The choice between grid and off-grid electrification in Kenya and its impact on system development

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Abstract

This paper explores the dynamics of the concurrent development of grid-based and off-grid electrification in Kenya. Consumers in Kenya who can afford to use electricity must choose to be connected to the national grid or to purchase a standalone system (usually diesel or photovoltaic generators). This decision is based not on price alone, but on the relative availability and reliability of the options. Although competition usually spurs growth, in this case it appears that the presence of strong off-grid choices may be hindering the development of the grid. If this is the true, energy planners may need to consider policy options which encourage complementary development of grid and off-grid markets.

Keywords

Electrification planning, Africa

Introduction

In Africa and India, less than 40% of the population has access to electricity. Particularly in Africa, electrification is hindered by poverty and the low population density of the region. Several authors (Nasen, Evertsson et al. 2002; Nguyen 2007) have speculated as to whether a decentralized or off-grid system architecture is more appropriate for developing countries, but have not explored the dynamics motivating the choice between grid and off-grid or the implications of that choice. This paper looks at the relationship between grid and off-grid planning for residential consumers in Kenya, and how the tension between these two architectures impacts the development of the electrification system as a whole.

Kenya's electrification rate is very low, even for Africa. Table 1 shows the percent of the population with access to grid electricity from 1993 to 2002 (Karekezi et al 2004). These figures show the discrepancy between urban and rural access. Although more than 70% of the population lives in rural areas, only about 1% of people have access to electric power.

	1993	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
National	4.4	4.5	4.6	4.8	4.9	5.0	5.1	5.4	5.5	6.1
Urban	16.7	17.0	17.3	18.1	18.2	18.7	19.1	20.0	20.4	22.7
Rural	0.5	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9

Table 1: Electrification rates in Kenya from 1993-2002

Gaining access to grid electricity can be costly and frustrating. The fee for connection is KSh 35,000 (about US$ 500) and there can be a delay of several years between the application for connection and the actual installation[1]. The grid can also be unreliable. A recent report estimates that there are 11,000 outages per month on the system (Hall 2006) and consumers reported in interviews that interruptions in service occur anywhere from

[1] This statement, and other anecdotal evidence presented in the paper, is based on interviews conducted in Kenya in 2006. Residential consumers reported wait times of 2 to 10 years from the time they had submitted their application and paid fees.

1-2 times per month to many times per day. Many areas also experience severe fluctuations in voltage, which damage appliances and cause the lights to fade in and out.

As a result of the limited grid access in Kenya, the market for off-grid technologies has grown. While diesel generators have been widely used in developing countries around the world for rural electrification, Kenya has built up a uniquely successful market for photovoltaics (PV) in rural areas. PV panels are used as generators for solar home systems (SHS), which consist of the panel, a charge controller, lead acid battery, lights and appliances. Kenya's market is unique because there have been roughly 150,000 SHS sold with no subsidy and very little access to credit for purchasers. Solar home systems are now available in most rural areas through central dealers (Agumba and Osawa).

Unlike households in developed countries, Kenyan consumers face a choice in where to obtain electric service. Table 2 summarizes the options based on the capital and operating cost, availability, and reliability.

	Installation cost	Operating cost	Availability	Reliability
Grid	KSh 35,000	7 KSh/kWh	All cities; not widely available in rural areas (see Figure 1)	11,000 outages per month (overall system); most interviewees reported between 2-10 outages per month
Off-grid diesel	50-75 KSh/W	Price of diesel	Widely available nationwide through international dealers	User must maintain system, otherwise reliability is dependent on fuel supply
Off-grid solar	400-600 KSh/W	Amortized battery cost	Widely available nationwide with hundreds of local dealers and several large importers	Depends on system size and local insolation

Table 2: Comparison of grid and off-grid options (US$ 1= KSh 75)[2]

[2] Data taken from interviews and cross-referenced with Technical and Economic Assessment: Off Grid, Mini-Grid and Grid Electrification Technologies, Discussion Paper, Energy Unit, Energy and Water Department, The World Bank, November 2005.

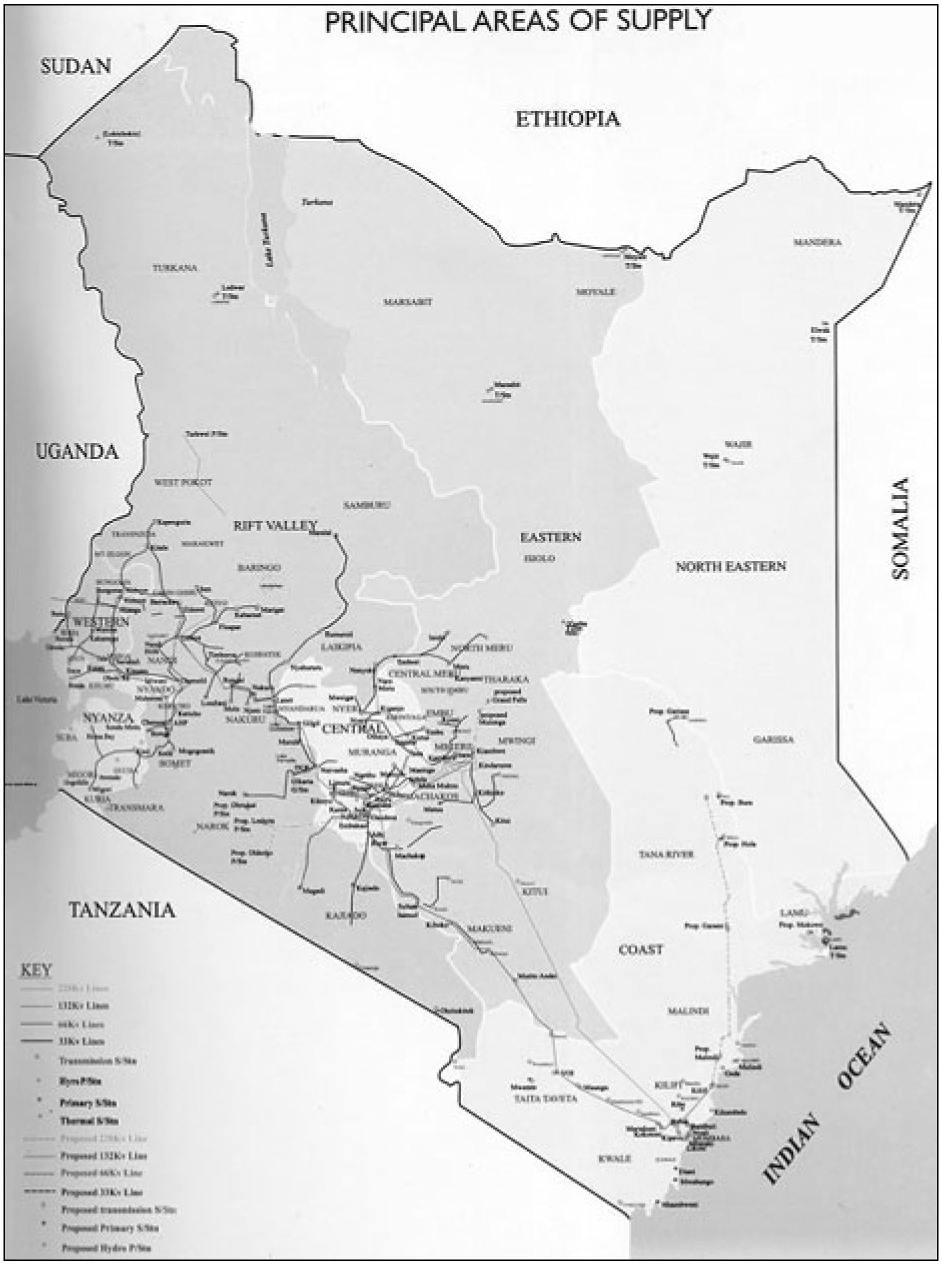

Figure 1: Map of national grid network in Kenya (KPLC 2006)

The low grid penetration in Kenya, coupled with the availability of off-grid options, creates feedback in the system development that is very different from the traditional story of electrification, as occurred in Europe, East Asia, and the Americas. This paper explores the difference by using system dynamics modeling to show how competition between grid and off-grid could affect the development of the electric power system in Kenya. Although the impact of industry of the development of the grid is significant, and there is a similar tension between grid and off-grid generation, for this paper, the focus is solely on residential consumers.

System dynamics

The study of electrification planning is not new to system dynamics, nor is the study of developing countries. However, there has been little application of the dynamics of economic development and how they impact the dynamics of infrastructure growth in developing countries. This section presents two standard system dynamics structures, lock-in and tipping points, in the context of Kenyan electrification choices.

It is not surprising that there are two competing models for Kenya's electrification system, however, it is interesting to consider if there is the possibility for lock-in with either of the systems. Lock-in typically occurs when two technologies compete for a market where network effects play an integral role in adoption. Examples include the choice between video recording formats, keyboard layouts, and computer operating systems. These are all cases where it is considered inefficient for customers to adopt multiple standards and where the market benefits from the uniformity. In the early stages of electrification in the US, there was a choice between using central generating stations and have commercial and industrial users generate their own power. In Chicago in the 1880s both options had a strong presence, but through the management of Samuel Insull, central generating stations became the dominant system (Platt 1991). Off-grid energy generators are still available, but they supply a niche market.

Technologies or architectures that succumb to path dependence typically reach a tipping point of market saturation, after which it is unreasonable for newly adopting consumers to choose the less popular item. The choices of late adopting consumers lock-in the technology as the dominant choice and give the lesser technology little chance to re-establish itself. The tipping point is usually reached when either there are price benefits to the large number of consumers (economies of scale in production and distribution) or when network effects make it undesirable to not be using the dominant technology. In the case of electrification in the US, price determined the path towards centralized architecture and network effects locked in 60 Hz alternating current as the standard power supply[3].

The case of electrification in Kenya is interesting because it is not clear yet if there will be lock-in, with either grid or off-grid electrification becoming the dominant architecture. It is also not clear if the market is approaching a saturation point, after which one system will dominate.

Reference modes

The historical reference mode for electrification based on the western model is slow uptake, followed by exponential growth. This pattern reflects the fact that there was a

[3] Although, in other regions of the world the power supply frequency and voltage became locked in at different standards. Similarly, there is still today a wide variety of outlet sizes and pin configurations, which is a sign that the network effects were confined to networks that were isolated regionally.

limited market for electrification at the beginning of the process, but that as the technology and management improved, the prices dropped and a greater portion of the population was able to afford electricity. When a large portion of the population is connected to a central grid, generation becomes cheaper due to economies of scale. In addition, a large group of diverse customers can improve the efficiency of an electric network by spreading the distribution of the load and improving the load factor. In both cases, past a threshold point, a large group of customers further encourages growth, which results in an even larger customer base.

Figure 2 shows the growth in electricity generation and sales in the late 1800s and early 1900s in the United States and United Kingdom (Hughes 1983). Both show the pace at which electricity "took off" after a threshold point.

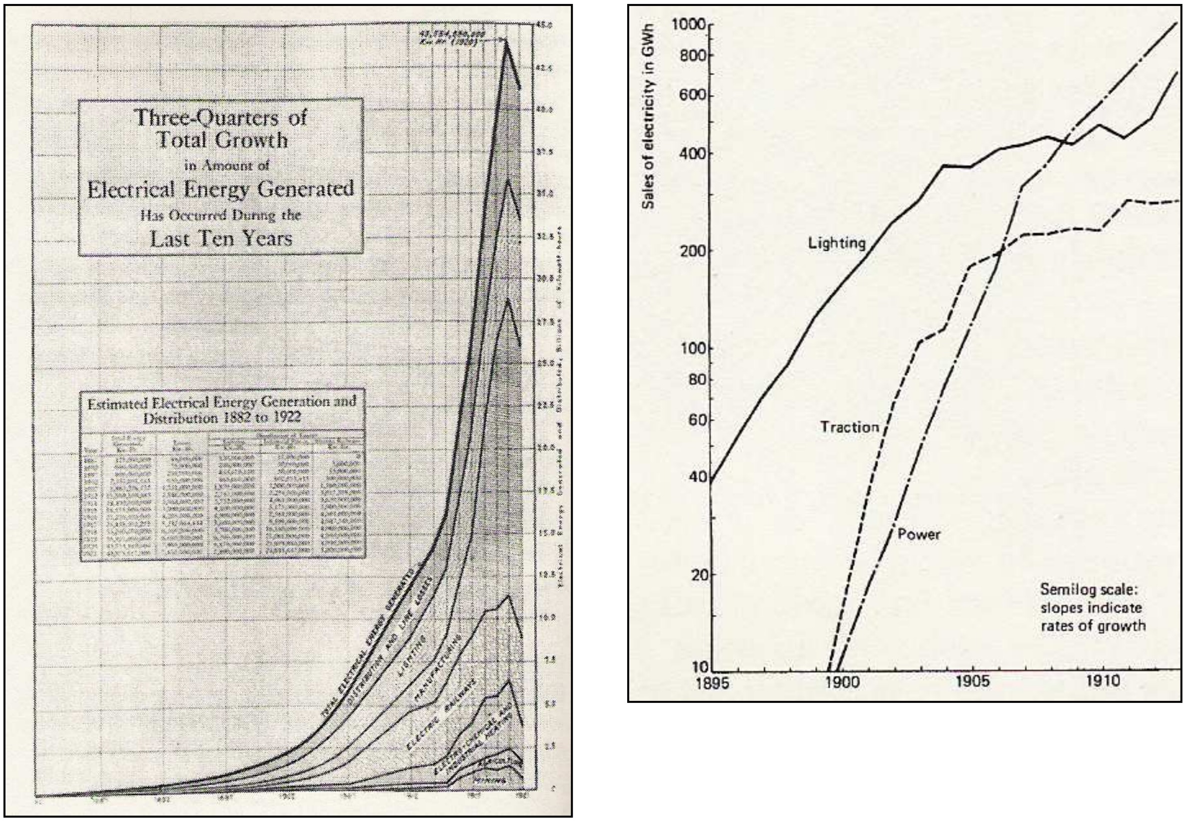

Figure 2: Growth in electrical energy generation from 1882 to 1922 (left) and growth in electricity sales by use from 1895 to 1915 in the United Kingdom (right, note semi-log scale on y-axis)

While there is not a historical reference mode for electrification which considers off-grid and grid options, there is a comparable trend in data on fixed line and mobile phones in Kenya. Based simply on price, mobile phones would have never been adopted in Kenya. Currently it costs more than 30 KSh/minute for an average mobile phone call, but only 6 KSh/minute for an average fixed line call[4]. However, mobile phones have a great advantage over fixed line phones because of the portability and convenience. Sales are also increased by the status symbol of owning a mobile phone. However, initially mobile phones broke into the Kenyan market by offering availability and reliability.

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[4] Costs figures based on fixed line to fixed line and mobile to mobile (in network) peak rates from http://www.telkom.co.ke/TelephoneTariffs.htm and http://www.safaricom.com

A report in 2007 on the cell phone revolution in Kenya (Arunga and Kahora) tells the story of an entrepreneur who was one of the early adopters of the cell phone. He purchased the phone in the mid 1990s after spending six months and US$ 300 trying to get a landline connection. Although there was a public phone outside his home, it frequently stopped working and could not be relied on for business. The cell phone cost him over US$ 3000 (about eight times the annual GDP per capita in Kenya at the time) but he considered it a good investment because he could be connected immediately and could usually find a reliable signal.

As a result of the advantages of cell phones over fixed line phones, sales grew rapidly and Kenya's mobile phone providers are now among the most profitable businesses in the country. Figure 3 shows the growth in number of subscribers of mobile and fixed line phones over the decade from 1994 to 2004 (Mbarika and Mbarika 2006). While the number of fixed line subscribers grew slowly and linearly, the mobile phone subscriptions grew exponentially.

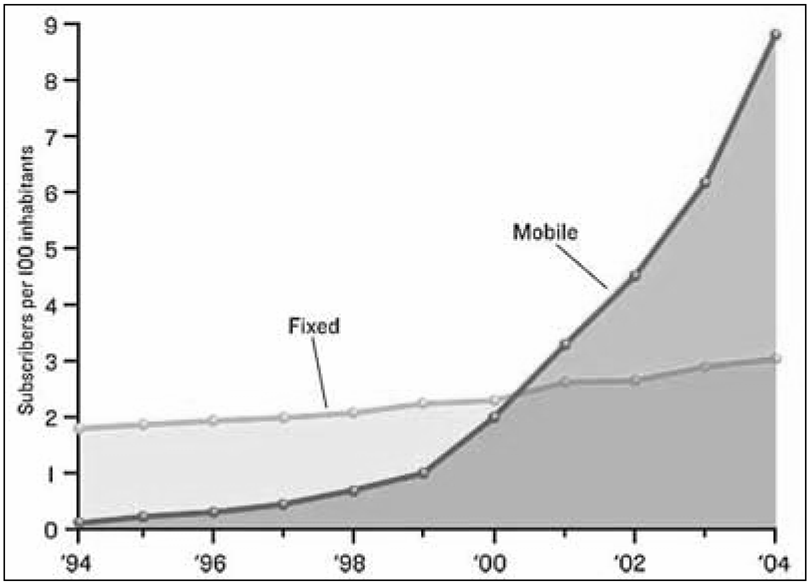
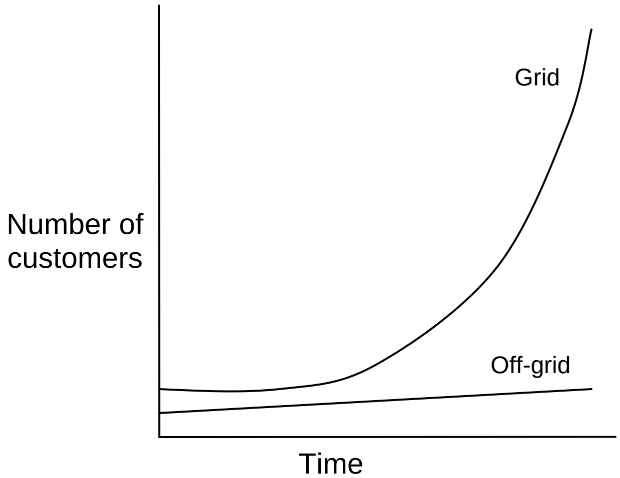


Figure 3: Growth in fixed line and mobile phone subscribers from 1994-2004

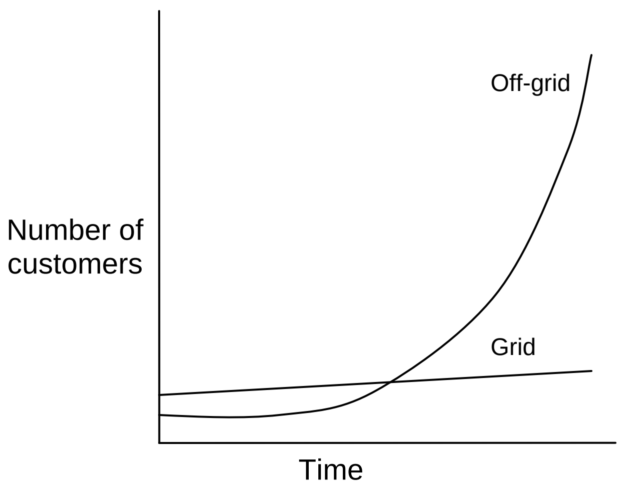
Electrification will not necessarily follow this model either. Mobile phones in developing countries are frequently seen as a substitute, as opposed to complementary, technology[5]. Few rural users will opt for a fixed line once they have purchased a mobile phone. It is not yet clear whether or not off-grid electrification systems in Kenya are complements to the grid, meaning they are used as back-ups, for specialized applications, or as a sowing technology which builds demand for grid electrification. Currently, off-grid technologies are used primarily as a substitute technology in places where the grid is not available.

Figure 4 shows three scenarios for how the number of grid and off-grid customers might grow. In the first two, one of the options becomes dominant and begins to grow exponentially while the other's growth stagnates. In the third scenario, neither option is able to secure a dominant position and the growth of both progresses slowly.

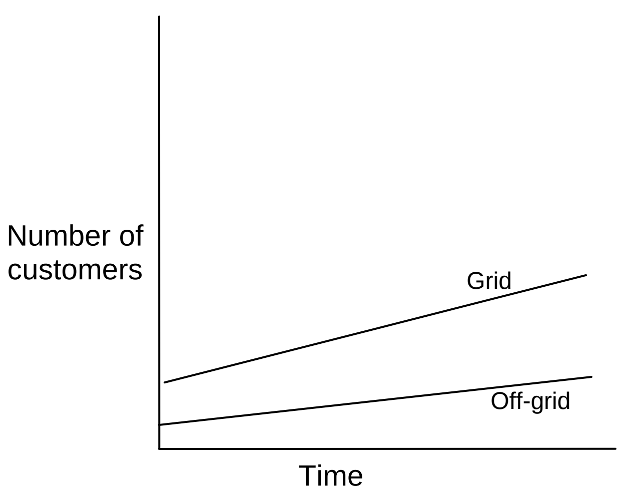
[5] This point is debated in Hamilton (2003) and she presents evidence that in the beginning mobile phones are complements to fixed line, but that as the market matures they may become substitutes.



<u>Scenario 1:</u>
Grid electricity becomes the dominant service, but there continues to be some growth in the use of off-grid for specialized applications.



<u>Scenario 2:</u>
Off-grid electricity becomes the dominant service, but the grid system continues to be used as the backbone system in urban areas.



<u>Scenario 3:</u>
Neither option is able to capture the market as both make slow improvements in service.

Figure 4: Scenarios for growth in number of grid and off-grid customers

Scenario 3 best reflects the current path of development. The question then is what policy measures could produce Scenarios 1 or 2 and which of these is the better option.

Variables and hypothesis

Most of the variables in this system are similar to those found in any other electricity markets model. However, those models usually use price as a signal for market changes. In the US electric power system, reliability and availability can be assumed. Although there are rare outages, customers do not generally have to consider whether electricity is available in their region or if they can count on the power to remain on during peak hours. Any model of the Kenya system must consider these variables.

If it is assumed the Scenario 3 from Figure 4 is the present trend, then one hypothesis is that the development of the off-grid market could be undermining the development of the grid. This hypothesis is based on there being two feedback loops, one for the growth of grid electrification and one for the relative reliability and availability of off-grid. The positive growth loop is a common feedback pattern, where the number of customers increases the ability of producers to exploit economies of scale advantages. This ability then improved quality and lowers price, which attracts more customers. The growth in Kenya appears to be stalled because the reliability and availability of the grid has not improved. In particular, it has not improved relative to off-grid systems. The presence of off-grid systems, and their relative advantages, creates a negative feedback where there would normally be positive growth (see Figure 5). If the off-grid systems are eliminated as a choice, or if the grid becomes sufficiently more reliable and widely available, this negative effect is eliminated.

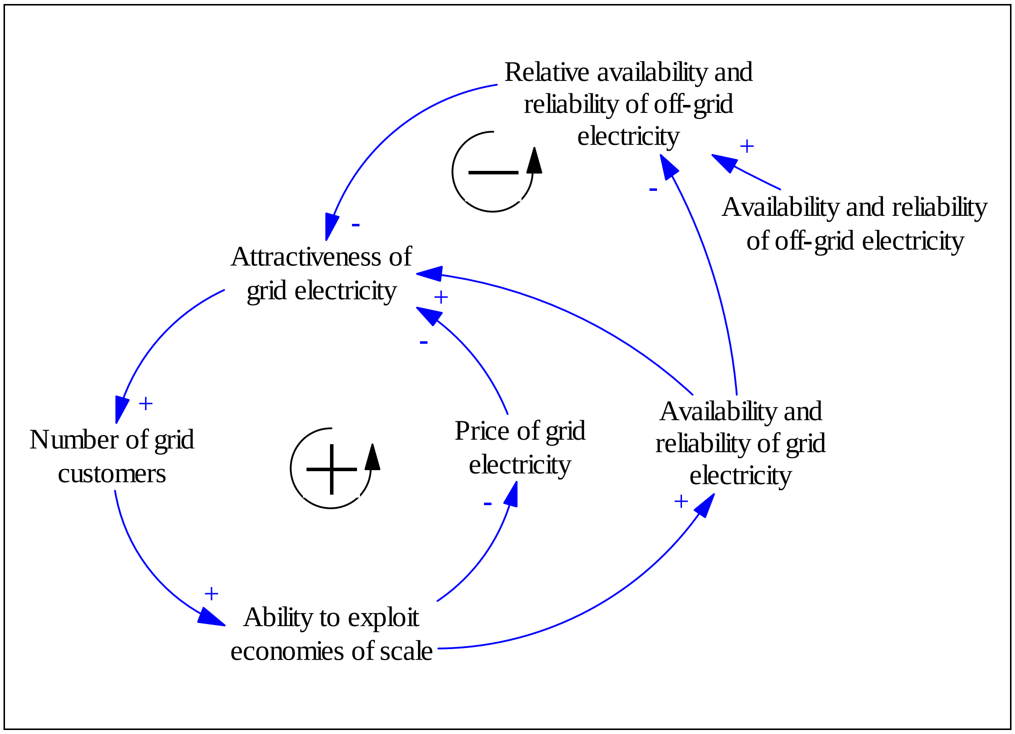


Figure 5: Impact of off-grid availability and reliability on the growth of grid-based electrification

Price of off-grid systems is not considered in this hypothesis, although it is possible that they could at some point compete with the grid prices. One difficulty in modeling price variables in Kenya is that so many of the elements that make up price are exogenous. For example, SHS prices in Kenya are dependent on world prices of PV. Given the lack of control within Kenya to fix prices and the inability to improve availability and reliability of the grid, the relative advantage of grid over off-grid may tip back and forth without either architecture ever becoming locked-in as dominant.

Next steps

The next task is to build a generic model based on the dynamics outlined above. The model will include variables for price, reliability and availability, with consumers making choices based the relative strength of the options. Ideally, this model can then be used with customer interview data to determine the most important factors in adoption of one system over the other. Additionally, it would be useful to test the hypothesis about the interaction of the two systems to see if the competition between the two is discouraging growth. The outcomes from this model have implications for system planning in Kenya and other developing countries, especially in Africa.

Conclusions

At this point in the research, the primary lesson is that we cannot treat electricity markets in Kenya as if they were US markets. The dynamics of a developing electrification system are very different than the mature systems found in most industrialized countries, primarily because of the assumptions one can make about availability and reliability. Industrialized countries also locked in to a centralized grid structure before renewable off-grid options were mature technologies. Now, in some cases, off-grid options can compete directly with grid electricity, but this may not encourage growth in electrification. Energy policy planners in developing countries need to consider the range of architectures possible and try to promote electrification programs that will improve energy services in the country.

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