens), results in higher costs for consumers (who typically cover the cost of the financial risk of the developers who may want to recover their investment costs quickly), and leads to a waste of material resources.

Grid-compatible microgrids are a special case. They require regulatory support since they are more expensive than the most basic non grid-compatible alternative and are unaffordable for most poor households. Thus, the developers of grid-compatible micro-grids need to be compensated in order to overcome the viability gap. These grid-compatible and predominantly renewable-powered microgrids deserve to be financially supported by regulation for several reasons: a) their assets are less likely to be discarded if/when the grid ultimately arrives, thereby reducing the risk to potential investors (as well as resource waste; b) if the original renewable-powered generation assets remain, they will not be replaced by the grid-connected generation mix, which is predominantly based on fossil fuels in most countries, setting the path for a less carbon-intensive model for the power sector; c) since grid-compatible micro-grids can provide a level of service similar to (or in many cases, better than) that of the existing grid, they reduce the consumer concern that establishing a micro-grid will only delay the arrival of the grid (a not-uncommon concern); and d) in those places that can be eventually reached by the grid, privately financed micro-grids reduce the pressure on the incumbent distribution company to extend the grid, delaying the utility's obligation until they are financially able to fulfill it.

In order to mitigate the risk of a stranded business when the grid connection arrives and to incentivize investment in microgrids, it is necessary to institute an appropriate regulatory framework to mandate compulsory purchase of power into the grid from such micro grids at a tariff to be determined considering depreciation of the microgrid investments, as approved by the appropriate energy regulatory authority. The microgrid developer should have the option to choose one of the following structures to govern its engagement with the incumbent utility: small power distributor (keeping the entire microgrid activity), small power producer (selling the network to the incumbent distributor, but keeping the generation) or buyout of the whole business (Tenenbaum *et al.*, 2014; OKAPI, 2017). See Box 2.

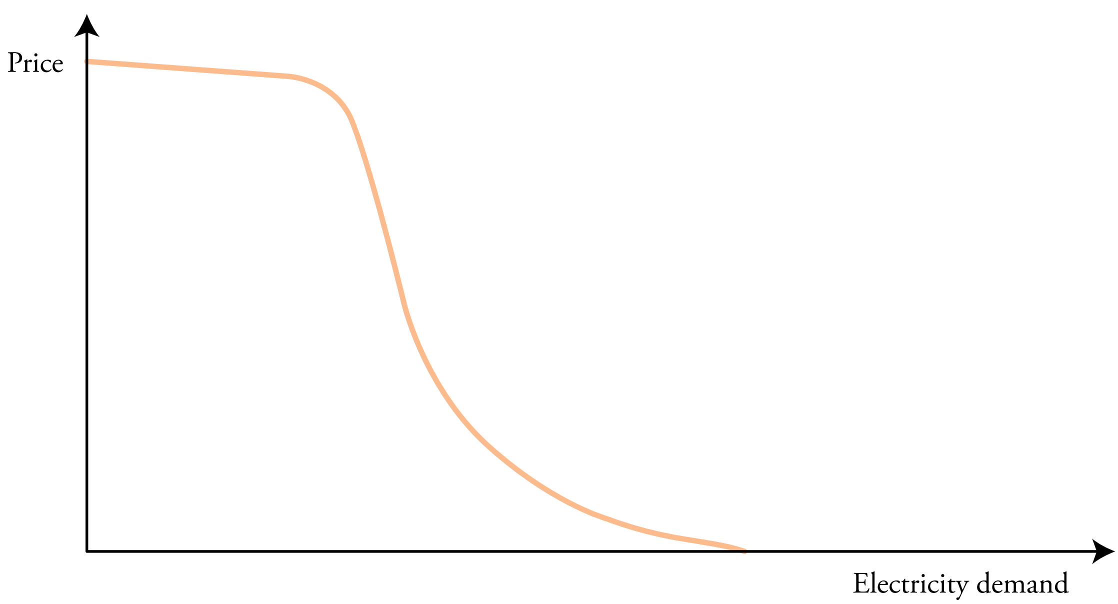
Regulation can prevent the waste of resources that follows from local off-grid systems being built independently, with different technical standards. Where technical standards are uniform, a market for components and replacement develops, facilitating a longer life to electrification projects and lower prices for maintenance. As indicated above, in many cases it is expected that the national grid will be eventually extended to reach isolated mini-grids. If the technical standards are identical or compatible, integration is easy, while if they are not compatible the isolated system may be fully replaced and parts of it abandoned even if not fully depreciated.

## How to engage the beneficiaries?

There is just one figure in this paper, purposely, to highlight its importance and the hidden complexity behind its deceptive simplicity. All consumers, wealthy and poor, give a very high value (utility) to the first watt-hours (electric energy) of consumption, the ones that allow them to meet the most urgent needs of lighting, communication, or the creation of a breeze on a hot night. The value decreases for each additional watt-hour used to meet less essential needs (this is just an extreme case of the basic principle of diminishing marginal utility). Not all consumers have the same needs, preferences, and affordability so each consumer has a different curve, however each has roughly the same shape. This curve will evolve over time, as the economic conditions, the new activities allowed by electricity access, and affordability change. Moreover, each curve also depends on the quality of supply. Consumers do not give the same value to a given quantity of reliable watt-hours, which can be used whenever they are demanded, as they give to unreliable electricity supply, which can unexpectedly fail when it is needed most.

This curve (or family of curves) illustrates the difficulty that an electrification planner faces when trying to estimate the demand to be supplied and

Exhibit 1



the willingness to pay of the beneficiaries. Demand level, quality of supply and willingness to pay are inextricably related.

Understanding and forecasting demand is critical to designing the supply of electricity. It is even more so when the potential consumers have not had the experience of using electricity, which happens to be an essential enabling factor for their development, both economically and in other dimensions of life.

How much are the beneficiaries of an electrification project willing to pay? How does that willingness change if a provider offers "perfect" service (*i.e.*, close to 100% continuity of supply, good quality of the waveform, no limit on the amount of power consumed) versus less-than-perfect service? How do we define these imperfect services (*i.e.* the reliability of the proposed service) so that they make sense as real options for the customers to be supplied?[23]

A viable business model must account for the preferences, priorities, social, behavioral, and cultural characteristics of the beneficiaries. Multiple aspects have to be considered: i) the projection of future demand, including the tight interdependence between demand, affordability, and reliability; ii) how to package the "product" (the electricity service) to be offered so that its "reliability" level is understood and actionable by the different stakeholders; iii) game changing technology options and trajectories from the beneficiaries' perspective, like ICT technologies and innovations or home solar kits; iv) implementing social, economic and environmental sustainability; and v) a holistic perspective that combines technology, business models, community engagement, and preferences for use of primary energy resources (Spratt *et al.*, 2016).

Community engagement is a key activity for the success of electrification projects, especially off-grid electrification modes, which are typically more tailor-made

23 The concept of reliability, or quality of electricity supply, is easily grasped in a first approximation, but it is difficult to convey in practical actionable terms that can be understood for a non-expert population. The performance metrics to be used have to be simple to understand, but have to be able to reflect what matters to people (frequency, duration and extent of outages, and when they occur). These metrics have to be integrated in the terms of contracts and in incentives of remuneration mechanisms to be used by regulatory authorities. They should be an essential element in the design of grid-extension plans and microgrids.

and require more interaction with the local communities. The required skills and the time devoted to this activity should not be underestimated, see (ITD UPM, 2017). Successful off-grid electrification solutions are often well adapted to the local context, enhance and leverage existing resources and capabilities, enable the creation of economic opportunities and enterprises, and increase capacity for social organization.

## How can an electrification project be made sustainable?

This is probably the most important factor for the long-term success of an electrification project. Sustainability has several dimensions: financial, technical, social, and environmental, all of which are critical. Any electrification plan must have a vocation of unlimited permanence. In this respect, business models should get as close as possible to the "utility model" (*i.e.*, an organization is responsible for the supply with a prescribed or agreed minimum level of reliability, at an efficient cost, forever).

- *Financial*. The financial design of the electrification plan must make sense, from the outset and forever. As indicated before, meaningful electricity access requires subsidies, in the up-front investment costs and also possibly in the future tariffs for those that cannot afford them. This has to be fully accounted for in the specification of the electrification plan.

- *Technical*. Distribution networks, and power systems in general, live forever. While transformers, cables, insulators, protections, and other gear are replaced and upgraded, and new circuits are created, the overall supply system remains. The same should be the case with off-grid supply technologies, whether they are expected to become connected to the grid or to remain isolated. Here the maintenance procedures are critical and they have to be included in the electrification plan and the selection of the supply technology and business model from the outset. Much has been discussed and written on the topic and much can be learned from successful and failed experiences. Different issues are involved here, from the technical capacitation of local people, to the sense of ownership by the community, to the allocation of responsibility to some stable organization with some utility-like characteristics for off-grid solutions.

- *Social*. This is directly related to consumer engagement and preferences. The beneficiaries must accept the business model, both individually and as a community, if the electrification plan is to survive. As a general principle, the higher the engagement of the community, the higher the chances of a sustainable business model. This engagement can be enhanced by the utilization of local energy resources. It can be added that the utility or utility-like models, if well accepted by the consumers, also provide a sound guarantee of social sustainability.

- *Environmental*. The environmental impacts of universal electricity access have been typically neglected, with the implicit assumption that the level of consumption of these new consumers will be so low that the impact on carbon emissions or other local environmental impacts will be insignificant. However, these assumptions have to be reconsidered, as some authors have pointed out recently: a vast number of consumers are expected to reach comfortable levels of electricity demand within a few decades, in addition to the people who are now benefiting from sound access in more developed countries. If the wrong supply technologies are adopted now, it will be very difficult to revert that trend later. Sustainability concerns should be present from the outset on the design board of any electrification plan and they should impact the choice of the adopted solution, both from the point of view of the supply technology and for the choice of business model.

Obviously, one of the potential concerns of the environmental sustainability of universal electrification is climate change. While emissions should not be used as an excuse to deny access to a basic level of electricity, neither should electricity access be planned without regard to the climate implications of growing access and consumption. This is the right time to guide the adoption of a long-term electrification path in developing countries that is based on economically and environmentally sustainable systems, leveraging close cooperation among governments, international organizations, and electricity players.

While a basic level of electricity access should not be sacrificed in the name of carbon emissions, as the emissions are small and the human dignity implications are large, it is increasingly possible that this is a false tradeoff. It is possible to expand electricity access while using low-carbon generation methods, as evidenced by the proliferation of solar-powered microgrids and home systems in India and Africa, and the significant regulatory and financial support from India's government for renewable-powered on and off-grid generation. Incorporating that off-grid generation into the central grid as it expands will not only do a favor for microgrid investors, but also for the climate.

## Electrification is much more than the last mile

This paper has focused mostly on the distribution component of electrification, at lower voltage levels, close to the end consumer. However, in the most frequent case of grid connection, when the volume of demand to be electrified is substantial, it is also necessary to reinforce or expand the high voltage distribution network –also named sub-transmission– and the transmission networks, as well as the addition of new generation.

Much has been discussed and written on the failure to deploy sufficient large infrastructures of generation and transmission, without which electrification is greatly encumbered. (Kapika and Eberhard, 2013) and (Eberhard *et al.*, 2016) state that the primary reason for the dismal record of Sub-Saharan Africa's power sector is simply that the region does not generate enough electricity. The lack of sufficient transmission capacity limits the support that trade between countries could contribute to mitigate power shortages. These and other references show that sound regulation (for instance, the use of cost-reflective tariffs), backed by independent regulatory agencies, can provide more revenue certainty and do much to encourage investment. Power planning and timely initiation of competitive tenders or auctions for new capacity are also important. The lack of sound transmission cost allocation rules makes it difficult for the parties involved to reach agreement in the planning and construction of interconnection lines (Rose, 2017). Novel approaches have been proposed recently to mitigate the financial risk of investors in large generation plants by centralizing and standardizing the tendering and contracting processes (Africa GreenCo and The Rockefeller Foundation, 2017).

## THE WAY FORWARD

Providing electricity –at a level that allows living with dignity in our time– to 1.2 billion people and to improve radically the quality of service to an additional 2 billion people requires a huge amount of investment, plus the costs of operating and maintaining the new assets. If the reader of this paper lives in a country –or a state in a large country– with, for example, forty million people, all of them with electricity supply, universal electricity access in the long-term –where the non-electrified people today can be assumed to attain a "normal" standard of living– will require thirty times the existing power sector infrastructure in this country of reference.

In today's world economy such a large investment can only be carried out by the private sector, leveraged by public financing and regulatory support. Therefore, this huge electrification effort has to be based on viable business models, which have to be indefinitely sustainable (economically, socially, and environmentally), replacing or replicating what the traditional utilities have done so far everywhere.

These viable business models of electrification must be well adapted to each specific country environment and, in particular, to the regulatory framework that enables them. It has been shown in this paper that this regulation must depart from the well-established practice. It is probably one of the major regulatory challenges of our time, if not the greatest, to determine how to make use of elements of classical regulation while also introducing new features that respond to the very different underlying assumptions in those regions of the world in most need of electrification. In some cases, the measures should just consist of applying the well-known principles and methods that have functioned well in developed countries. Creativity will be needed in other cases in the search for solutions to new problems.

Both grid-extension and off-grid solutions will be necessary, although off-grid assets might end up being often transitory, as in many places the interconnected grid will in the end prevail. Where this is the case, the off-grid infrastructure –if properly designed as grid compatible– can be the support that will ultimately facilitate grid extension and retain local renewable generation resources.

The agents of this transformation could be a multiplicity of small developers, large energy companies that still are only marginally at present in these least developed countries, the incumbent distribution utilities, or combinations of them under different possible formats: parallel operation with total independence from one another, off-grid developers as franchises of the incumbent distributor, licenses given to external large companies to electrify a territory under regulated monopolistic conditions, some form of aggregation of multiple small business models via association or acquisition by a larger firm, or some other approaches, such as rural cooperatives. This is one of the most uncertain aspects of the future electrification process.

Electrification business models must be defined with a permanent provision of service in mind, without an end in sight, as the classical electric utilities were conceived, and with the capability to grow, imposing no limits to the economic development of individual users and communities. This requires paying attention to and demonstrating the technical, economic, environmental, and social dimensions of sustainability. This implies that the future supply costs will be covered for the economic life of the facilities and beyond, that the facilities will be properly maintained without any time limit, and that the environmental impact associated to the production and consumption of electricity will be tolerable.

Economic sustainability requires squarely addressing the "viability gap" issue, *i.e.* how to cover the difference between the true costs (*i.e.* "no subsidies") of electricity supply and the official tariff applied to the consumers, or, alternatively, their willingness to pay for an agreed service with a prescribed reliability level. A large viability gap associated to a given electrification plan will suggest the need for a gradual or "phased" approach, conditioned by financial limits and the need to engage the beneficiaries, at whatever pace it may take.

Good governance and sound regulation do much to reduce investment risk and therefore the cost of capital of an electrification plan. Innovative financing approaches that are adapted to the specific conditions of the power sector in least developed countries can facilitate investment in large infrastructures.

Understanding and engaging the consumers' side at individual and community levels is of essence for the social component of the sustainability of an electrification plan. This is of critical importance for off-grid solutions. Special attention should be paid to the interrelationship between demand level, quality of service, and willingness to pay.

Planning for universal electricity access in countries currently with a low electrification level will entail large numbers of new grid connections. This may require the reinforcement or expansion of the transmission network and the addition of new generation, therefore demanding a complete appraisal of the power system.

Given the scale of the challenge and the diversity of options for electrifying vast regions, effective planning tools are necessary to help governments, electrification agencies, donors and other stakeholders plan and allocate their limited resources wisely, and to reduce the risk for investors and consumers. These tools can be very powerful if they can make use of digital databases of customers and electrical network facilities. They can facilitate the assessment of the economic viability of the business models, –either from the private investor perspective or from a regulatory authority that establishes a remuneration or a tariff for service–.

Due attention should be given to the specific characteristics of the countries where the business models might be deployed: political stability, governance of the institutions, independence of the regulatory authorities, corruption level, and sound energy policy, among others.

A viable business model must be consistent with high level strategic or policy considerations (the "top down viewpoint") for the specific country being considered. High level matters include: i) consistency with priorities in energy policy, *e.g.*, what are the target levels of access? ; ii) climate change implications of the adopted electrification mode and the role that international cooperation could play; iii) the economic value of electricity access and the implications for establishing priorities and allocating scarce resources to different sectors; iv) implications for global security, foreign policy, and energy security in least developed countries; and v) interaction with other drivers of development: water and sanitation, ICT, education, health, agriculture, or transport. The potential contribution of electricity access to development can only be realized if the other enabling factors are also present.

The time is now ripe for the adoption of one or more comprehensive and ambitious approaches, spearheaded by large energy companies in parallel with a multiplicity of local initiatives under some common purpose and coordination, commensurate with the scale of the problem and conscious of the local constraints associated to each specific country and the beneficiary communities. These approaches must be consistent with the global effort towards the use of clean energy technologies, and must be based on a rigorous quantitative assessment of the technical and economic efforts involved, while also including sound measures to overcome the important financial, regulatory, political, technological, managerial, and social barriers that exist.

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## CASE STUDIES

**Box 1. The experience of Acciona Microenergía in Peru**[24]

In the Peru extremely poor mountain region of Cajamarca an interesting new business model has been implemented for stand-alone residential solar home systems. The story initiated in 2008 when Acciona, a large Spanish construction company operating worldwide and expanding into renewable energy, set up Foundation Acciona Microenergìa as its channel for social action initiatives related to basic services. In 2009 Acciona set up an association in Peru called Acciona Microenergìa Perú, acting as a small social service company that provides service in isolated communities. The association started a project called "Luz en casa", installing basic solar systems in 100 small villages scattered in a large territory, and progressively expanded to reach 4,000 households in 2015. Luz en Casa broke even at the end of 2013, charging the equivalent of US$ 3.50 monthly for three lamps and one socket, that is only two thirds of what they paid before for candles, kerosene, and mobile charging. Default rates for this program have been lower than 1%.

In 2010 the Peru Office for electricity tariffs regulation introduced the photovoltaic tariff, which allows the application of the "social" tariff to the electricity users supplied by off-grid solar home systems. A "social" tariff was in force in Peru, as similar provisions are in many countries, to reduce the burden of electricity bills on households in weak economic conditions; its application to isolated systems was an innovation worth considering by many countries.

24 See (https://www.acciona.com/sustainability/society/acciona-microenergia-foundation/).

**Box 2. Regulation for grid-compatible microgrids in India**

The amendments to India's Electricity Act of 2003 require state regulators to propose regulations for buying power generated by microgrids when they are connected to the main grid. This description does not capture the whole story, however, as the costs of the network and other non-generation components of the microgrid are also significant investments requiring some compensation.

These aspects are, however, addressed in the Forum of Regulators' model regulation in this area. It sets forth a framework in which a microgrid would operate as the franchisee of a utility, with a license and an exclusive right to provide service within their geographical area. The microgrid would be required to charge tariffs that are no higher than the grid's tariffs, which would certainly be below the costs of supply. To reimburse this viability gap, the costs of generation would be subsidized through a Feed in Tariff agreed upon in a Power Purchase Agreement with the incumbent distributor through franchisee fees. Before receiving their license, the microgrid would be required to obtain the consent of the local governing body, after presenting them with a comprehensive plan.

The State Electricity Regulatory Commission would be required to determine the amount of the Feed in Tariff for each renewable generation technology recognized by the Ministry of New and Renewable Energy. The determination of the Feed in Tariff would be through a cost-plus methodology, in which the tariff is set to cover the expected costs of operation plus a rate of return on capital investments, and would thus require only infrequent re-examination. Microgrid operators could request a revision in this tariff if they felt it was unfair. The other costs of distribution and management would be subsidized through a franchisee fee paid by the distribution company to the microgrid operator, determined by mutual agreement of the distributor and the microgrid.

Once the central grid reaches the franchisee, the incumbent distributor is to buy out the franchisee's network assets at book value. The franchisee will continue to own the generation and will continue to sell generated power to the grid at the pre-determined feed-in-tariff.