Electrification planning with a focus on human factors

Roxanne Rahnama and Ignacio Pérez-Arriaga

Despite the steady improvement in electrification rates in low income and developing countries (LIDCs) in the last few decades, an estimated 16 per cent of the global population – over one thousand million people, largely concentrated in India and sub-Saharan Africa – still lack access. Progress toward the Sustainable Development Goal of universal access by 2030 remains elusive in sub-Saharan Africa, where population growth matches the electrification rate. Even these statistics are gross underestimates of the true magnitude of access challenges, given the inconsistencies in how electrification is measured by various governments, as well as the financial and psychological costs imposed on the millions more living with unreliable power.

The stubbornness of the problem has financial, technological, and social roots. Populist policies directed at meeting residential and agricultural demands have kept electricity tariffs below supply costs in practically all sub-Saharan countries, rendering the distribution utilities bankrupt and thus unable to invest to connect more customers, which would further exacerbate their financial situation. The traditional approach to electrification by grid extension becomes impossibly expensive for the small and dispersed demand in rural areas. Frustrated customers with unreliable service stop paying their bills or decide to connect illegally, developing an adversarial relationship with the distribution company. Governments periodically must bail out these companies at a high cost, because of their enormous losses, leaving the root cause of the problem untouched. Other dimensions of the problem, in particular the lack of investment in generation and transmission infrastructure, are beyond the scope of this paper.

Only recently, developments in photovoltaic generation, battery, and information and communication technologies have offered the possibility of off-grid electrification in rural areas. These off-grid supply technologies further serve as complements or alternative to unreliable supply anywhere. Although off-grid solutions are cost competitive with grid extension for small and dispersed loads, they may not be affordable for many potential users, and may not be suitable for electricity-intensive appliances and community and production uses.

Too often, electrification planning is exclusively addressed from the technical and economic perspectives, without seriously questioning the nuanced ways in which electricity services are actually perceived, used, and paid for at various levels. Here we argue that no solution will be satisfactory unless it addresses the complex socio-political, cultural, and behavioural factors that contribute to the present unsatisfactory situation of electricity access in LIDCs.

The complexity of electricity consumers has often been neglected in the discourse on financially sustainable electrification. Recent experiences and studies have revealed widespread variability in the attitudes, behaviour, and decision-making processes of the energy poor – and show the consumers’ valuation of different electricity attributes, their aspirations for access and reliability, and their opportunities for future productive growth. Differences in the political, informational, and technological environment for consumers in low-access countries create non-negligible effects on their psyches and subsequent valuations of different electricity attributes. To serve these populations well requires consumer-centred business models.
Utility metrics

In this section we define and examine in detail the key metrics that are used in electrification planning to characterize energy poverty, welfare, reliability, and access levels. We focus on willingness to pay, ability to pay, and the cost of non-served energy, examining their relationships with quality of service.

The ultimate goal of electrification planning is to maximize the social welfare associated with electricity supply. Assuming that the price of electricity is known, its affordability (and that of electrical appliances) for the customers and their preferences will determine their optimal level of consumption and the associated utility function of electricity utilization for each customer, which equals his or her willingness to pay (WTP) for the service.

WTP is constrained by ability to pay (ATP). WTP reflects not what customers would pay if they could, but what they are willing to pay out of their actual resources. It cannot exceed ATP, and it may not be realized in practice if there is insufficient access. The perfect access level can be defined as the one that does not limit the supply of electricity that customers are willing to use and to pay for, as described by their WTP, adjusted for any existing subsidies.

The WTP of any customer for the first few watt hours of consumption is very high (if you do not believe this, check the first lesson in any microeconomics textbook on the price/demand curve). This is why many poor customers in LIDCs pay, in monthly or weekly fixed amounts, an extremely high price – when calculated in per unit of electricity consumption – for the small amounts of electricity that they consume in on- and off-grid systems. When the ATP increases, the total amount of electricity consumed increases and (again the price/demand curve) the marginal WTP decreases. Efficient tariffs are based on this marginal WTP, resulting in consumer surplus, since the consumers are willing to pay more than this marginal WTP for the first units of energy. If tariffs are not regulated, the poorest customers may end up paying a high price, close to their marginal WTP, with a very low surplus.

Failures of electricity supply reduce the continuity and quality of the electricity received by customers, and consequently their utility functions or WTP. The corresponding loss of utility to each customer is also termed the cost of non-served energy (CNSE).

The term ‘reliability’ broadly describes how well the power system does in supplying electricity – the quality of service. It encompasses the continuity of the service, which in turn is described by the frequency, duration, and quantity of demand affected by an interruption, as well as the time at which the interruption occurs. Reliability also includes the technical quality of the supply: the voltage level, waveform shape (if in alternating current), and micro-interruptions. Studies of consumers’ responses in LIDCs have concluded that WTP critically depends on reliability, with its many attributes.

In industrialized countries, most customers are accustomed to almost perfect reliability and almost never have to make choices in this respect. The situation in LIDCs is very different: both planners and customers face trade-offs between cost and reliability. Nonsophisticated customers have to choose among several delivery modes and options within each mode, each of which comes with varying costs and levels of reliability. It seems that we have not yet been able to figure out a fully satisfactory approach to incorporating reliability performance metrics into human-centred business model planning in LIDCs.

The term ‘willingness to pay’ (WTP) suggests a method of measuring or estimating the value of individual utilities, just by asking customers how much they would be willing to pay for a supply of electricity with certain characteristics. However, this is more simply said than done. Just think what you would pay to have one unit of electricity at different times of the day and under different circumstances (e.g. while sleeping, in an elevator, or charging your phone). In practice it is somewhat simpler to ask for the CNSE – how much a customer would pay to avoid an interruption of electricity of a specific duration at a given time. However, again, in the context of
electricity supply in LIDCs, it is more useful in the interaction with customers to use, for instance, the WTP per month for an electricity supply of some characteristics. Current methods for estimating these WTP values include contingent valuation and discrete choice experiments that aim to model either directly stated or indirectly revealed preferences.

Electrification planners who use computer models need to represent the cost of lost supply in their simulations. In this context, it is useful to assign a CNSE value to every kWh that is curtailed in the power system. If the model is able to work at the individual customer level, as is the case for the Reference Electrification Model REM (see http://universalaccess.mit.edu), it may be possible to distinguish between a CNSE for critical loads at certain times of the day and another, lower CNSE for the rest of the demand. But it remains difficult to estimate the value of CNSE. A simple way to circumvent this problem is to use the computer model to obtain the electrification plan several times, each time with a different CNSE value, and let the customers (or the system planner with input from the customers) decide which plan, with its combination of cost and performance, is preferred.

One more nuance regarding CNSE relates to the context in which electrification planning takes place. In a multisectorial planning context, the planner may have to, for example, assign limited resources to health, education, transportation, and electrification objectives. In this case, the CNSE refers to the difference between having some level of electricity access and having none at all. This can make a major difference in the wellbeing of a household or community. On the other hand, in the context of electrification planning alone, everybody is supposed to receive some kind of electricity supply, and the meaning of CNSE is the one described before: the cost to the customer of an interruption to existing supply levels.

Understanding income-constrained consumers

As indicated above, the relationship between electricity users and suppliers is generally much more complex in LIDCs than in industrialized countries. Commercial losses – resulting from unpaid bills and illegal connections – are very high, as shown in the following sample of revenue collection rates in western Africa. Off-grid options for many of these existing or potential customers complicate the picture even more.

Revenue collection rates
The success of an electrification plan under these complex conditions critically depends on a well-thought-out consumer engagement plan, and on understanding what the customer wants. The utility derived from electricity use has two main components: the ‘utilitarian’ attributes that are directly associated with its instrumental and functional purposes, and the more subjective ‘hedonic’ attributes such as pleasure, happiness, and social stature that it provides. When consumers choose between various options, the ways in which they assess the trade-offs are influenced by social, economic, demographic, behavioural, and technical components that interact with each other. The continuity of power supply and other measures of quality of service – like voltage level or customer interaction – have a major impact on consumers’ valuation of the utilitarian attributes for both grid and off-grid services. There are also large differences in the social and hedonic attributes. For example, while the actual utilitarian or functional attribute of reliable electricity from a microgrid or solar home system may be much higher than that of unreliable grid access, the perceived hedonic attributes of grid electricity, such as higher social status associated with connection to the grid system, may hold greater weight.

Socioeconomic and demographic factors such as higher income, educational status, number of school-age children, and ownership of or aspiration to own a home business generally indicate an increase in the perceived utility or WTP. In contrast, studies have found age, occupation, and household structures to have more ambiguous effects. WTP depends on how reliability is measured or presented to consumers. For example, household WTP differs according to whether the expectation of an outage is communicated beforehand. WTP also depends on differences in households' financial ability to cope with outages by using alternative backup sources (e.g. diesel or kerosene) or simultaneous grid and off-grid connections.

Behaviourally, different cognitive factors – including negative reciprocity, trust, reference dependence, status quo bias, mental accounting, and information and inattention bias – can theoretically influence consumers’ WTP; often, the direction of the effect varies based on the aforementioned demographic, socioeconomic, and technical parameters. For example, the age or educational status of a household member has important implications for the degree of reference dependence, status quo bias, and inattention bias held and the ways in which this affects WTP. The ways in which information is communicated to consumers can also have profound effects on trust and the propensity to hold a bias of negative and/or positive reciprocity toward the government or a private electricity service provider.

**Implications for customer-focused electrification approaches**

Several successful experiences with distribution franchises, mostly in India, have shown that a prerequisite for any kind of consumer engagement activity is an electricity supply with an acceptable technical quality of service. However, diverse complementary measures are also necessary to promote sustainable, long-term shifts in consumers’ attitudes and behaviour. We have grouped them into three categories.

- **Electricity theft, attitudes toward tariff hikes, and bill payments:** Where trust and reciprocity are low – with outbreaks of hostility when utility employees attempt to enforce bill payment – strategies based on the threat of pecuniary penalties or social shaming may backfire. Receptivity to messages can depend heavily on the person or entity communicating the message: a threat or shame-based nudge may carry much more weight when it is communicated by a trusted local leader rather than by a service provider who is perceived as illegitimate or untrustworthy. Some degree of experimental testing should be carried out by the electricity provider, in partnership with a local community network, to identify the social signalling design that would work most effectively and sustainably under local social and cultural norms.

- **ATP-related challenges:** Sensitivity to local cultural and social norms is also necessary in relation to ATP. It has been found that a financial incentive scheme that involved monetary awards for energy conservation and penalties for poor conservation practices rebounded, likely due to low-income consumers’ mistrust of particular financial contracts. Default (opt-in/opt-out) schemes for saving money may have lower levels of acceptance than individual or pooled savings mechanisms administered by locally trusted savings and credit
groups that partner with the electricity service provider. The efficacy of some personalized messaging tactics may be contingent on the prevalence of mobile applications and mobile payment adoption in a particular country or region. Thus, sensitivity to both technological and cultural constraints should be maintained when designing interventions to enhance ATP.

Closing the gap between appliance ownership and aspirations:

- When planning interventions to help consumers acquire the appliances they aspire to own, it is important for electricity service providers to take into account phenomena that may vary with local economic and social conditions. For example, an opt-in/opt-out ‘appliance savings account’ may be effective where a service provider is well trusted and has a strong relationship with consumers. But it may fail in the absence of ground-level capacity and long-term trust-building; in environments with high information asymmetries and poor communication about expectations, consumers will likely perceive it as a scam allowing the service provider to steal their money. An initial analysis of attitudes toward government vs. private electricity service provision and randomized testing of different promotional tactics is important for creating approaches that will be effective in a specific country and context.

Conclusion

There is enough evidence to support the idea that a better understanding of customers and a focus on customer engagement is essential for the success of electrification processes in LIDCs.