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Can developing countries leapfrog the centralized electrification paradigm?

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ABSTRACT

Due to the rapidly decreasing costs of small renewable electricity generation systems, centralized power systems are no longer a necessary condition of universal access to modern energy services. Developing countries, where centralized electricity infrastructures are less developed, may be able to adopt these new technologies more quickly. We first review the costs of grid extension and distributed solar home systems (SHSs) as reported by a number of different studies. We then present a general analytic framework for analyzing the choice between extending the grid and implementing distributed solar home systems. Drawing upon reported grid expansion cost data for three specific regions, we demonstrate this framework by determining the electricity consumption levels at which the costs of provision through centralized and decentralized approaches are equivalent in these regions. We then calculate SHS capital costs that are necessary for these technologies provide each of five tiers of energy access, as defined by the United Nations Sustainable Energy for All initiative. Our results suggest that solar home systems can play an important role in achieving universal access to basic energy services. The extent of this role depends on three primary factors: SHS costs, grid expansion costs, and centralized generation costs. Given current technology costs, centralized systems will still be required to enable higher levels of consumption; however, cost reduction trends have the potential to disrupt this paradigm. By looking ahead rather than replicating older infrastructure styles, developing countries can leapfrog to a more distributed electricity service model.

Introduction

Direct electricity access eludes almost 20% of the world's population, the large majority of whom live in rural regions of developing countries, and providing universal electricity access has become a fundamental humanitarian goal of our generation (IEA, 2014a). This imperative has been formalized through the Sustainable Energy for All (SE4All) initiative that was launched by the United Nations in 2012 with the objective of achieving universal access to modern energy services by 2030. In 2013, an initial Global Tracking Framework was published, which formalized this goal and provided a consensus methodology for measuring and tracking progress toward its achievement. [1] It was estimated at the time that investments of \$60–\$160 billion dollars per year above current levels may be required in order to meet these goals (Angelou et al., 2013), and it is vital that any such investments are channeled to support technological and institutional solutions that are as forward-looking and cost-effective as possible. A second edition of the Global Tracking Framework was published in 2015 and provides an update on progress toward meeting the objectives that were established in the first edition (IEA and World Bank, 2015a). The findings of this report unfortunately indicate that the rate of progress over the two a year tracking between 2010 and 2012 falls “substantially short” of what would be required to obtain the SE4All objectives by 2030. It is therefore more important than ever that cost-effective pathways for increasing global energy access in a sustainable manner are identified and pursued.

Traditionally, nations seeking improved electricity access pursue centralized electrification. This strategy requires large upfront infrastructure investments in order to take advantage of economies of scale at large coal, natural gas, nuclear or hydroelectric generation facilities and has seen tremendous success over the past century throughout the developed and developing world. However, due to cost reductions of new distributed technologies such as rooftop solar panels, small wind turbines, and energy storage, the economics that motivated a centralized approach are changing. This is particularly the case in regions where electricity consumption is low and the costs of grid expansion are high (Levin and Thomas, 2012). In the developed world, the rapid introduction of utility-scale renewable generation is driving down wholesale electricity prices and reducing revenues for large nuclear, coal, and natural gas generators, while at the same time increasing the

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[1] The Global Tracking Framework also established two goals in addition to achieving universal access to modern energy services. These are doubling the global rate of improvement in energy efficiency and doubling the share of renewable energy in the global energy mix. While all three are worthy pursuits, the first is of primary relevance to this work.

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cost of ensuring system reliability (Ela et al., 2014). Consumers are also increasingly adopting decentralized generation technologies and reducing their reliance on the traditional centralized grid model. This combination of factors may force a fundamental shift in way the utilities and governments approach the long-term planning and development of power systems infrastructure.

In the developing world, centralized power systems have still yet to reach a significant portion of the population. Furthermore, even those who do have access to electricity receive no tangible benefit if such access is not affordable, reliable, or functioning (Mainali et al., 2014). Throughout the developing world, many poor families reside in "electrified" regions but still lack electricity for economic reasons. Electric grids are also often extremely unreliable in the developing world due to generation capacity shortages, poor transmission and distribution infrastructure, and a host of other operational issues. In many developing countries, outages can be an almost daily occurrence and many homes and businesses maintain backup diesel generators even when they have grid access (The World Bank, 2012). While many of these problems could be addressed through additional generation and infrastructure investments, such investments have not materialized for a variety of reasons. Therefore, many consumers continue to be reliant on costly personal generators to guarantee reliable access to electricity. Because of these complexities, the concept of "energy access" does not have a universally agreed upon definition and the binary metrics that are commonly used to evaluate energy access programs can often be misleading (Angelou et al., 2013). For example, one metric used in India considers an entire village to be electrified if only 10% of the homes have access to electricity but does not consider isolated homes powered by individual solar home systems (SHS) to be electrified (Palit and Chaurey, 2011). Similarly, many people who do not have direct access to electricity – electricity in the home – still have reasonable access to cell phones, battery-powered lights, and other electronic devices that may be charged at distributed charging stations. Many of these challenges are exacerbated by the fact that data on energy access and usage are scarce in many developing countries. This makes it harder to for policy makers to identify high-priority areas for public intervention and also to evaluate the effectiveness of programs that are designed to increase energy access. With this understanding in mind, the SE4All initiative has also proposed a multi-dimensional methodology to measure energy access across five consumption tiers and eight energy attributes (Angelou et al., 2013; Angelou and Bhatia, 2014). This methodology extends well beyond the traditional metrics annual energy consumption and a binary energy access indicator, incorporating a range of other factors into a multi-tier classification of energy access. The considered attributes initially included peak availability, duration of availability, evening supply, affordability, legality, and quality of access. These have been further expanded in the second edition of the Global Tracking Framework to also include reliability and health and safety (IEA and World Bank, 2015a).

Moving beyond the traditional definition of energy access toward one that accounts for reliability and affordability, it becomes clear that centralized and distributed electrification strategies are not always perfect substitutes for one another (Murphy et al., 2014). As a result, distributed approaches may be preferred in some regions even when centralized strategies appear to be the lowest cost option (Levin and Thomas, 2014a). Centralized approaches may still dominate in some regions; however, at a national scale, it will likely be the case that a socially and economically optimal power system will contain both centralized and distributed components. Therefore, developing countries have a unique opportunity to leapfrog the traditional centralized model and transition directly to a more distributed approach to electrification, particularly in regions that are not currently electrified. A comparison can be drawn to the rapid adoption of cellular telephone technologies throughout much of the developing world over the past decade, which bypassed the traditional landline model.

Policy makers are increasingly becoming aware of the potential for distributed electrification strategies to provide services in regions that have traditionally been too costly to serve with grid expansion (Narula et al., 2012). However, distributed rural electrification programs are generally poorly integrated with their grid-based counterparts (Urpelainen, 2014), and often are not afforded the same level of large-scale institutional support. In South Asia for example, it has been observed that most distributed rural electrification programs are grant and donor driven, but the few that have received significant institutional support at the state or national level tend to be the most successful (Palit and Chaurey, 2011). Grid-based electrification programs that are developed through the centralized utility model are also easier to subsidize than the more disaggregated, community-scale approaches that are often pursued by distributed programs. This effect has been quantified in Laos where subsidies for grid-based electrification usually exceed 70% of total costs, while those for distributed electrification average only 26% of total costs (Martin and Susanto, 2014). In rural regions of Thailand, homes receive 50 kWh of free electricity from the grid each month at a cost to the government of over US$30 million; this level of government sponsored financial support is simply not available for distributed electrification programs (Martin and Susanto, 2014). In Ghana, a similar "lifeline" tariff is offered, which charges all customers who consume less than 50 kWh in a month a flat fee of approximately $1.25 (World Bank, 2010), well below cost recovery in rural regions.

Over the last decade, Brazil has embarked upon an aggressive and fairly successful universal electrification campaign. However, the current focus on grid-expansion has reached its economic limits due to the extremely high costs of grid-expansion in the rural Amazon region. Off-grid approaches are likely necessary to reach many of the 500,000 households that still lack electricity access. Electrified homes in these regions are currently supplied by isolated diesel generators and mini-grids that exist outside of the institutional electrification framework in Brazil (van Els et al., 2012). As a result, it has been difficult for the Brazilian government to provide direct, or indirect, subsidies for these distributed approaches to rural electrification. In an effort to address these issues and achieve truly universal electrification, the government has recently expanded their program to provide support for smaller third-party organizations that are able to serve these rural populations with distributed technologies (Gómez and Silveira, 2015). Such an institutionally centralized approach to implementing distributed electrification technologies may enable the Brazilian or other governments to more effectively cross-subsidize energy access in regions that are costly to serve through grid expansion. For additional discussion on the Brazilian electrification program, see (Zerriffi, 2008; Gomez and Silveira, 2010) and for the cases of several national rural electrification programs, including Brazil, see (Zerriffi, 2011).

By offering or mandating low tariffs for grid electricity in rural regions, governments are either explicitly or implicitly providing subsidies for centralized, grid-based approaches to electrification. In situations where electricity consumption levels are low or grid connection costs are high, the grid subsidy may exceed the entire cost of electricity provision through a distributed technology such as a solar home system (Levin and Thomas, 2014b). We therefore present an analysis of the unsubsidized costs of electricity provision through both a centralized grid and through distributed SHS technologies. We first review SHS costs that have been reported in a number of different countries in recent years as well as the costs associated with grid expansion, showing that both of these costs can vary significantly in different geographical regions. We then develop a general analytic framework for analyzing the choice between grid expansion and implementing distributed electrification technologies.

A number of studies have examined the choice between grid expansion and distributed electrification technologies by conducting detailed analyses of specific regions and also more generally (Parshall et al., 2009; Deichmann et al., 2011; Szabó et al., 2011; Levin and Thomas, 2012, 2013; Sanoh et al., 2012; Kemausuor et al., 2014). Rather than performing a detailed original case study analysis of electric