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The energy challenge in sub-Saharan Africa: A guide for advocates and policy makers

Part 2: Addressing energy poverty

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CONTENTS

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ACRONYMS AND ABBREVIATIONS

ICT	information and communication technology
IEA	International Energy Agency
LCOE	levelized cost of electricity
LPG	liquid petroleum gas
PV	photovoltaic
SHS	solar home system
UNDP	United Nations Development Programme
WHO	World Health Organization
ANC	African National Congress

EXECUTIVE SUMMARY

Energy poverty is a stark problem in sub-Saharan Africa. Currently 633 million people are estimated to lack access to electricity, and 792 million people are forced to cook with traditional biomass on unimproved cookstoves. While efforts at electrification are expected to bring down the number of people who do not have access to electricity, the number of people using unimproved cooking facilities is expected to increase through 2030.

Energy-poor households suffer from a wide range of impacts, from increased risk of premature death due to indoor pollution to forgone productivity gains and lower quality of life. On top of these impacts, energy-poor households must spend a greater proportion of their income to meet their basic energy needs. They also spend more time engaging in energy-intensive tasks than do wealthier households who have access to modern energy sources.

Past efforts to address energy poverty have focused on promoting energy access. Historically these efforts have centered on providing people with electricity, resulting in a binary measure of energy poverty in which people are either "connected" or "not connected." More recent research has shed light on the complex ways in which households use energy, showing that it is determined by a variety of factors, including the affordability, reliability, and quality of the energy sources available. The result has been an evolution toward a tiered measure of energy access. Overall energy access is hypothesized to offer significant benefits, providing access to services (such as street lighting and schools), improving welfare, driving better health and environmental outcomes, and promoting economic development.

This report forms the second of a two-part series. It is an effort to **explore the technological opportunities for addressing energy poverty, as well as the policy challenges involved in promoting and deploying these technologies**. The first report deals with questions regarding the role of fossil fuels in closing the energy gap in sub-Saharan Africa. Overall this series finds that addressing energy poverty will require a mix of technologies. Within these, there are a number of important areas that policy advocates can focus on as levers to promote effective efforts to address energy poverty.

In the policy environment surrounding energy access, a major focus has fallen on providing **access to electricity**, and recent changes in the price of renewable energy technologies have sparked debate about the best way to do so. Different approaches include the following technologies:

1. **Large-scale grids.** Expanding the electrical grid is the most established approach to providing access to electricity. Electricity supplied by the grid is

available at the lowest tariffs because the grid offers opportunities to exploit economies of scale. A large-scale grid can also integrate large amounts of renewable energy. Expanding the grid, however, involves high up-front costs, and the ability to take advantage of economies of scale is limited in sub-Saharan Africa, where populations are dispersed and have limited ability to pay for electricity. Finally, the grid's physical characteristics mean that it operates as an almost perfect monopoly and as such is best managed as a regulated utility. In sub-Saharan Africa, where regulation is often weak, utilities have performed notoriously poorly.

2. **Mini-grids.** Although mini-grids involve lower up-front costs than expanding the grid on a large scale, they are still capable of supplying electricity in quantities that can match the services supplied by the grid. However, the current high cost of renewable components and battery storage means that electricity from mini-grids tends to be more expensive than that provided by the grid. Notably, future reductions in the cost of renewable components and storage are not expected to fully close this gap. This challenge is particularly significant given the low incomes of energy-poor households. In addition, although the up-front costs of mini-grids are lower than grid expansion, they are still high compared with the incomes of local entrepreneurs - who might be expected to finance and run such grids. There are a variety of ways to address the high costs of electricity from mini-grids, but they all require the creation of bespoke energy systems, which limit the technology's ability to be deployed for mass electrification. This challenge is exacerbated by the current lack of technically trained personnel in sub-Saharan Africa who could design and maintain such energy systems.

3. **Solar home systems (SHSs).** SHSs can supply electricity to isolated households that are too dispersed to be connected through mini-grids. However, SHSs suffer from limited capacity, which is sufficient only for lighting, information and communication technologies (ICTs), entertainment, and cooling. In addition, electricity from SHSs is more expensive than electricity from both the grid and mini-grids. Although SHSs can provide households with basic quantities of electricity, they can also suffer from regulatory issues and be compromised in conditions where theft of solar panels is a problem and where demand on the system grows rapidly.

4. **Solar appliances.** Solar appliances provide electrification on an even smaller scale than SHSs and therefore result in the lowest up-front cost, but also the highest cost of electricity of all the technologies mentioned here. Nonetheless, given the high value placed on electrical energy for lighting, electronics, and cooling, solar appliances have been observed to generate rapid transitions in household energy economies. Challenges around promoting solar appliances pertain to ensuring their quality and socializing people to the potential advantages of electric energy sources.

Although access to electricity has received a disproportionate amount of attention within energy access efforts, electrification alone—whether supplied via the grid or distributed technologies—has only limited effects on energy poverty.

1. In terms of **household energy poverty**, households tend to use electricity for illumination, electronic devices (ICTs and entertainment), and some cooling. Newly connected households do not tend to use electricity to meet their thermal energy needs (cooking and heating).
2. Regarding the impacts of electrification on **economic development**, the empirical literature is ambiguous. Some cases document generalizable and significant improvements in household incomes as a result of electrification; other empirical works find that electrification has few, if any, impacts on economic development. Overall, I take this to mean that electricity can play an important role in driving economic development, but this role depends on the existence of complementary policies, infrastructure, and services.
3. The impact of electrification on the availability of **services** (such as street lighting, schools, and clinics) is not well studied in the literature. The greatest impact appears to result from the improved quality of life made possible by electrification, which makes trained service providers (teachers, nurses, government bureaucrats) more willing to reside in remote rural areas.

Overall, while electrification is expected to lead to important improvements in welfare as well as some conditional economic development, it will not address the dangers of cooking with solid and liquid fuels. Efforts to tackle energy poverty therefore must go beyond electrification only.

Promoting access to improved cookstoves and more modern cooking fuels have been the mainstays of efforts to address the challenges of cooking with solid biomass. Although improved cookstoves are relatively cheap and simple technologies and have been a focus of development efforts for more than 40 years, their uptake has been frustratingly slow. Efforts to promote improved cookstoves have been bolstered recently by international efforts such as the Global Alliance for Clean Cookstoves, but more still needs to be done to ensure access to improved cooking facilities in households. Promoting modern fuels requires the use of modern appliances—and therefore suffers the same challenges as improved cookstoves—but is also frustrated by supply chain problems. In addition, efforts to promote access to modern fuels through subsidies have been shown to raise complicated problems of leakage to nonpoor groups.

Biogas digesters have been touted as a potential alternative source of energy for cooking, but efforts to promote biodigesters have proven that, despite the simplicity of the technology, they are difficult to roll out for the purposes of promoting energy access. Their maintenance has also proved challenging.

With this array of technical opportunities for addressing energy poverty, the following issues will be important for policy advocates focused on improving energy access and addressing energy poverty in sub-Saharan Africa:

1. Efforts to address energy poverty will need to **focus on both the grid and distributed technologies**. The grid will provide the cheapest energy and allow for the greatest penetration of renewables at the lowest cost. Rolling it out, however, will be costly and slow, so distributed generation technologies should be used to help increase access to electricity. To this end, energy policies should promote a mix of technologies based on considerations such as population and income density, distance from the grid, resource availability, and terrain.

2. Support for distributed technologies must **not only cover the higher up-front costs for the technology, but also support the development of the entire supply chain**. This means reducing the cost of renewable components and offering appropriate training to the individuals who will be needed to site, install, manage, and maintain these systems.

3. To support the expansion of the grid, energy policy will need to focus on **reducing the cost of connections.** In addition, because the arrival of the grid threatens the sustainability of distributed technologies, **plans for grid expansion need to be transparent, with explicit mechanisms for integrating distributed technologies into the grid when it arrives**.

4. To ensure that electrification is sustainable, it must be accompanied by economic development. **Electrification thus needs to be undertaken within the context of a broader set of development efforts**. This will include making sure that complementary services, infrastructure, and policies are rolled out along with electricity access.

5. Even if policies effectively address all of the above challenges, the poorest households will still likely require subsidies in order to meet their basic energy needs. At the same time, tariffs will have to be set high enough to ensure the long-term sustainability of any energy infrastructure. In this respect a central feature of energy policy will be **striking the correct balance between tariff rates and subsidies**.

6. Although developments in renewable energy technologies are changing the possibilities for improving electricity access, there is a danger that advocacy communities will focus solely on the technologies of energy delivery and ignore the institutional context. Experience rolling out these new technologies suggests that the institutional context will remain of central importance, and thus core development **concerns about governance and accountability should remain priorities, regardless of the technology being deployed**.

7. Policy makers have long prioritized electrification over addressing energy needs for cooking, and current efforts promoting improved cookstoves will likely be insufficient to address energy poverty. The number of people cooking with traditional biomass is expected to increase through 2030. Because biomass is expected to play a significant role in household energy economies, **energy policy should include an explicit effort to manage solid biomass in a sustainable way**.

8. Issues of financing will lie at the heart of efforts to roll out energy access. Financing will be needed not only for new infrastructure, but also for subsidies to support energy access among the poorest populations. At the moment, public and donor financing is insufficient to meet the investment needs, and as such there is an imperative to **use public and donor finance to leverage private investment**.

1. INTRODUCTION

Access to energy is fundamental to human welfare. We need energy to cook our food and heat our homes. We use illumination after the sun goes down to extend our productive hours and provide us with huge improvements in quality of life. Beyond these basic functions, we rely on energy to provide services such as telecommunications, health care, and education as well as many of the conveniences available to people in modern economies. Without access to modern and efficient fuels, households are forced to rely on polluting and dangerous sources of energy such as the burning of dung, charcoal, and kerosene.

Energy poverty presents a serious challenge in sub-Saharan Africa. Despite longstanding efforts to address energy poverty, in 2014, 633 million people lacked access to electricity and 792 million people relied on traditional biomass as their primary energy source for cooking (IEA, 2016). The result is drudgery, poisoning, fires, burns, limited economic opportunity, and premature death due to respiratory diseases.

Whereas developing Asia contains the largest number of people without access to modern cooking facilities, sub-Saharan Africa contains the largest number without access to electricity. Sub-Saharan Africa is also home to the largest number of countries with the lowest rates of electrification and has the highest rates of people forced to cook using traditional biomass. Furthermore, whereas Asia is expected to see declines in the total number of people living in energy poverty, in sub-Saharan Africa population growth is outstripping the rate at which people are transitioning away from solid biomass for cooking. Based on current trends, the number of people in sub-Saharan Africa who are forced to burn solid biomass in unimproved cookstoves is expected to rise to 823 million by 2030. Notably, however, recent efforts focusing on electrification are expected to drive down the number of people lacking electricity through to 2040 (see Table 1).

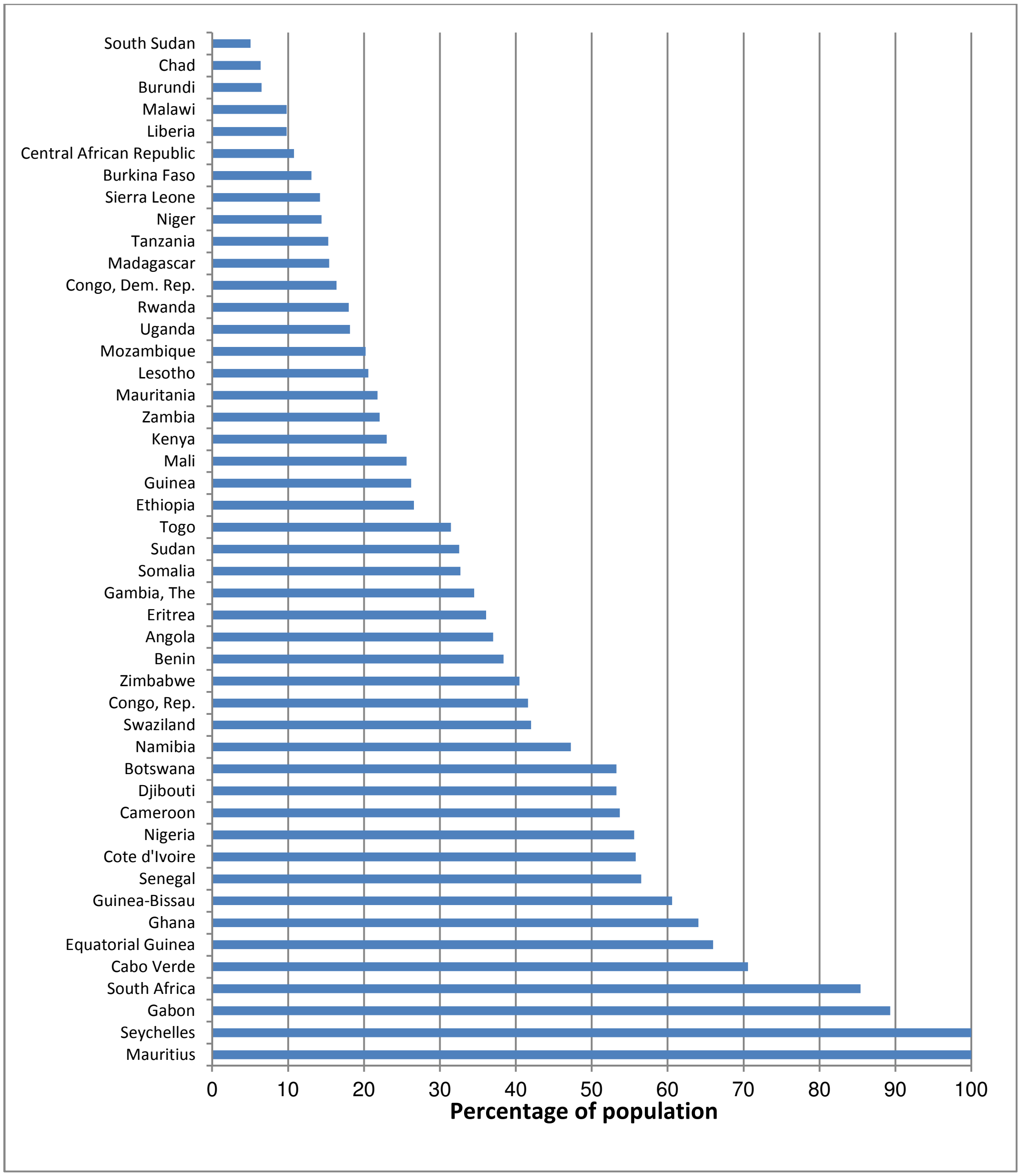
Table 1: Predicted changes in energy-poor populations in sub-Saharan Africa, 2014–2040

	2014	2030	2040
Number of people without access to electricity (millions)	633	619	489
Number of people reliant on traditional biomass for cooking (millions)	792	823	708

Source: IEA, 2016.

When considering the state of energy access and energy poverty in sub-Saharan Africa, it is important to remember that regional and national averages can obscure vast disparities in levels of energy access between and within countries. Some countries, such as South Sudan and Burundi, have electrification rates in the single digits, whereas the small island states of Mauritius and the Seychelles have energy access rates of 100 percent (see Figure 1).

Figure 1: Rates of electricity access across sub-Saharan Africa countries



Source: World Bank, 2012.

More needs to be done to address energy poverty in sub-Saharan Africa. Yet Africa faces challenges in using fossil fuels to generate electricity. Fossil fuels are susceptible to major variations in price that have significant impacts on the economic viability of electricity production. Burning fossil fuels in power plants creates significant health risks as a result of dangerous smog. Finally, the burning of fossil fuels drives climate change, which threatens to compromise food security, drive sea-level rise, exacerbate drought and flood events, and increase exposure to disease (Boko et al., 2007; Goodes, 2011; Kundzewicz et al., 2007; Nicholls & Mimura, 1998; Schlenker & Lobell, 2010; Tanser et al., 2003). Although Africa's limited role in driving climate change means that the its citizens should not shoulder the burden of addressing it—especially not when considering the grave levels of impoverishment represented by current levels of energy poverty—Africa's vulnerability to climate change does give it a real incentive to seek to minimize its greenhouse gas emissions where possible.

While the task of addressing energy poverty and limiting greenhouse gas emissions seems daunting, price reductions in a number of renewable energy technologies are creating new possibilities for achieving energy access in Africa, and as such the policy discussion over how best to prioritize energy investments is changing rapidly. Many actors now call for a complete overhaul of the traditional focus on investing in centralized power generation and expanding the grid. Instead, they call for a focus on distributed renewable energy technologies, which are believed to be cheaper, faster to deploy, and not reliant on the slow and bureaucratic power utilities that have served African countries so poorly in the past. In addition, such energy sources are thought to mitigate the local emissions from large, centralized, fossil fuel–burning power stations, which currently impose major health costs on surrounding communities. Other actors reject this argument, suggesting that a distributed approach is incapable of supplying power in the quantities required. Assessing the merits of these arguments is challenging owing to the technical characteristics of energy technologies, the rapidly changing prices of renewable components, and the complex economics and financing questions that dominate the energy sector.

This is the context that frames this report. The report sets out to review the challenges posed by energy poverty in sub-Saharan Africa and explore the possibilities for addressing it while minimizing greenhouse gas emissions. The report is intended to be an accessible appraisal of potential technologies and approaches for expanding access to electricity, including grid expansion and distributed technologies. The report also considers the potential for improved cookstoves to provide people with access to safe cooking facilities. In all cases the report emphasizes the challenges surrounding the available technologies and highlights the policy requirements for addressing such challenges. In this respect, this report is intended as a guide to advocates and policy makers as it seeks to explain the technical, economic, and policy challenges surrounding energy access in Africa.

The work is based on a six-month review of the literature on energy poverty and energy access. This report (Part 2) on energy poverty is intended to complement another Oxfam report exploring the challenges of closing the energy gap in Africa and the need to minimize the use of fossil fuels in that process. That report, referenced in this work as Part 1, can be found where this report was downloaded.

HOW TO READ THIS REPORT

Because this report is a comprehensive account of the opportunities and challenges for addressing energy poverty in sub-Saharan Africa, different readers with different levels of understanding of the issues will find different parts of the report interesting and relevant. As such, the report need not be read as a single document, but can be read selectively according to readers' interests.

The report is structured as follows: Section 2 of the report, intended for people with no background in the subject matter, details the conceptual and definitional aspects of energy poverty and energy access. The principal technical section of the report, Section 3, describes the technical opportunities and challenges posed by different electricity technologies including grid expansion, mini-grids, solar home systems, and solar appliances (the role of biodigesters is discussed in Text Box 5, located in Section 5). Section 4 reviews the empirical evidence on the impacts of electricity on human and economic development, before Section 5 makes the case for focusing on solid biomass fuels when addressing energy poverty. Section 6 discusses vital areas of policy focus that need to be resolved or considered in any energy access policy. Finally, Section 7 concludes with important areas of policy focus for advocates and policy makers.

2. ENERGY POVERTY AND ENERGY ACCESS

The term “energy poverty” has no formally agreed definition. Usually, the term focuses on household energy use, such as energy for cooking, lighting, and heating. More recently, however, the notion of energy poverty has been expanded to include both the energy needed for small-scale commercial activity (such as energy needed to run appliances in a small business) and energy for services (such as street lights and health clinics) (Practical Action, 2014). Work on energy poverty usually excludes discussion of the energy provided by nutrition and the energy needed for transportation.

Energy poverty tends to be understood in two main ways. The first is the idea of energy poverty as the energy consumption habits of populations who are deemed poor by other measures, such as income (Khandker et al., 2010). The second idea is that energy poverty is itself a form of deprivation, so that energy-poor populations are those that lack access to the energy required to meet their basic needs (Bhattacharyya, 2012; Khandker et al., 2010; Practical Action, 2014). In the latter case, the notion of energy poverty is also thought to account for the fact that many populations must expose themselves to undue risks (such as risks from pollution) or hardships (such as having to walk long distances and expend significant amounts of time collecting fuelwood) in order to meet their basic energy needs.

ENERGY POVERTY AS THE ENERGY USE OF THE POOR

Energy poverty—when understood as the energy usage habits of poor households—highlights the extent to which poor people spend a greater portion of their income and time meeting their energy needs than do wealthy households, despite the fact that wealthy households tend to consume more energy overall (Bacon et al., 2010; Khandker et al., 2010). The reason for this is that all people, no matter how poor, need some basic amount of energy to survive. Among very poor households, accessing even the small amount of energy needed for survival can mean spending a greater proportion of their income on energy than the proportion spent by wealthy households that consume much more energy. Poor households are also often forced to rely on fuels and appliances that are less efficient than those available to wealthy populations. As a result, they often have to spend more time and money to meet their most basic energy needs. Empirical investigation has revealed that poor households spend somewhere between 5 and 20 percent of their income on meeting their energy needs (Africa Progress Panel, 2015; Clancy, 2006; Khandker et al., 2010). The most commonly used measure of energy poverty is households that spend more than 10 percent of their income on meeting their energy needs (Khandker et al., 2010).

As high as they are, these measures of expenditure do not capture the extra time poor households spend to meet their energy needs, nor do they account for the fact that, in developing countries, poor households often collect their own fuels (and therefore don't pay for them). Thus, even these high figures may underrepresent the extent of energy poverty in less industrialized countries.

ENERGY POVERTY AS DEPRIVATION

The second conception of energy poverty—as the experience of deprivation or exposure to undue risks or hardships—has driven an important focus on the notion of "energy services." The idea here is that the availability of energy itself (i.e., potential energy, or kinetic energy) has no direct impact on human well-being. However, when that energy is able to provide services, such as heat for cooking or light for illumination, it can have a profound effect on human well-being. What matters when addressing energy poverty is providing people with the energy services required to meet their basic needs.

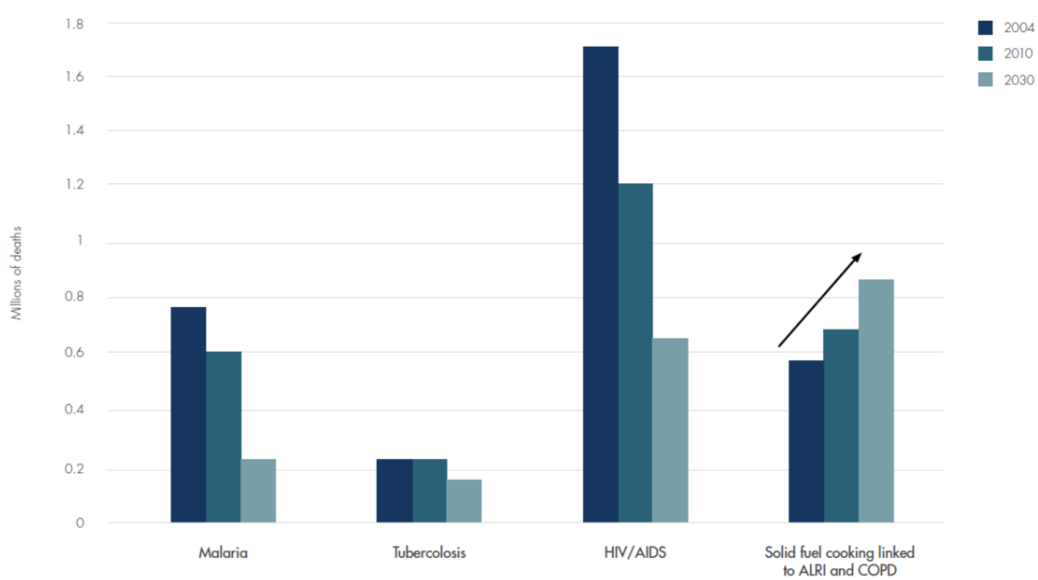
Focusing on energy services makes clear that definitions of energy poverty are both context specific and subjective (Bhattacharyya, 2012). This is because people in different circumstances need different amounts of energy to meet their basic needs (for example, people in cold climates need more energy to heat their homes than do people in warm climates) and because exactly what constitutes a need (or an undue risk) is itself fundamentally subjective (Bhattacharyya, 2012).

Although definitions of energy poverty have been hard to come by and contentious when offered (Bhattacharyya, 2012), a prominent effort has recently come from Practical Action, which suggests defining energy poverty as deprivation of "the full range of energy supplies and services required to support human social and economic development …[for]… households, enterprises and community service providers" (Practical Action, 2014, p. 2). Beyond this, Practical Action (2014) has provided a set of basic thresholds for energy services against which energy poverty might be defined. These thresholds pertain to illumination, thermal energy, cooling, refrigeration, and access to information and communications technology. The thresholds include metrics related to both risk and opportunity cost (Practical Action, 2014).

THE IMPACTS OF ENERGY POVERTY

Energy poverty poses a substantial challenge for development. If people lack the ability to light their homes after sunset, activities such as studying, domestic chores, and even small business endeavors must end when the sun goes down. Likewise, if people are unable to warm or cool their houses, they can be left very uncomfortable at certain times of the year, with particular risks to the very young and very old. Further, when populations living in energy poverty do gain access to fuels, they often risk significant harm. For example, the burning of traditional biomass in people's homes is estimated to cause 600,000 deaths annually in sub-Saharan Africa alone (Africa Progress Panel, 2015). Unless current trends change, deaths from indoor air pollution are forecast to exceed deaths from tuberculosis and AIDS by 2030 (see Figure 2) (Africa Progress Panel, 2015). Kerosene,[1] which is used for cooking and lighting, is associated with respiratory infection (though less so than cooking with solid fuels), and it also poses risks of poisoning and fires (see Text Box 1).

Figure 2: Deaths caused by major infectious diseases compared with acute lower respiratory infections, 2004, 2010, and 2030



Source: World Bank Group, 2012, in Africa Progress Panel, 2015.

[1] Kerosene is also referred to as paraffin in some parts of the world.

Text Box 1: The dangers of kerosene

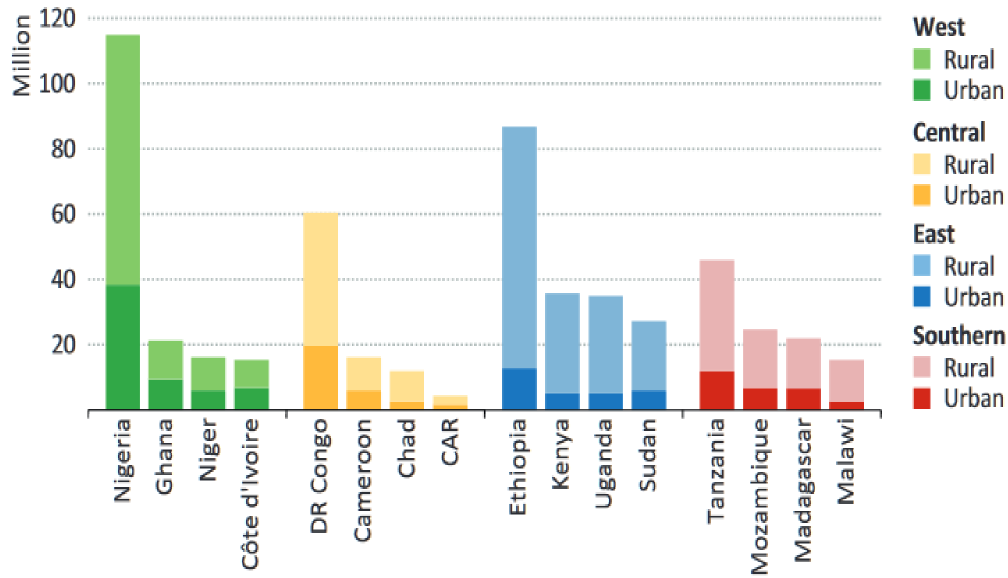
While the literature on energy poverty has much to say about the dangers of indoor air pollution, it generally pays less attention to the dangers of home kerosene use, even though an abundant literature on the subject points to the risks of both poisoning and fire.

The exact incidence of unintentional kerosene poisoning across Africa is unknown (Veale et al., 2013), but good data from studies in South Africa are instructive. There, kerosene ingestion, is the most common cause of acute poisoning among South Africa's black population, and is estimated to result in as many as 171–996 fatalities a year (Carolissen & Matzopoulos, 2004). Even nonfatal cases of poisoning (estimated at 46,530–93,060 a year) cause problems for families because they often result in long and expensive hospital stays (Tshiamo, 2009). Aspiration of kerosene by children can raise the likelihood of respiratory conditions such as tuberculosis and asthma later in life (Tshiamo, 2009). Risks of kerosene poisoning are greatest among children in rural areas, which are far from hospitals (Carolissen & Matzopoulos, 2004; Meyer et al., 2007; Tshiamo, 2009).

Fire risk is also a major problem. In South Africa alone, 200,000 individuals are estimated to be injured by, or lose property as a result of, kerosene-related fires. Kerosene is identified as the cause of fire in 53 percent of cases (candles account for another 30 percent of cases) (Kimemia et al., 2014).

On top of these difficulties, the time spent collecting fuelwood and cooking food on unimproved stoves places an additional burden on energy-poor populations. The losses in Africa due to cooking and collecting firewood are estimated at $36.9 billion annually, if the value of unpaid labor is included. The impacts are greatest among women and girls, who are usually responsible for these chores (Lambe et al., 2015). Moreover, these impacts take place within a context in which women and girls already bear a disproportionate burden of the unpaid work within the household (Karimli et al., n.d.). Finally a lack of access to energy compromises the efficacy of social services, such as clinics and schools, and limits economic opportunities by constraining productivity and economic growth (Modi et al., 2006).

Figure 3: The largest populations cooking with traditional biomass in sub-Saharan Africa, 2012



Source IEA, 2014, reproduced from Lambe et al., 2015.

Given the challenges of energy poverty, providing energy to households in safe and sufficient quantities is hypothesized to result in myriad positive outcomes,[2] including the following:

- **Improved health outcomes**: Reduced burning of biomass and kerosene in homes will reduce people's exposure to harmful pollutants. Access to modern fuels is expected to help prevent the cuts, falls, bites, and episodes of sexual harassment and assault that women and girls might otherwise sustain while collecting fuelwood. Finally, access to electricity allows for improvements to the cold chain, which are believed to be vital for vaccination, and access to electrified clinics is anticipated to improve health outcomes.

- **Increased household income**: Households that purchase modern fuels are expected to reap savings from the use of more efficient fuels. Access to sufficient illumination will give households more productive hours, including increased study hours for students. Finally, access to modern fuels allows for pumped irrigation, potentially improving farm incomes, as well as for the diversification of income as households engage in agroprocessing and undertake light manufacturing.

[2] See Modi et al. 2006 and Practical Action 2014 for a comprehensive account of the potential positive outcomes of providing energy services and addressing energy poverty. Much of this list is generated from these two reports.

- **Improved environmental outcomes**: Reduced demand for biofuels will lessen pressures on forests (Lewis & Pattanayak, 2012), with positive impacts for forest services including reducing runoff and climate change mitigation.

- **Improved quality of life**: Addressing households' reliance on fuelwood will reduce the drudgery experienced by women and girls whose job it is to collect those fuels. Greater access to entertainment services requiring electricity will improve people's well-being.

- **Access to ICTs and improved services**: Most ICTs require electricity to operate. The impact of television, radio, cell phones, and computers on people's lives will be significant. They can increase productivity, provide people with access to crucial information, and create new industries. In terms of services, schools, clinics, and government offices are all thought to be made more effective by access to electricity, with important impacts for the well-being of people who access them. Finally, improved quality of life in rural areas is expected to help retain qualified staff (such as teachers, nurses, bureaucrats), which will further improve access to services.

ENERGY ACCESS

Efforts to address energy poverty have focused on providing energy access. As with energy poverty, until recently there has been little agreement on how to define "energy access" beyond a general sentiment that it includes increasing households' access to sufficient quantities of energy while ensuring that they can avoid unnecessary risk or undue drudgery (Bhattacharyya, 2012). The vagueness of the term has not, however, diminished efforts to promote energy access. Given the myriad potential benefits mentioned above, it has been a mainstay of government policy in many countries.

Electricity has come to play a central role in energy access owing to its particular ability to provide an enormous array of energy services (see Text Box 2). As a consequence, efforts to promote energy access have often been reduced to a narrow focus on providing access to electricity. One result has been a binary view of energy access in which people are either "connected" or "not connected" (Practical Action, 2014).

This narrow, binary approach belies the complexity of how people actually consume energy. To understand why consider a household that is connected to a source of electricity so unreliable that it has access to energy services for only four hours a day. Or imagine a household that has access to electricity but is unable to afford to pay for the service. Under such conditions, households may still find themselves cooking or lighting their homes using solid fuels, with the associated dangers, disadvantages, and drudgery. As such, simply focusing on whether or not households are connected to electricity is a poor indicator of whether they have access to the energy they need to avoid the deprivations, risks, and injustices associated with energy poverty.

Text box 2: Electricity and energy services

What people require to improve their well-being is not simply energy, but energy services. To understand this, consider the chemical energy contained in solid biomass, or the kinetic energy in a wire carrying an electrical current: By itself, such energy is of little value for improving a person’s well-being.

Instead, when people have access to, for example, the light generated by passing an electric current through a filament or by burning kerosene, their productive hours are not limited to daylight hours. Likewise, when people are able to access the heat created by passing an electric current through an element or by burning wood or charcoal, they can cook their food and heat their homes. Given that addressing energy poverty is about improving well-being, energy access is about providing people with access to energy services.

When it comes to delivering energy services, electricity has distinct advantages. First, electricity can provide virtually all the services that a household might use. It can provide heat, light, and telecommunications, and even run machinery. In addition, unlike a fire, which takes time to light and burn down to embers, electricity can provide those services almost instantly; users need only turn it on. Finally, electricity is able to provide services while producing almost no emissions at the point of consumption, and it is relatively safe to use.

Electricity presents other advantages as well. It is easier to transport than solid or liquid fuels like charcoal and diesel, which must be moved along roadways. As long as two areas are connected to one another, electricity can be provided to either one almost instantly.

Yet using electricity to provide energy services to the poor also presents a few disadvantages. First, households have to be connected to electricity in order to receive it. Second, using electricity to access energy services requires owning an appropriate appliance—an electric stove, kettle or lightbulb—which can be costly. In contrast, a basic stove for burning wood or charcoal can be made from nothing more than three large stones. In addition, for electricity to provide these services, the supply of electricity must be both sufficient and reliable.

Energy access policy has frequently focused on only the first of these issues: connecting households. This has led to an overly simplified account of energy access.

As a result, there has been a recent push to develop more comprehensive measures of energy access that capture the multidimensional and multi-tiered nature of the term. This has included tiered considerations of the energy's (1) capacity, (2) duration and availability, (3) reliability, (4) quality, (5) affordability, (6) legality, (7) convenience, and (8) health and safety. For each category the energy source is broken down into energy for household electricity and energy for household cooking (World Bank Group, 2012) (see Figure 4). Despite this more comprehensive approach, imperatives to see people rise above the most basic level of access, and to create energy access goals against which progress can be measured, have driven a push back toward a binary definition whereby some tier within the energy access matrix is considered the basic threshold for "energy access."

Figure 4: Multi-tier matrix of energy access

Attributes of energy supply		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Capacity	Household electricity	No electricity[a]	Very low power	Low power	Medium power	High power	
	Household cooking	Inadequate capacity of the primary cooking solution				Adequate capacity of the primary cooking solution	
Duration and availability	Household electricity	<4 hours	4–8 hours		8–16 hours	16–22 hours	>22 hours
	Household cooking	Inadequate availability of the primary cooking solution				Adequate availability of the primary cooking solution	
Reliability	Household electricity	Unreliable energy supply				Reliable energy supply	
Quality	Household electricity/cooking	Poor quality of energy supply			Good quality of energy supply		
Affordability	Household electricity	Unaffordable energy supply		Affordable energy supply			
	Household cooking	Unaffordable energy supply				Affordable energy supply	
Legality	Household electricity	Illegal energy supply			Legal energy supply		
Convenience	Household cooking	Time and effort spent sourcing energy cause inconvenience			Time and effort spent sourcing energy do not cause inconvenience		
Health and safety	Household electricity	Unhealthy and unsafe energy system				Healthy and safe energy system	
	Household cooking[b]	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5

Source: World Bank Group, 2014.

In summary, the field of endeavor linking energy and development has been animated by concerns about the impacts of energy poverty and a desire to address these by promoting energy access. Despite the longstanding focus on both issues, neither has a clearly established definition, although recent efforts to provide nuanced definitions that capture the complexity of these issues have been advanced. Policy advocates in this field have found it challenging to move the conversation beyond a simple focus on electrification as a means to address energy poverty, and the binary definitions of energy access this focus has created.

3. EXPANDING ACCESS TO ELECTRICITY

Traditionally electricity has been provided to households through connections that link households to centralized power plants. The interconnection of all of these households into one large energy system is known as the electricity grid, or simply “the grid.” The grid has advantages (principally around economies of scale) and disadvantages (principally around high up-front costs) when it comes to expanding energy access. Frustration at the disadvantages, along with growing cognizance of the challenge of climate change and advances in renewable energy technologies, has driven an increasing focus on providing electricity through distributed sources. Under this model, instead of being connected to a single centralized generating source, households are connected to distributed sources, which are close to the point of consumption, largely renewable, and not connected to one another through the main grid. Such systems have the advantage of being able to reach poor and remote populations quickly and cheaply (Bhattacharyya & Palit, 2016; Deshmukh et al., 2013; TERI-GNESD, 2014; Terrapon-Pfaff et al., 2014), while simultaneously mitigating carbon emissions (Alstone et al., 2015).

Text Box 3: Electricity fundamentals

Electricity is generated in power stations. The electricity from the power station is transmitted to households or other users through a set of wires that can carry electric current at different voltages. The linking up of many households through an interconnected system of wires is known as the electricity grid. Any set of interconnected households can be thought of as a grid, but some grids can be very large, connecting entire countries, while mini-grids can be small, connecting just a few households.

Dispatchable and Intermittent Sources

The sources of energy for producing electricity are classified into two major types: dispatchable and intermittent. Dispatchable sources of energy can be turned on or off whenever the person managing the plant wishes. Intermittent sources of energy are not available all the time; their availability is determined by factors beyond the control of the plant manager. Fossil-fuel plants provide dispatchable energy (so long as the fuel is available), while sources such as wind and solar are intermittent, available only when the sun is shining or the wind is blowing. Some low-carbon sources of energy are dispatchable, such as hydroelectric power (assuming water levels are sufficient) and nuclear power.

Alternating and Direct Current

Electricity is generated in two principal forms: alternating current (AC) and direct current (DC). Individual appliances are built to handle one type of current only. Electric current can be transformed from one form to another, though it is easier to transform AC to DC than it is to transform DC to AC. The grid uses AC because large power stations tend to produce AC (except in the case of solar PV, which produces DC). It is more efficient to transport AC at high voltages, and it is possible to increase or decrease the voltage of AC with relative ease via a transformer, though this step involves losses of energy.

In general, electricity is generated at relatively low voltages. Voltages are then "stepped up" to very high levels as electricity is transported long distances through high-voltage power lines known as the transmission network. High voltages, however, are dangerous in households, so voltages are "stepped down" to lower levels as electricity is delivered to households through low-voltage power lines known as the distribution network.

AC can be delivered through either three-phase or single-phase current (these terms describe the timing with which alternating current alternates). Three-phase current, which is more efficient and uses less electricity to run an appliance, is more common in electrical grids around the world.

Matching Demand and Supply

One major downside to using electricity to provide energy services is that energy cannot be stored as electricity. This means that the amount of electricity being produced needs to be balanced with the amount being consumed; any excess electricity is wasted. Given that demand varies during the day—usually with a large peak in the early evening as users come home and start cooking, heating their homes, and turning on their lights—such balancing is central to the management of electricity generation.

Patterns of usage with large peaks create challenges for electricity systems. Systems must have enough generation capacity—that is, a sufficient number of power plants—to meet peak demand, even if this demand lasts for only a short period of the day. This makes it difficult to finance generation capacity because power plants rely on the sale of electricity to make money. Cases in which peak demand is much greater than average demand cause the whole electricity system to be more expensive as capacity sits unused for long periods of time. Consequently there are good reasons to try to smooth out peak demand so that more of the energy generation capacity is being used more of the time, resulting in a more efficient use of the grid's resources.

The problem of having too little electricity when demand is high is matched by the problem of having too much electricity when demand is low (for example, if the wind is blowing on wind turbines in the middle of the night). In such circumstances, energy generation capacity has to be curtailed (i.e., switched off). Curtailment makes financing renewable projects more difficult because, as mentioned, generators make most of their money by selling electricity, not by generating it. If they cannot sell the electricity they generate because there is no demand, then recouping a profit on those assets is more difficult.

Resolving Intermittency

The fact that energy cannot be stored as electricity poses additional challenges for intermittent energy sources. When demand does not coincide with sunny or windy conditions, users must (1) go without electricity, (2) get electricity from somewhere where the sun is shining or the wind is blowing, or (3) have access to a dispatchable source of electricity. This source could be a fossil fuel, a dispatchable renewable source (such as hydropower), or stored energy that was generated when the intermittent energy source was available (such as a battery or pumped water storage).

All of the options for resolving intermittency raise challenges. Going without electricity (especially if outages are unplanned) often imposes significant economic losses and social costs. Transporting electricity across a grid involves energy losses of at least 6 percent (in Africa the losses can be even higher, between 15 and 30 percent) and requires the presence of expensive grid infrastructure. Furthermore, using the grid as a form of backup is only effective when the grid is large enough to have significant diversity in demand and generation. Small grids are vulnerable to fluctuations in both demand and generation and therefore have greater needs for storage and/or backup in order to deal with intermittency.

The use of fossil fuels as a backup causes climate change and has other social costs (such as the health costs associated with pollution from burning fossil fuels). The variability of fossil-fuel prices also means that electricity prices can fluctuate, creating shocks for the users. Finally, in remote areas, access to fossil fuels can be unreliable. In such cases fossil-fuel generation sources are not viable as a backup to intermittent sources.

Finally, storage is expensive. Batteries are a promising option, but in addition to being expensive, they must be carefully maintained to ensure their longevity. Although lead-acid batteries are a proven technology and are relatively cheap, even when carefully managed their life expectancy is much less than that of other renewable components, such as solar panels. In addition, effective management means limiting how deeply one discharges the batteries. For lead-acid batteries, limiting battery discharge to 20 percent provides for the longest battery life, but limiting discharge to that extent means that more batteries are needed to achieve the same amount of overall storage capacity in a system. Lithium-ion batteries allow for greater depth of discharge (around 80 percent) and more charge cycles, and thus a longer life, but they have much higher costs than lead-acid batteries (IRENA, 2016b). In general, batteries of any type should not be fully discharged, or discharged too quickly. Doing so decreases their life span, which—given the cost of batteries—can substantially increase the cost of the overall electricity system.

Another solution to the storage challenge is pumped storage, in which water is pumped up a hill and then stored before it runs down over a generator. In order for pumped storage to be cost-effective, an area must be proximate to high ground on which reservoirs can be built.

Terminology

Finally some energy terminology: Energy is measured in joules (j), while power is measured in watts (W). Power is the rate at which energy is converted from one form to another and is measured in joules per second ($W = j/t$; where "t" = time in seconds). Electric power stations convert energy from one source (a fuel) into electricity at a given rate; as a result their capacity (or power) is expressed in watts based on the rate at which they produce electricity. Quantities of electricity are measured in watt-hours. One watt-hour is the amount of energy used when a one-watt appliance is run for one hour (note that watt-hours can also be expressed in joules, as both are quantities of energy, but a joule is such a small unit of measurement that using it is unwieldy). The most common measures of electrical energy are kilowatt- and megawatt-hours (kWh or mWh), and thus energy prices are usually set in terms of the price per kWh ($/kWh).

The cost of different electrical generation systems is most effectively expressed as the levelized cost of electricity (LCOE). The LCOE is determined by dividing the total cost of a generating system (including any necessary fuel, replacement parts, maintenance and decommissioning costs) and dividing it by the total amount of energy the system will generate over its lifetime. LCOE is measured in $/kWh or $/mWh.

Such a broad overview of electricity generation technologies ignores, however, the detailed technical and economic complexities of generating and distributing electricity. A lack of understanding about these technical challenges, and therefore about the associated institutional challenges, has resulted in polarized and simplistic discussions about the capacity for different approaches to provide electricity and address energy poverty. This section of the report focuses on four potential electricity generation and distribution technologies, looking at the specific advantages, opportunities, and challenges associated with each. The report considers four dominant approaches: (1) connecting households by expanding the grid, (2) providing electricity via mini-grids, (3) providing electricity via solar home systems (SHSs), and (4) providing energy services via the sale of solar appliances. Once the case has been made for ensuring that households have energy for thermal needs such as cooking and heating, the report also discusses the potential for biodigesters to address energy poverty (Text Box 5).

EXPANDING THE GRID

All countries that have significantly increased their electrification rates in recent years have done so by expanding the grid to connect unelectrified households (e.g., China, Vietnam, Philippines, and South Africa) (Bhattacharyya, 2012; Dinkelman, 2011; Khandker et al., 2009b; Modi et al., 2006). Compared with other technologies, the grid is uniquely able to take advantage of economies of scale by connecting many people to a single piece of infrastructure (ARE, n.d.). Because the cost of expanding the grid is shared by all of the connected customers, the grid provides electricity at the lowest retail price of all the technologies (see Text Box 4). The grid can also provide electricity in very large quantities and at very high voltages, which some industrial users require. Finally, because the grid is the dominant way that households receive electricity around the world, it has the advantage of being a well-understood technology with blueprints for how to finance and build the necessary infrastructure, as well as how to sell electricity. The institutional requirements and challenges involved in operating and managing such a large piece of infrastructure are also well known.

Challenges to expanding the grid

Grid expansion also involves a number of challenges. Foremost among these are the high up-front costs of extending the grid and the high cost of connecting individual households (ARE, n.d.; Hogarth & Granoff, 2015). The World Bank–administered Energy Sector Management Assistance Program estimated the cost of expanding the grid at $8,000–$10,000 per kilometer in 2000.[3] The majority of these costs ($7,000) were for equipment, with poles and then conductors being the most expensive components (ESMAP, 2000). Such high costs and the fact that it takes advantage of economies of scale mean that the grid is well suited to serving densely populated areas in which people can afford to connect to the grid and pay for electricity in fairly large quantities. It also means, however, that the grid is poorly suited to supplying electricity to sparsely populated, poor, and remote areas, where only small amounts of electricity will be consumed. This is especially the case if these populations reside in challenging terrain where the necessary infrastructure is difficult to build and maintain (ARE, n.d.). Notably, much of sub-Saharan Africa's rural population has these challenging characteristics: low density, low incomes, and low levels of demand. In addition, the current extent of the grid is extremely limited in much of sub-Saharan Africa, so expansion plans would need to be ambitious.

Moreover, simply connecting households to the grid will improve their access to energy only insofar as the gird infrastructure is reliable and the generating capacity on the grid is sufficient to meet demand. In sub-Saharan Africa, most countries are currently experiencing a generation shortfall (see Part 1 of this series). Expanding people's access to an unreliable grid, without addressing capacity problems, is only likely to place greater demands on the system and make the grid less reliable for everyone who is already connected (Bhattacharyya, 2012; Murphy et al., 2014). Finally, because of the centralized nature of the grid, the overall infrastructure is vulnerable to localized impacts so that damage to one part of the grid (caused, for example, by severe weather or

[3] It was estimated that this figure could be brought down to about $5,000 over normal terrain in developing countries.

the breakdown of a single large generator) can proliferate and bring down the entire system.

In addition, because the grid approximates a perfect monopoly (with high capital costs and low marginal costs), it is not amenable to private competition and is therefore best managed by a regulated utility. In contexts where regulation is weak, as it is in much of sub-Saharan Africa, utilities have tended to underperform (see the section on Tariffs below) and have even become major sites of patronage (Africa Progress Panel, 2015). In the context of an unresponsive utility, electrification through grid expansion is highly unlikely, especially into areas that are politically and economically marginal (ARE, n.d.).

Historically the grid has been powered by fossil fuels, which has significant implications for climate change, but this does not need to be the case. It is technically feasible for the grid to integrate large quantities of renewables (see Part 1 of this series). In this respect the grid actually presents an important advantage for renewable energy because its geographic extent allows for the integration of a greater diversity of supply and consumption (see Text Box 3).

Grid: Solutions

Efforts to address the challenges involved in rolling out the grid have focused on bringing down the costs of connecting to the grid by using cheaper materials (e.g., bamboo) in transmission and distribution networks (see Text Box 3) and through the use of "ready boards" to reduce the cost of household wiring (Mostert, 2008). Other options for reducing connection costs include bulk purchasing of the materials needed for the distribution network (Modi et al., 2006).

Countries have also sought to innovate to get around the problems of corrupt or dysfunctional energy utilities. Their efforts have principally involved reforming the utility, largely through commercialization and the introduction of competition. The hope is that such reforms will "improve the technical, commercial, and financial performance of utilities; boost sector cash flow; facilitate mobilization of resources for capital investment on a commercial basis, thereby releasing public funds for other investments; and extend access to electricity to poor and rural communities" (World Bank, 2005, p. 1).

The impact of these reforms on poor people has been difficult to assess. Many countries have seen rates of access to electricity increase in the wake of reform, but these advances are thought to have been driven more by government policies, programs, and subsidies that have sought to connect households and reduce tariffs than they have by the reform efforts themselves (World Bank, 2005). Critics of utility reform argue that it has limited impacts on access because private sector participation tends to result in tariff increases as the private utility seeks to improve its financial standing. In addition, introducing a profit motive to the utility causes it to focus on providing electricity to communities that are already connected and proven to be profitable or that can be connected at a low cost. Such a focus comes at the expense of efforts to expand access to currently poor and unconnected areas (Mostert, 2008; Scott et al., 2003). On the other hand, proponents of reform point out that no African country has completely unbundled its utility, and thus impacts on price and access have not been fully realized (Eberhard et al., 2008; World Bank, 2005).

In addition to reform, innovations related to utilities have focused on improving and simplifying bill collection by installing prepaid metering or by imposing flat tariffs and installing load limiters (which limit how much energy any household can use) instead of meters (Mostert, 2008). In other cases countries have sought to outsource functions in which the utility does not have a natural comparative advantage, such as meter reading and bill collection (Mostert, 2008). In some cases countries have even outsourced the retailing of electricity, creating a system in which wholesalers purchase electricity from the grid and then sell it to customers directly[4] (Scott et al., 2003). This model has helped improve access in Phnom Penh, but regulation of the wholesalers has proved difficult, so much so that some households were being charged up to three times the standard tariff. As a result there have been calls to abandon the program (Scott et al., 2003).

Because of the cost of expanding the grid to Africa's sparse and remote population and the unresponsiveness of many African utilities, there has been a recent push to focus on distributed generation technologies. Proponents of distributed technologies hope that the private sector will be heavily involved, circumventing the need to engage an unresponsive utility.

[4] In many African cities, households that are connected to the grid sell power to their neighbors (usually in informal dwellings) through unregulated connections via an extension cord (Mostert, 2008).

Table 2: The relative strengths and challenges associated with four electricity generation technologies

Technology	Key features	Strengths	Challenges
Expanding the grid	Success in providing electricity to populations around the word Advantage of economies of scale Large role for the state	Can sell electricity at low cost Can provide large quantities of electricity Essential for increasing overall penetration of renewables Known technology	Very expensive to build State bureaucracy and unresponsiveness Currently heavily reliant on fossil fuels
Mini-grid	Very limited economies of scale New technology Amenable to future reductions in price of solar and storage	Very large scope for renewables Can provide large quantities of electricity Lower capital costs Quick to deploy Some role for the private sector	Relatively expensive electricity Relatively high capital costs (for local investors) Requires resource-intensive, bespoke approaches to make electricity affordable Current lack of supply chains and relevant skilled personnel First-order challenges to new technology
SHSs	No economies of scale Amenable to future reductions in price of solar and storage	Large role for private sector 100% renewable Relatively established technology	Expensive electricity Limited quantities of electricity Novel challenges around system management
Solar appliances	No economies of scale	100% renewable Large role for the private sector Potential to drive rapid changes in household fuel use	Very limited quantities of electricity Very expensive electricity Difficult to exercise quality control over different appliances

MINI-GRIDS

Mini-grids refer to a variety of electricity generation systems drawing on a variety of sources, including solar photovoltaic (PV), wind, small-scale hydropower, and fossil fuels (usually in the form of a diesel generator), or some combination of these. Mini-grids connect a number of households and/or services to a generation point. They can provide power at a variety of scales, ranging from very small amounts for limited hours of the day to large amounts comparable to those consumed by grid users available 24 hours a day (ARE, n.d.). They can be stand-alone systems connecting households that are remote from the grid, or they can be connected to the grid and used to smooth out problems with grid supply.[5] Power from mini-grids can be made available in either AC or DC, and as either single-phase (known as nano/pico-grids) or three-phase power (known as mini-grids) (IRENA, 2016b) (see Text Box 3).

Because mini-grids and nano-grids (hereafter simply referred to as mini-grids) can generate large quantities of electricity, they have the potential to provide “motive power” (power to run motors and machines) that could supply small businesses and promote economic development (Bhattacharyya & Palit, 2016; Deshmukh et al., 2013; TERI-GNESD, 2014). In addition, mini-grid systems are modular, meaning that they can be broken down into individual modules in the form of solar panels and batteries (M. Lee et al., 2014). Consequently, systems can initially be built with only limited generation capacity and then add capacity as demand for electricity increases.

The cost of electricity from mini-grids varies by the generation source available as well as the demands on the system (M. Lee et al., 2014). Micro-hydropower is the cheapest energy source (assuming the river runs all year), but such systems are limited to areas with appropriate geography (ARE, n.d.). Wind, although cheap, is also highly site-specific, and careful assessment of local wind availability is essential before making investments in wind-driven mini-grids (ARE, n.d.). Solar PV is ubiquitously available and relatively predictable; as a result it has been thought to offer the greatest promise for promoting energy access via mini-grids. Given the focus on PV in Africa, the remainder of this section will consider PV-based mini-grids.

Challenges for mini-grids

Although the initial capital requirements for mini-grids are significantly lower than the initial capital requirements for extending the grid (Alstone et al., 2015; Deshmukh et al., 2013; Hogarth & Granoff, 2015), the up-front costs for mini-grids are still large compared with the capital available to local entrepreneurs in many developing countries (Bhattacharyya, 2015). The small size of mini-grids means that they require storage, in the form of batteries, and experience few economies of scale (see Text Box 3). The need for storage increases the overall system cost, both because batteries themselves can be costly and because adding batteries requires building excess generation capacity as batteries place an extra strain on the system (Murphy et al., 2014). Owing to the diseconomies of scale, the costs of increasing the capacity of a mini-grid must be passed on to consumers, making the electricity from mini-grids expensive compared with that from the grid and relative to the incomes of the populations they are intended to serve (see Text Box 4). Finally, when mini-grids are placed in remote or hard-to-

[5] Using mini-grids (which include generation capacity and storage) to smooth supply problems from the grid has been shown to be cheaper than trying to smooth supply using batteries alone (Murphy et al., 2014).

reach locations, maintenance costs can be high, further increasing the cost of the overall system (Africa Progress Panel, 2015; TERI-GNESD, 2014).

Text Box 4: The cost of electricity

It is impossible to provide an accurate estimate of the average LCOE for electricity from mini-grids, for several reasons. The costs of components and labor vary across countries, and the cost of energy from a mini-grid depends on the size of the system, the source of the energy, and the pattern of demand placed on the system (see Text Box 3). Research from Bangladesh (Bhattacharyya, 2015), however, which looks at the price of energy based on different mini-grid configurations, can provide us with a useful sense of what costs might look like.

The research modeled four types of systems, each of increasing capacity. They ranged from a basic system that covered immediate needs (such as household lighting, a fan, and a television, available for limited periods of the day) up to a system that could handle relatively large household loads, as well as productive and commercial loads, and that was available 24 hours a day.

The study used the HOMER model and considered PV-diesel hybrid mini-grids, using component costs thought to reflect the market price for these goods in Bangladesh. It found that for the low-capacity system, a diesel-only approach was cheapest (assuming a diesel price of $0.6/liter, or $2.27/gallon). For this system, the LCOE was $0.47/kWh. For larger systems, hybrid arrangements were cheapest, resulting in a LCOE of $0.34–$0.37/kWh, with costs decreasing as the capacity of the system went up. These numbers are comparable to theoretical resource assessments of mini-grids in Africa (using component and labor costs from Germany), which put the LCOE of PV mini-grids at $0.24–$0.35/kWh (€/0.18–€/0.25kWh, in 2014) (Huld et al., 2014).

We can compare these costs with the cost of electricity from other sources (see table below). SHSs in Bangladesh have an LCOE of about $0.72/kWh and provide services equivalent to those of the lowest-capacity mini-grid used in the above study (Bhattacharyya, 2012). Diesel-only mini-grids are thus a cheaper way to generate electricity than SHSs, assuming households are suitably clustered together. On the other hand, grid tariffs in Bangladesh are only $0.04/kWh for consumption up to 100kWh a month. When comparing these prices, we should keep in mind that in Bangladesh these prices are based on PV-hybrid systems (with the diesel generator contributing substantially to generation) and that purely PV systems would be more expensive.

In Africa, where grid tariffs are so high that they are widely considered an impediment to development, retail prices from the grid are about $0.13/kWh (World Bank, 2013)—though they can be much higher in some cases. To get a sense of what these numbers mean, consider that the International Energy Agency definition of energy access suggests that an urban household needs at least 500 kWh of electricity annually to meet its basic energy requirements for lighting, communications, and some cooling, while a rural household needs at least 250 kWh (IEA, n.d.). Based on the 2008 average income for an African household of $762[6] (Lakner & Milanovic, 2013), 10 percent of that household budget (the income threshold for energy poverty) would provide $76.20 for spending on energy. At mini-grid prices ($0.34/kWh), the average African household could afford only 224 kWh a year. At average African grid prices ($0.13/kWh), the average household could afford about 586 kWh annually.

All of this together means that the average African household could not afford to purchase the basic electricity required for a rural household even if it spent as much as 10 percent of its annual budget on electricity obtained from a relatively large-capacity mini-grid. Such a household could only just meet the needs of an urban household when buying electricity from the grid. When we consider that this 10 percent budget share excludes energy for cooking, it becomes clear just how large a challenge energy costs present for improving energy access among poor, rural households.

Table 3: Comparing different costs of generation sources

Generation source	LCOE ($/kWh)		Total energy average African household - 10% budget (kWh/yr) (IEA basic: rural - 250, urban – 500)
	Small system	Large system	
Hybrid PV-diesel mini-grid	0.47	NA	162.1
PV mini-grid	NA	0.34–0.37	205.9–224.1
SHS	0.72	NA	105.8
Grid in Bangladesh (retail price)	0.04	0.04	1905[7]
Grid in Africa (avg. retail price)	0.13	0.13	586.2

The fact that the cost of electricity from mini-grids is generally higher than that provided by the grid (Deshmukh et al., 2013) (see Text Box 4) creates challenges for using mini-grids to drive increases in energy access and in human development. First, the high cost limits the extent to which mini-grids are accessible to the poor (TERI-GNESD, 2014; World Bank, 2008). Second, even among populations who do get access to the electricity, high costs mean that households tend to limit the services they are willing to access to those requiring only small amounts of electricity (such as lighting and cell-phone charging) and

[6] This average increased only $20 over the preceding 15 years and thus is unlikely to have changed dramatically since 2008.

[7] Note that the Bangladesh retail price is $0.04/kWh for consumption up to 100 kWh/month. A consumer who uses more than 1,200 kWh/year would pay more than the $0.04/kWh tariff. Thus this is a theoretical value.

do not use electricity for productive purposes (Bhattacharyya, 2015). The high cost of electricity from mini-grids therefore poses a significant challenge to the profitability of mini-grids, which in turn limits interest from the private sector.

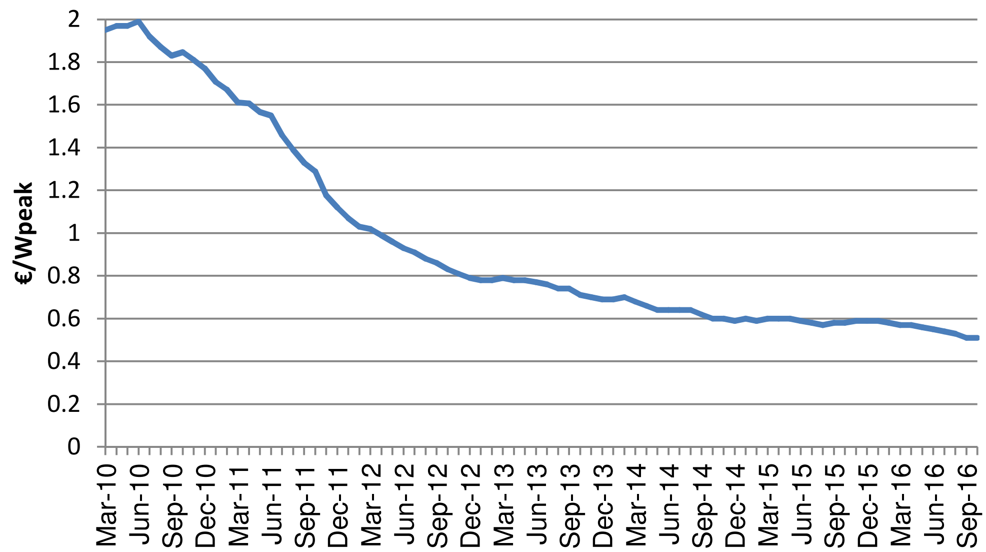
Problems of profitability are compounded by the risk of grid encroachment, which occurs when the grid is expanded to communities currently receiving electricity from a mini-grid. Given the cheaper price of electricity from the grid, consumers are liable to abandon the mini-grid, and the investor who owns the infrastructure stands to lose money on the project.

Finally, as will become clear below, it should be remembered that operating a mini-grid is essentially like operating a mini-utility and therefore requires considerable economic, financial, and technical skill (Bhattacharyya & Palit, 2016). A lack of trained installers, technicians, and trainers therefore presents a hurdle to their effective deployment in sub-Saharan Africa. Mini-grids also suffer from the fact that they are a new technology and as such present a “risky business environment due to unknown consumer characteristics and unfamiliar business activities, weak institutional arrangements… [that arise]… from non-supportive regulatory and policy frameworks, limited access to low cost finance and inadequacies in local skills and capacities” (Bhattacharyya & Palit, 2016, p. 167).

Mini-grid: Solutions

Because the principal barrier to mini-grids is the high tariffs that stem from the high cost of capital (TERI-GNESD, 2014), reviews of experiences with mini-grids have focused on how to keep the capital costs down. A number of potential solutions exist, but they all come with their own challenges. Before talking about such challenges, however, it should be noted that mini-grids stand to benefit greatly from the advances in renewable technology, which will lower the cost of both PV generation and storage (see Figure 5). Likewise, the arrival of new low-watt appliances will mean that households can experience improved services despite the high price of electricity from mini-grids. Considering opportunities for mini-grids to address energy poverty therefore requires a serious consideration of future prices for solar and storage technologies, which should be justified and made explicit in any energy access policy.

Figure 5: The falling price of solar panels: March 2010–October 2016



Source: PVXchange, n.d.

Beyond technical advances, however, the most obvious solution to the problem of high up-front costs is to cut corners on the size of the system by reducing its capacity and storage or to purchase cheaper, low-quality system components. However, reviews of experiments with mini-grids warn strongly against both options, as both are likely to result in more rapid system failure and consumer dissatisfaction. In the long run these outcomes will lead to higher costs and raise the risk that the project will be abandoned altogether (M. Lee et al., 2014). Instead, it is thought that investing in the longevity of the equipment and minimizing replacement costs is the best way to keep costs down over the long term (ARE, n.d.).

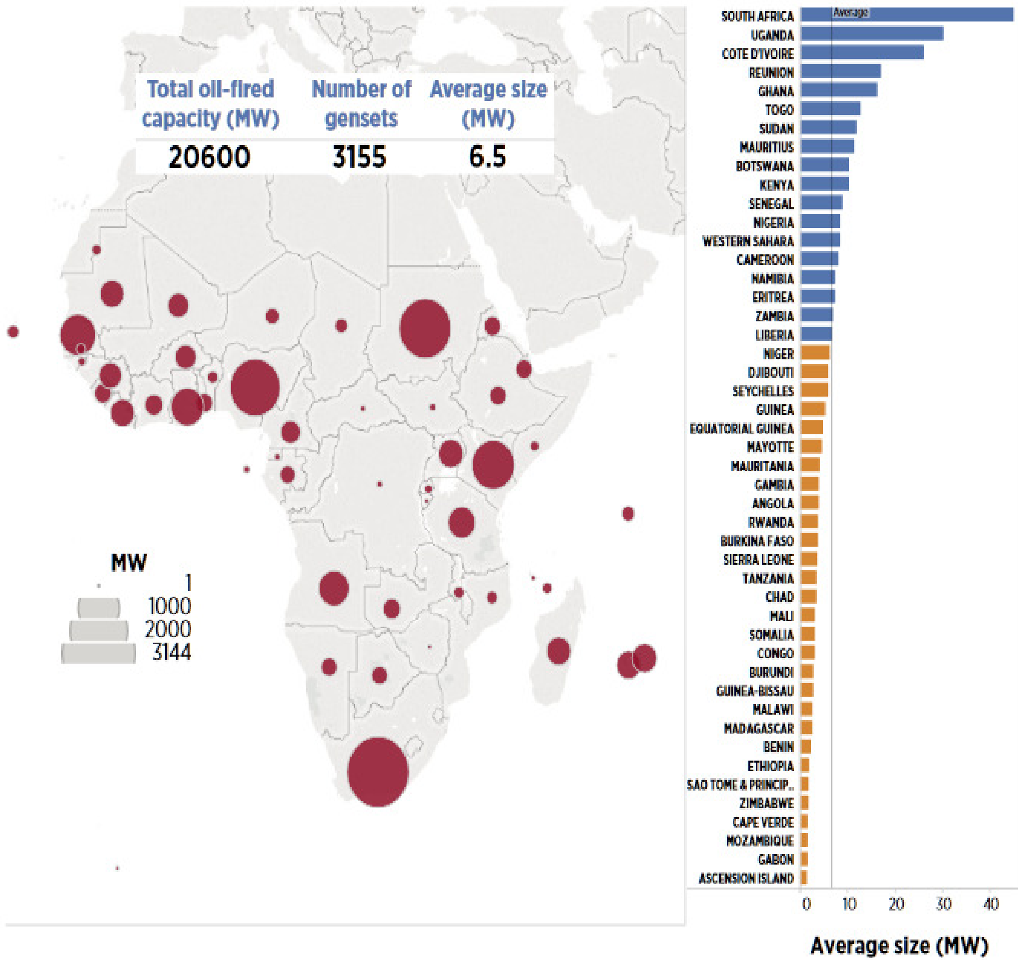
Without cutting corners in terms of size or quality, another way to hold down the costs of a mini-grid system is to keep the system as small as possible while still meeting people's energy needs. Achieving this requires exhaustive analysis of likely system demand prior to embarking on any project (ARE, n.d.; Deshmukh et al., 2013). While this is certainly good advice, as well as a means to ensure that demand-side management is built into any mini-grid system (Deshmukh et al., 2013), it can be highly resource intensive. Unelectrified rural households rarely know how much electricity they will use once they are connected. As a result, demand analysis usually involves extensive assessments of household energy use patterns. Mini-grid costs can potentially be lowered further by asking households to sacrifice some reliability in return for lower tariffs (M. Lee et al., 2014). Such a strategy, however, requires knowing not only exactly what demand is likely to look like, but also how consumers will react to changes in reliability and what an acceptable level of reliability would be.[8] Understanding such dynamics requires an even more detailed assessment of how users will consume energy services—down to the hourly level—which is, again, very resource intensive (M. Lee et al., 2014).

Another means of reducing the cost of electricity from mini-grids is to integrate domestic and productive uses, limiting the latter to off-peak periods. Doing so will distribute peak demand more evenly, allowing for more effective use of generation capacity, which in turn, improves, cost recovery, and therefore allows for lower overall tariffs (Bhattacharyya & Palit, 2016) (see Text Box 3). An effective way to achieve this is to identify “anchor tenants”—relatively large reliable consumers such as a cell tower or a mill—that can guarantee the consumption of a basic amount of electricity during off-peak hours (ARE, n.d.; Deshmukh et al., 2013; Modi et al., 2006; Palit & Sarangi, 2014). Residential and small business users can then be added to the system, and the system can be scaled up as demand increases. The use of an anchor tenant can also help address the financing challenge, because private investors have the security of selling a basic load of electricity to that tenant. Still, it can be challenging to integrate productive and domestic loads as the former do not always easily arise from electrification; the reasons for this are discussed in greater detail below.

Another means of reducing capital costs is to focus on hybrid systems in which PV generation is augmented by a diesel genset—an electric generator powered by a diesel engine (ARE, n.d.; Bhattacharyya, 2015; Murphy et al., 2014). The genset can provide power to the system in cases of prolonged cloudiness and also maintain the battery discharge at a minimum level, thereby increasing its longevity (see Text Box 3). The system’s generation capacity does not have to be oversized to the same extent, and battery packs can be smaller—two advantages that save on up-front costs (Bhattacharyya, 2015). The integration of PV and battery modules into existing diesel mini-grids can also effectively reduce energy costs by cutting diesel consumption (Bhattacharyya, 2015; IRENA, 2016b; Murphy et al., 2014). The cost savings made possible by switching from PV-only or diesel-only generation to hybrid systems get larger as the size of the system increases (Bhattacharyya, 2015), and there is thought to be considerable scope for such gains across sub-Saharan Africa given the scale of generator use (see Figure 6) (IRENA, 2016b). Obviously, the possibilities for cost-savings based on hybridization depend on the prices of diesel and PV components, but for most prices in the near future, hybrid diesel-PV systems will provide the lowest-cost electricity (Murphy et al., 2014) (see Figure 7).

[8] If households use electricity for irrigation, for example, the loss of electricity for 12 hours three times a year would not be a problem. If, however, electricity is used to provide refrigeration for food stocks or vaccines, then outages of more than three hours become problematic.

Figure 6: The distribution of existing oil/diesel generator capacity in sub-Saharan Africa



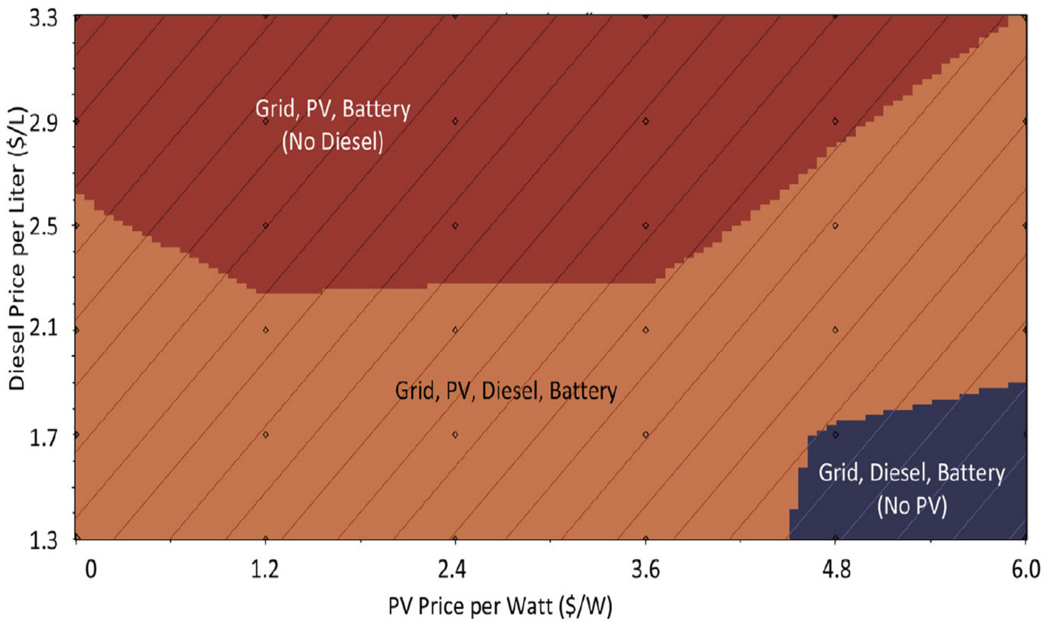
Source: IRENA, 2016b, p. 59; data originally from World Electric Power Plants Database, n.d.

Yet hybrid diesel-PV systems also pose challenges. The introduction of diesel results in carbon emissions[9] and can cause electricity prices to become unstable owing to fluctuations in the price of fuel.[10] Diesel gensets also require maintenance which has proven challenging in some contexts, and on top of this, there are instances in which diesel supply chains are weak, rendering the PV-hybrid mini-grids vulnerable in cases where diesel cannot be procured (M. Lee et al., 2014; Murphy et al., 2014). Given these challenges, expert advice has begun to suggest eschewing hybrid systems in favor of purely PV generation, despite the increased costs (M. Lee et al., 2014; Murphy et al., 2014).

[9] In these systems PV generally ends up providing between 75 and 90 percent of the power (ARE, n.d.), so carbon emissions and diesel price impacts are relatively small.

[10] See footnote 4.

Figure 7: Price points at which PV-only, hybrid, and diesel-only mini-grids produce the lowest-cost electricity



Source: Murphy et al., 2014, p. 533.

Proper battery management is essential to the longevity of mini-grids. While management can be automated (ARE, n.d.), having skilled technicians to manage the mini-grid can reduce overall system costs. Technicians can make appropriate decisions about balancing battery life with system reliability in cases of reduced generation or in times of heavy load (M. Lee et al., 2014). Sub-Saharan Africa, however, currently lacks skilled technicians (Bhattacharyya, 2012). In addition, introducing discretion on the part of technician can open the door for battery mismanagement (see Text Box 3), which can end up increasing overall energy costs and threaten the sustainability of the system (ARE, n.d.). Such problems have been observed in Bangladesh, where batteries have been observed to last as little as 4–5 years (TERI-GNESD, 2014) when their expected life should be closer to 10 years (Bhattacharyya, 2015).

In principle it would be possible to lower the cost of electricity from mini-grids by using grid-connected consumers to subsidize the expansion of distributed electricity infrastructure just as one would subsidize grid expansion (dividing the cost of any expansion by all the existing grid-connected customers) (Deshmukh et al., 2013). This analogy does not hold perfectly in the case of mini-grids, however. All grid users benefit from a more diverse pool of consumers (so long as there is sufficient generation capacity), but connecting households to an isolated mini-grid does not diversify the national grid. Subsidies could still be justified on social justice grounds, but in practice such an approach raises questions about whether existing consumers should subsidize private purveyors of mini-grids or only state-owned mini-grids that will eventually be incorporated into the grid. The complexities of such an arrangement appear to have prevented it from being implemented anywhere (Deshmukh et al., 2013; TERI-GNESD, 2014).

The final means for keeping tariffs down is to ensure that the equipment used in the mini-grid is used for the full extent of its lifespan. Given that the longest-lasting components in a mini-grid can last for 25 years, ensuring that mini-grids operate for the full 25 years is an effective means for keeping tariffs as low as possible because no component value is wasted (ARE, n.d.). This solution, however, compounds problems of grid encroachment, which dissuades private investment in distributed energy systems with long payback periods.

Challenges related to grid encroachment can however be mitigated. Mini-grids can be designed to be incorporated into the grid when it arrives. Under such a scenario, generation capacity as well as distribution infrastructure could be bought by the utility and then integrated into the overall grid (ARE, n.d.; Deshmukh et al., 2013). Similarly, the utility could purchase electricity from the owner of the mini-grid at a set price until the costs of the system have been fully recovered. In both cases, however, the utility will likely be subsidizing the private seller, who will be forced to sell electricity at a higher price than that available from the grid. In addition, designing mini-grids so they can be incorporated into the grid imposes higher up-front costs during construction. These mainly involve ensuring that the system can deliver three-phase power (ARE, n.d.) (see Text Box 3) by adding inverters (which require maintenance and are expensive to replace) to PV systems in order to convert the DC produced by solar panels to AC. Another potential solution to grid encroachment is to keep mini-grid systems separated from the grid after it arrives (a process known as “islanding”). Such an approach can be used to ensure cost recovery on investments in mini-grids (Deshmukh et al., 2013), but it can also create political challenges if populations that could connect to the grid are stuck paying higher tariffs for a potentially inferior service, as they could be on the mini-grid.

Addressing issues of (1) financing, (2) lack of technical staff to support mini-grid operation and maintenance, and (3) challenges associated with first-generation technologies will likely require heavy support from donors and the state. Such support would include the development of tools for financing local entrepreneurs in this space; training for the array of personnel involved in mini-grid siting, installation, operation, and maintenance; and support for data sharing and learning around the creation of effective business models (Alstone et al., 2015; ARE, n.d.; Deshmukh et al., 2013).

While there is certainly scope for the private sector to deliver mini-grids, the idea that the private sector will simply fill the vacuum left by the failure of the state and exploit the untapped market among unelectrified households in sub-Saharan Africa appears naïve. In this respect all assessments of mini-grid success and failure point to the need for a strong regulatory and policy environment in order for the private sector to operate effectively (Alstone et al., 2015; ARE, n.d.; Deshmukh et al., 2013; IRENA, 2016a; Palit & Sarangi, 2014; TERI-GNESD, 2014). While there are no silver-bullet solutions to the policy and regulatory challenges surrounding mini-grids, a number of generic actions to be taken have been identified. The state should (1) ensure that subsidies are available to make mini-grids economically viable (see below), (2) develop a regulatory environment that lays out the rules of the game for different actors, (3) take the lead in at least providing resource surveys, (4) make public all plans for grid expansion, (5) ensure the safety and reliability of the mini-grid and make allowances for islanding or integration of the mini-grid when the national grid arrives, and (6) provide training in design, siting, operation, and maintenance of mini-grids (Deshmukh et al., 2013).

The state or utility can also play an important function in bundling mini-grid projects together so that they start to make financial sense for the private sector (ARE, n.d.). This is often achieved on the basis of geographic concessions, offered via tenders, in which companies take responsibility for supplying mini-grid systems to all the potential users in a geographic area (Mostert, 2008).

It should be noted, however, that even under supportive conditions the private sector has been known to refuse to deliver mini-grids to certain areas if they are considered too remote, too poor, or too small to offer serious potential for growth in demand (Bhattacharyya & Palit, 2016). In this respect, even though distributed energy technologies are intended to improve energy access among the poor, reviews show that they continue to benefit the relatively well-off (Bhattacharyya & Palit, 2016; World Bank, 2008). Community-managed mini-grids could help address this challenge, but any community-driven development effort takes a great deal of time and resources and therefore does not scale quickly or easily (ARE, n.d.).

Overall, mini-grids provide a potentially valuable way to deliver electricity to areas for which grid access will be a challenge. Even though the up-front costs are less than those for grid extension, they still pose significant challenges for financing projects and result in high costs of electricity. There are ways to get around these challenges, but they all involve creating bespoke energy systems in which demand patterns are analyzed exhaustively and systems are built to purpose. The extent to which such systems are context specific and reliant on new technology poses major challenges to their scalability and creates a significant technical burden. At the moment mini-grids in Africa are focused on pilot efforts, and to be a source of mass electrification they will need to be scaled up significantly and quickly. Studies examining the challenges to scaling up distributed energy systems in South Asia have identified problems similar to those that dominate the sub-Saharan African context: small markets, lack of financing, uncertain policy environments, and a lack of business models for managing and maintaining a huge amount of distributed infrastructure (Bhattacharyya, 2014).

SOLAR HOME SYSTEMS (SHSs)

Smaller than mini-grids, solar home systems are generation systems designed to provide electricity to a single household using solar panels and a small battery. While SHSs can be large, including many solar panels and a large battery, for the purpose of increasing energy access among low-income groups such systems usually include only a couple of panels and a small battery, providing very limited amounts of power. The major advantage of SHSs is that they can be used to provide electricity to isolated households (in contrast to the mini-grid, which requires that households be clustered together so they can all be connected to the generating source via a low-voltage distribution line[11]). Because utilities traditionally lack expertise in retail, they often leave the provision of such systems to the private sector, through either direct sales or concessions (Mostert, 2008).

Challenges with SHSs

The downside of SHSs is that due to the small size of these systems they can only provide small amounts of electricity (suitable for lighting, entertainment, charging a cell phone, and cooling) that are available for only a limited number of hours a day. These systems are unable to supply energy for heating or cooking and are not sufficient to provide motive power to support small industry. As such, the technology provides only the lowest tiers of energy access. Like mini-grids, SHSs stand to gain from likely future advances that reduce the cost of renewable generation and storage components and from the arrival of new low-watt appliances on the market.

Theft of solar panels can be a problem. Where this is the case households have been known to surround panels with locked steel cages or remove panels from their roofs so they can better watch them, and then lock them indoors while households are unattended. In all instances changing the installation of the solar panels decreases their generation capacity,[12] compromising the capacity of the system even further (Azimoh et al., 2014).

[11] SHSs have sometimes been set up in nano-grids to allow for better sharing of batteries and capacity.

[12] Solar panels are usually placed on unshaded roofs facing the equator at an angle that maximizes their exposure to incoming solar radiation (“insolation”). Moving panels so that they no longer face the equator or stand without and angle or covering them (e.g., with cages) all serve to reduce the insolation they receive and therefore reduce system capacity.

The low capacity of the SHSs not only limits potential development impacts, but can also cause problems for sustainability. As a household slowly purchases appliances, it increases the load on the system (Gustavsson, 2007; K. Lee et al., 2016). If a household overloads the system, placing extra strain on the battery, it shortens battery life and increases the cost of the overall system (see Text Box 3) (Ellegård et al., 2004).

SHSs also raise regulatory challenges. In South Africa, for example, some local technicians have been involved in a black-market service in which they offer to bypass load control units on batteries (see below under "SHS: Solutions"). Likewise, battery mismanagement, and the associated costs, has put subsidies under pressure. Eventually this has resulted in nonpayment to the companies responsible for the concessions, causing them to drop out of the program (Azimoh et al., 2014). In Bangladesh there have been reports of problems caused by the use of low-quality components, poor installation practices, and inadequate control mechanisms, all of which compromise long-term sustainability (Bhattacharyya, 2015).

Finally, SHSs are truly unable to take advantage of economies of scale. While they are the cheapest way to deliver electricity to isolated and remote households, the electricity from an SHS is usually more expensive than that provided by a mini-grid that provides the same level of services (Bhattacharyya, 2015) (see Text Box 4). In addition, even with relatively low capital costs, many poor households remain unable to afford the up-front costs of SHS installation.

SHS: Solutions

As with the mini-grid, problems related to the affordability of both the system and the electricity it produces can be addressed by providing subsidies (as in South Africa[13]) (Azimoh et al., 2015) or creating accessible credit schemes (such as the Grameen Shakti program in Bangladesh).

To help improve battery management and prevent excessive discharging, load control systems can be added to the system. It should be noted, however, that there are documented cases of such systems' being circumvented and batteries' being discharged anyway (Azimoh et al., 2014). Risk of theft can be reduced by using mobile racks that hold the solar panels off the ground and at an appropriate angle,[14] yet allow households to move them inside when the dwelling is unattended (Azimoh et al., 2014).

It is thought that many of the challenges with SHSs can be addressed if the communities receiving the technology are suitably well engaged so that they

[13] As part of this program, the subsidy covered all of the capital costs of the system and provided a monthly payment of ZAR 48 (approximately $3.50).

[14] See footnote 9.

understand the capacity of the system and the challenges to sustainability posed by system mismanagement. Yet it can be difficult to manage people's expectations when they have a desire for higher-capacity systems (Benjamin, 2015; Lee et al., 2016), especially when the populations being served by SHSs are interacting with consumers who are served by mini-grids or the national grid, who pay less for their electricity, and who receive a higher-quality service (Azimoh et al., 2014; Mostert, 2008). As with mini-grids, households sometimes abandon SHSs when the grid arrives in their area (Khandker et al., 2009b).

Finally, as with mini-grids, the rollout of SHSs will require an active role for the state or utility, which will, at least, have to create the appropriate conditions for the delivery of such services. These conditions will include an appropriate regulatory environment that ensures the quality of the systems being installed and engages project recipients in understanding the need to manage the service appropriately and the challenges related to system capacity. As with mini-grids, bundling households into concessions is an effective tool for making their installation profitable to the private sector. Finally, issues of grid encroachment will remain a challenge. The utility must not only make transparent statements about grid expansion plans (and remain true to these), but also have a policy in place for managing how distributed technologies will interact with the grid when it arrives.

Overall SHSs provide an important means for providing access to electricity, but the general success or failure of a program depends on the specific context. In many cases households have been satisfied with the service they receive from SHSs despite the costs (Ellegård et al., 2004). In general satisfaction results of the fact that using liquid fuels for illumination (candles or kerosene) is so inefficient (Mills, 2003) that SHS can still prove a cheaper way for households to meet their illumination needs. Furthermore, because illumination from an electric bulb is preferred to illumination from a candle and solid fuels cannot provide cooling, entertainment, or ICT services. As a result households have even been willing to pay more for electricity from SHSs than they would normally spend on kerosene and candles (Ellegård et al., 2004). In other cases, however, the limited capacity of SHSs has resulted in high levels of dissatisfaction, especially if recipients live near consumers who receive electricity from the grid (Azimoh et al., 2015; Schillebeeck et al., 2012). Studies have shown that people can have a sense of isolation or discrimination when they receive inferior electricity services as a result of their access being limited to distributed technologies (Bhattacharyya & Palit, 2016). In some cases households have resisted being connected via SHSs in order to avoid being marked as "connected" and undermining their chances of gaining access to the grid at a later date (Ellegård et al., 2004). Provision of SHSs should thus not be viewed as a substitute for grid connections; rather, SHS technology must be incorporated into a broader process of connecting households to larger energy systems.

SOLAR APPLIANCES

Solar appliances refer to individual appliances (torches, radios, cell-phone chargers, lanterns) that run on solar power and provide energy services. The major advantage of such appliances is that they have very low capital requirements, have supply chains that can be established relatively easily, and offer a big market for the private sector. There is evidence that such appliances are having rapid and significant impacts on domestic energy systems, replacing dry-cell batteries as well as solid and liquid fuels for illumination purposes (Turman-Bryant et al., 2015). In two Kenyan towns, for example, the number of off-grid lighting products rose by 77 percent between 2012 and 2014, with sales from such products more than quadrupling, from $32,000 to $180,000, over the same period (Turman-Bryant et al., 2015).

Challenges with solar appliances

The principal challenge for solar appliances is that they provide only small quantities of electricity and have limited storage capabilities. As such, they are only useful for meeting the lowest tiers of energy access and do not supply motive power to support livelihood diversification or help meet thermal energy service needs. In addition, because they are a new technology, uptake can be slow. Such appliances have relatively low capital costs, but compared with household incomes, they may still be considered expensive.

Solar appliances: Solutions

Little can be done about the limited capacity of such devices, but as with mini-grids and SHSs, future gains are possible from the development of low-watt appliances and cheaper solar components. To improve uptake, it is thought that providing guarantees of the quality of the devices, as well as socializing their advantages over solid fuels, can increase households' willingness to spend relatively large sums of money on untested technologies (Turman-Bryant et al., 2015).

Overall, under the right conditions, it appears that solar appliances can play an important role in providing people with the lowest tiers of energy access. Their rapid success in transforming the energy system in certain contexts suggests that solar-powered devices are considered significantly superior to solid and liquid fuels when it comes to illumination and that ICTs (which can only be powered by electricity) are highly valued. Efforts thus need to be focused on promoting these technologies and then incorporating them into a process that delivers energy systems capable of more completely meeting people's energy needs.

4. ELECTRICITY AND ENERGY POVERTY

Before discussing the empirical work on the impact of electrification on energy-poor households, it is worth pointing out that there are significant experimental challenges when it comes to testing this relationship. When areas receive electricity (especially grid electricity), they also tend to be undergoing other changes, such as significant economic and/or population growth, which means that they are also likely to be experiencing other changes in terms of resourcing and infrastructure. As a result, it is difficult to disentangle the impacts of electrification on development from the effects of other processes taking place in a population (Burlig & Preonas, 2016; Dinkelman, 2011; Khandker et al., 2009a). To resolve these challenges, researchers have used a host of novel and sophisticated methods.[15] It is worth keeping in mind, however, that "in the end it must be admitted that all cross-sectional analysis have their shortcomings, and … [that] … impacts [of electrification] may be short-term. [In short:] The patterns observed today may not hold in the future" (Khandker et al., 2009, p. 22). Nonetheless, multiple works on electrification show a few recurrent features regarding their impacts on household energy poverty, economic development, and services.

IMPACTS ON HOUSEHOLD ENERGY POVERTY

When people receive access to electricity in their home, they principally use it for lighting, entertainment and ICTs, and cooling. The results are increased use of appliances, reduced candle and kerosene use, increased access to lighting, and less time spent collecting fuels (Azimoh et al., 2015; Bhattacharyya & Palit, 2016; Broto et al., 2015; Dinkelman, 2011; Prasad & Visagie, 2006).

Beyond this, while access to electricity changes household fuel choices and reduces the use of some solid fuels (Dinkelman, 2011), it generally does not cause households to shift away from using predominantly solid fuels for cooking and heating[16] (Bailis et al., 2005; Broto et al., 2015; Gebreegziabher et al., 2012;

[15] These methods include panel data, control groups (Khandker et al., 2009b), instrumental variables (Dinkelman, 2011; Khandker et al., 2009a), regression discontinuity (Burlig & Preonas, 2016), propensity score matching (Khandker et al., 2009a), and simple qualitative impact assessments.

[16] There are some minor exceptions to this finding around the use of electric rice cookers in Asia (World Bank, 2008).

Khandker et al., 2009b; Madubansi & Shackleton, 2006; Malla & Timilsina, 2014; Masera et al., 2000; Prasad & Visagie, 2006; World Bank, 2008). This overall pattern persists even when electrification rates are high (Bailis et al., 2005; Broto et al., 2015) and long after electricity access has been established (Bailis et al., 2005; Cowan & Mohlakoana, 2005; World Bank, 2008). The relationship holds among very wealthy households (Hiemstra-Van der Horst & Hovorka, 2008; Khandker et al., 2010), including those in the 90th income percentile[17] (Bacon et al., 2010). It holds when access to fuelwood decreases (Madubansi & Shackleton, 2006) and when electricity is the cheapest available fuel source (Hosier & Kipondya, 1993). And the pattern largely holds across rural and urban areas (Broto et al., 2015), though urban areas have seen greater use of electricity for cooking (Bacon et al., 2010; Cowan & Mohlakoana, 2005).

Despite the failure to transition energy-poor households toward using electricity for cooking and heating, electrification has a significant impact on people's well-being. For example, the illumination provided by SHSs in South Africa was found to be used effectively to improve safety and scare away reptiles from people's dwellings. Access to entertainment has also been noted to improve people's quality of life (Azimoh et al., 2015; Prasad & Visagie, 2006). Finally, electrification was found to have positive impacts on education by increasing study hours (Azimoh et al., 2015; Khandker et al., 2009a; Prasad & Visagie, 2006) and school enrollment rates (Khandker et al., 2009b). However, caution about simple emphatic claims of the positive impact of electricity on education may be warranted. A study involving 30,000 Indian villages, for example, showed no evidence of increased school enrollment as a result of households' being provided with access to electricity through the grid (Burlig & Preonas, 2016).

The value of electricity to recently connected households is also evidenced by the fact that newly connected areas are repeatedly found to experience a subsequent increase in demand. This is thought to be due to households' slowly purchasing appliances that they have had to save up for (Khandker et al., 2009b). This increase in demand also occurs after households get connected to mini-grid projects (ARE, n.d.; Burlig & Preonas, 2016). The impact of appliance purchases is compounded when households that were initially skeptical of the project subsequently want to be connected after they witness the benefits experienced by connected households. In fact, this trend is so common that it is considered good practice to oversize mini-grid installations in order to cope with the subsequent increases in demand that are likely to take place (ARE, n.d.). If revealed preferences are an indicator of welfare maximization, then such increases in demand speak to a robust trend whereby households gain substantially from accessing electricity.

[17] This percentile was measured as household earnings as much as $800 a month (2005, purchasing power parity) (Bacon et al., 2010).

IMPACTS ON ECONOMIC DEVELOPMENT

While the evidence on the impact of electrification on household energy poverty is clear, the evidence on the economic impacts of electrification is much more ambiguous (Cook, 2011). Although the literature tends to agree that access to electricity in rural areas does not drive industrialization (Dinkelman, 2011; Khandker et al., 2009b; World Bank, 2008), the findings on the impacts on small business development, livelihood diversification, and household incomes are mixed. Reviews of the impacts of both grid connections and distributed energy find no particularly noticeable impacts on economic development, which are generally thought to be uncertain and largely anecdotal (Schillebeeck et al., 2012; Terrapon-Pfaff et al., 2014). Yet there are single studies that find systematic and generalizable impacts, showing that electrification drives increases in income and improvements in economic activity. These mixed results suggest that while electrification matters for economic development, by itself it is insufficient to drive development, and other factors likely matter in determining economic outcomes (Cook, 2011).

Reviews find that only a few households use electricity for productive purposes (World Bank, 2008). Among those that do, the focus is on a few small business owners who use electric lighting to extend their business hours (Azimoh et al., 2015; Bhattacharyya & Palit, 2016; Broto et al., 2015) or the small number of households that use electricity to start new businesses, such as hairdressing salons (Broto et al., 2015; K. Lee et al., 2014) and cold storage facilities (Broto et al., 2015). In particular, electrification has been shown to favor the creation of sectors that provide electronic services (such as showing TV, charging phones, and playing music). Notably, there is limited evidence of households using electricity for productive purposes involving motive power (such as carpentry or milling) (Khandker et al., 2009b; K. Lee et al., 2014).

The limited effects of electrification on economic development have been observed in both rural and urban contexts. A study of 30,000 Indian villages electrified under the Prime Minister's Rural Electrification Program,[18] for example, found that, at best, electrification leads to only small changes in economic outcomes in the medium term (three to five years) (Burlig & Preonas, 2016). The pattern persists in urban areas: in Cape Town's informal settlements, for example, electrification was found to have almost no discernable impact on economic activity (Cowan & Mohlakoana, 2005).

On the other hand, studies showing strong generalizable links between access to household energy and the creation of informal sector enterprises point out how women's income opportunities have been observed to increase in urban areas as a result of access to electricity. Women use it to support commercial activities

[18] This program is termed the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY).

such as dressmaking, washing, ironing, and hairdressing (Clancy, 2006). The rollout of the grid in the KwaZulu Natal Province, in South Africa, was found to drive an increase in employment, with female employment found to rise significantly. Not only did electrification increase the number of jobs in rural KwaZulu Natal, but it also increased the hours women worked, with most of this work thought to come through the creation of cottage industries (Dinkelman, 2011). Large-scale studies on the impact of grid rollout in Bangladesh and Vietnam found that access to electricity increased household incomes from both on-farm and off-farm sources. In Vietnam the gains were greatest among on-farm sources because electricity was used for irrigation (Khandker et al., 2009a; Khandker et al., 2009b).

Increases in household incomes as a result of increasing energy access appear to happen slowly at first, rising over time before they plateau. Again, the slow increase is thought to be due to the time it takes households to be able to purchase appliances necessary to take advantage of electricity to provide services (Khandker et al., 2009a; Khandker et al., 2009b).

IMPACTS ON SERVICES

Little research has looked explicitly at the impact of electrification on the availability and quality of services (Practical Action, 2014). That said, research on the impacts of electrification in Maputo showed that people found the provision of street lighting to be important for safety, for making it easier to run errands after dark in the winding walkways of an informal settlement, and for creating a welcoming neighborhood (Broto et al., 2015). Although expanding access to electricity has been used to improve the cold chain (which is important for vaccines) questions have been raised about whether this translates into increases in immunization rates (World Bank, 2008). The largest impacts of electricity on service provision are thought to result from a greater willingness on the part of health and education workers to remain in rural areas once they are electrified (World Bank, 2008).

Although energy is necessary for a host of services that can have profound impacts on human well-being, simply providing electricity, whether from the grid or from distributed sources, does not guarantee that people will start consuming those energy services. In general, newly electrified households tend to use electricity for lighting, communications, entertainment, and cooling. They do not, for the most part, use electricity for cooking or heating. In terms of the economic impacts of electricity access, the results are decidedly mixed. Many studies indicate that economic impacts are small and limited to a few individuals, with the deployment of electricity for motive power being extremely limited. At the same time, other studies point to large, generalizable positive effects on income through improved access to irrigation and the creation of cottage industries. Predictions that rural electrification would lead to large-scale improvements in well-being among poor populations in low-income countries, fueled by a huge diversity of small-scale industries, do not appear to have been borne out in the empirical literature to date. In terms of services while the evidence base is limited access to electricity does appear to have improved access to services.

While the benefits to income and well-being that result from access to electricity should not be overlooked, users' failure to use electricity for thermal services, and ambiguous findings on the economic impacts, present real challenges to efforts at addressing energy poverty. In developing countries, cooking and heating consume more household energy than any other activity—as much as 90 percent (Bhattacharyya, 2012; Malla & Timilsina, 2014)—and using solid fuels for these activities drives the most severe negative health outcomes (Africa Progress Panel, 2015). The limited use of electricity for productive purposes not only suggests a failed opportunity to stimulate development gains, but also strains the financing of energy projects. This is because exclusive domestic energy use causes peak loads to concentrate in the early evening, increasing the cost of the overall system (see Text Box 3) (World Bank, 2008). In addition, the failure to increase household incomes threatens the long-term sustainability of electricity access efforts because poor populations remain unable to afford the tariffs that are required to cover the full costs of generating the electricity (Terrapon-Pfaff et al., 2014) (see section on tariffs and subsidies below for details).

As a result, efforts to address energy poverty need to go well beyond simply providing access to electricity. They need to account for the persistent use of solid fuels for meeting people's thermal needs, and they need to integrate better with the factors driving economic development.

5. BEYOND ELECTRICITY: THINKING MORE BROADLY ABOUT ENERGY ACCESS

In addition to improving access to electricity, any serious effort to address energy poverty will need to pay greater attention to questions of energy for cooking and heating. To understand why efforts at electrification have failed to address household energy poverty, it is useful to begin by discussing the paradigm that informed the strong focus on electricity.

UNDERSTANDING FUEL CHOICES

The hope that access to electricity would address household energy poverty stems from a particular conception of how households make choices about fuels, known as the "energy ladder" (Agbemabiese et al., 2012; Hiemstra-Van der Horst & Hovorka, 2008; Masera et al., 2000). Under this conception, households are expected to purchase the most sophisticated fuel they can afford based on what is available to them. Households are expected to choose less-polluting, more efficient fuels, so that they substitute dung for wood, wood for charcoal, charcoal for kerosene, and kerosene for liquid petroleum gas (LPG) or electricity—with each fuel representing a higher, rung on the energy ladder. In this model, wood is the fuel of the poor, and people's fuel choices are determined by constraints related to access to fuels and low incomes (Hiemstra-Van der Horst & Hovorka, 2008). Thus the focus on electricity has been based on the assumption that households have a natural preference for electricity and will use it based on the savings to be had from using a more efficient, less locally polluting fuel. However, the energy ladder has been criticized for ignoring human agency in fuel choices and for doing a poor job at predicting them (Hiemstra-Van der Horst & Hovorka, 2008).

Subsequent empirical studies looking at fuel use have suggested that a more effective conceptualization of fuel choices is the idea of "fuel stacking" (Bacon et al., 2010; Hiemstra-Van der Horst & Hovorka, 2008; Masera et al., 2000). In this conception, rather than simply exchanging traditional fuels for modern ones, households make deliberate choices to use specific fuels to meet particular needs (Hiemstra-Van der Horst & Hovorka, 2008; Madubansi & Shackleton, 2006). Choices regarding which fuels to keep in the household and when to use them are based on assessments of both needs and opportunities, which are located in complex household energy economies. Relevant considerations include the availability and price of different fuels, cultural preferences for using certain cooking methods, and the opportunity cost of acquiring those fuels considering the resources available to the household (Bacon et al., 2010; Gebreegziabher et al., 2012; Khandker et al., 2010; Khandker et al., 2009b; Malla & Timilsina, 2014; Meikle & Bannister, 2003).

Fuel stacking accounts for the complex fuel choices that households have been observed to make. Within this framework, the persistent use of solid fuels for cooking and heating, even when electricity and LPG are available, is explained by the fact that collected fuelwood has no monetary cost and because household-labor is often abundant. Charcoal, which must be purchased, has the advantage of being available in small quantities that match households' limited access to cash (Bacon et al., 2010). In contrast, LPG must be bought in a large canister (a problem referred to as "lumpiness"[19] in the literature), and many households are unable to afford it at any one point in time (Cowan & Mohlakoana, 2005). Finally, in addition to concerns around reliability mentioned earlier, households continue to use solid fuels because of cultural preferences regarding how different fuels affect the flavor of food and because the individuals preparing food know how to use them. In this respect households have been observed making highly strategic choices about using different fuels for different foods—for example, making "modern foods" such as tea, coffee, and macaroni on an electric hotplate while using fuelwood to prepare traditional foods that require long simmering times (and that are also vulnerable blackouts if prepared on an unreliable grid) (Cowan & Mohlakoana, 2005; Hiemstra-Van der Horst & Hovorka, 2008).

Research on the complex energy economies apparent within households has also found that households will maintain fuels such as kerosene and candles in the home for illumination even when they have access to electricity (K. Lee et al., 2016). The reason for this is that the grid is liable to suffer blackouts, and SHS/mini-grid connections may not provide sufficient energy to cover illumination needs for the whole household.

Overall, work on fuel choices has observed that although introducing modern fuels into households drives changes in how households access energy services (such as reducing the kerosene used for lighting), it does not lead to the

[19] The issue of cash flow and fuel choice is addressed in the economic literature through the concept of "lumpiness." Lumpy items are those that cannot be bought in continuous or small quantities, but which instead must be purchased in some large discrete quantity. If a fuel is lumpy, it means that a household must have money on hand to afford it. For example, a large LPG cylinder is lumpy because a household has to have enough cash on hand to pay for a fuel supply that will serve them well into the future. Charcoal, however, can be purchased in small quantities sufficient for a day's worth of cooking. Given cash-flow constraints in energy-poor households, the lumpiness of a fuel is thought to be an important consideration for access. As such, it is suggested that modern fuels can be promoted if their supply chains allow for them to be bought in small quantities that match household cash-flow dynamics.

complete substitution of those fuels. Instead, when households gain access to modern fuels, they tend to further diversify the array of fuels they use, adding electricity and/or LPG to the mix (Madubansi & Shackleton, 2006; Masera et al., 2000).

Despite the abundant literature criticizing the concept of the energy ladder, the ladder metaphor is invoked in contemporary discussions about energy access. In contemporary conceptions however rungs of the energy ladder refer to the extent to which households use modern fuels to access an increasing number of energy services – essentially conflating the notion of a ladder rung, with tiers of energy access. The first rung of the ladder, for example, is the use of electricity for lighting, communications, and entertainment (see, e.g., Lee et al., 2016; Africa Progress Panel, 2015). This new usage still focuses on the idea that people will increasingly move toward using modern fuels to meet more of their energy service needs and that their failure to do so is driven primarily by constraints on their ability to choose their fuels. This conception still generally fails to account for the agency of households in choosing fuels (Hiemstra-Van der Horst & Hovorka, 2008). Problems of the energy ladder aside, it should be pointed out that the fuel-stacking model, despite its advantages, fails to effectively explain why and when households begin to abandon solid biomass fuels and use modern fuels to meet all of their energy service needs.

The limitations of these respective models of fuel choice aside, both models have focused heavily on the potential role of fuel price and income as constraints on fuel choice. As such these two factors have received particular attention in the literature.

THE IMPACT OF HOUSEHOLD INCOME AND FUEL PRICE ON FUEL CHOICES

Within household energy economies, the impact of household income and fuel price on fuel choices is particularly complex. On the one hand, income has been shown not to determine household fuel choices (see above). On the other hand, household income is repeatedly identified as one of the few factors that is reliably associated with the likelihood that households will use more modern fuels (Lewis & Pattanayak, 2012; Malla & Timilsina, 2014). Likewise, while fuel price has been shown not to determine fuel choices, increases in the price of a particular fuel have, in certain cases, been observed to cause households to revert to using less desirable fuels (Malla & Timilsina, 2014; Meikle & Bannister, 2003). In other cases, households respond to price increases by simply decreasing their energy consumption and using less of that fuel or by minimizing other household expenses to free up income to spend on the more expensive fuel (Meikle &

Bannister, 2003). Any fuel substitutions are likewise context specific and play out in terms of the complex array of factors shaping the household energy economy.

One outcome of the complex relationship between fuel price, household income and fuel choices is that research has noted how increased access to electricity can have highly varied outcomes across different income groups. For example, within groups that are all classified as monetarily poor, the wealthiest individuals have been observed to make increasing use of modern fuels for thermal needs (even though solid fuels remain the dominant source for thermal energy needs). Among the poorest individuals, however, access to electricity has been shown to drive no changes at all in the way people meet their thermal energy needs (Prasad & Visagie, 2006). Such outcomes mirror findings showing that electrification projects tend to primarily drive improvements in economic outcomes among the wealthy and that access to electricity tends to benefit the most well-off households while resulting in few to no economic impacts among the poor (Bhattacharyya, 2012; World Bank, 2008).

The fact that solid fuels continue to dominate household energy use, however, means that even with the provision of electricity, households are still exposed to the myriad challenges involved with using those fuels (Cowan & Mohlakoana, 2005). Pollutants generated while cooking remain, as do the other the dangers (e.g., burns) and the drudgery associated with collecting fuelwood and long cooking times. Although exposure to particulates from burning kerosene might be diminished as a result of the switch to electric lighting, the fact that households still keep kerosene means that the risk of poisoning persists (Cowan & Mohlakoana, 2005; K. Lee et al., 2014). Finally, given the persistence of candles and kerosene, dangers of fire remain (though they may be diminished by their decreased use) (Cowan & Mohlakoana, 2005). As such there is a clear need to consider a broader set of approaches to addressing energy poverty than simply focusing on access to electricity.

THE ROLE FOR IMPROVED COOKSTOVES

Given the problems associated with the persistent use of solid biomass for cooking, it is clear why promoting “clean” or “improved cookstoves” (hereafter “improved cookstoves”) is an important complementary approach to electrification. Although there is currently no formal definition of an improved cookstove, it generally refers to any stove that cooks more efficiently than the traditional three-stone stove (Practical Action, 2014).

The potential impacts of improved cookstoves range from a simple reduction in indoor air pollution as a result of improved combustion rates to the virtual elimination of pollutants in stoves that incorporate forced ventilation. Beyond reducing pollution, improved cookstoves also reduce cooking times and fuel requirements. Together the result is improved health outcomes, less time collecting fuel, savings from reduced purchase of fuel, and less environmental stress on stores of fuelwood (Lewis & Pattanayak, 2012).

While the designs of improved charcoal-burning cookstoves are well established, fuelwood cookstoves are still a challenge as they must be specifically designed to handle local fuels, which can vary by moisture content, size of the logs, and the density of wood (Modi et al., 2006).

Although efforts to promote improved cookstoves have been ongoing since the 1980s (Agbemabiese et al., 2012; Bhattacharyya, 2012), rates of adoption have been frustratingly slow (Bhattacharyya, 2012; Malla & Timilsina, 2014). As of 2009, for example, only 4 percent of the population of sub-Saharan Africa had access to improved cookstoves (WHO-UNDP, 2009). Part of the problem is that, with the heavy focus on electrification, clean cookstoves have received relatively little policy attention (Bhattacharyya & Palit, 2016). More recently, the issue of clean cookstoves has gained greater traction at an international level with the creation of the Alliance for Clean Cookstoves, which plans to foster the adoption of clean cookstoves and fuels in 100 million households by 2020 (Bhattacharyya, 2012; Global Alliance for Clean Cookstoves, n.d.).

Questions about the barriers to, and determinants of, clean cookstove adoption have spawned an extensive literature. Several factors have consistently been found to show a positive association with the use of improved cookstoves: degree of urbanization, household income, and education and awareness (Gebreegziabher et al., 2012; Lewis & Pattanayak, 2012; Malla & Timilsina, 2014). The relevance of education and awareness has been found to vary depending on who is educated—it is women and the household head whose education drive increased use of improved cookstoves (Lewis & Pattanayak, 2012; Malla & Timilsina, 2014).

Findings from the literature on the adoption of improved cookstoves tend to mirror the findings on the adoption of improved fuels, and lessons from the discussion on the energy ladder are relevant. The factors listed above should be seen as associated with improved cookstove adoption rather than determining it. Like fuel choices, improved cookstove adoption needs to be understood within the larger social context in which households make complex decisions regarding the suitability of different technologies (Lewis & Pattanayak, 2012). This context includes, for example, cultural preferences about cooking and the suitability of stove technologies in relation to cultural norms (Agbemabiese et al., 2012; Broto et al., 2015; Malla & Timilsina, 2014). Finally, evidence on the importance of female education in fuel choices suggests that previous explanations regarding the persistence of solid biomass for cooking based on its low monetary cost might actually be determined by the opportunity cost of women’s time, with that cost increasing when women are educated (Madubansi & Shackleton, 2006).

LIQUID PETROLEUM GAS (LPG)

Beyond policies promoting improved cookstoves, the other dominant solution to persistent energy poverty has been promoting the use of LPG. While such policies have had some success, for example in India, challenges remain around efforts to make LPG a common household fuel among the poor. Such challenges include weak supply chains (Bacon et al., 2010; Clancy, 2006), especially in rural areas, and the "lumpiness" of the fuel[20] (which can be exacerbated by supply chain problems if households have to purchase backup canisters) (Bacon et al., 2010). In addition, qualitative studies have revealed that people have concerns about the safety of LPG, fearing that the canisters are liable to explode (Madubansi & Shackleton, 2006). As with electricity, adoption of LPG is hindered by the fact that people must purchase appliances in order to cook with it or use it for heating (Bhattacharyya, 2012). As a result, LPG use faces many of the same barriers as the use of improved cookstoves. Finally, some authors have identified cultural barriers to the use of LPG, reporting that people complain that food tastes different when prepared using LPG (Clancy, 2008).

Text Box 5: Biodigesters

Along with distributed renewable electricity generation technologies, local biogas digesters are frequently identified as a means of addressing energy poverty by complementing distributed electricity generation with energy for cooking and thermal services. Yet, while biodigesters have made a significant impact in some contexts, they have proven a difficult technology to get right, and caution should be exercised when advocating for biogas digesters as a short-term solution to energy poverty.

Biodigesters generate combustible gas from organic waste (from humans, animals, and crop residues) through the decomposition of organic matter in an anaerobic environment. In addition to gas, the slurry from biodigesters can be used as fertilizer, which restores nutrients to the soil more effectively than regular composting[21] (Smith et al., 2014). The gas from a biodigester can be used for household cooking, requiring only a slightly modified butane-burning stove (Bond & Templeton, 2011). Biogas can also be used to generate electricity through a modified diesel generator, but this requires first scrubbing the sulfur out of the gas, a task that is not amenable to remote locations. It is also possible to use the gas to drive a fuel cell, but the gas again needs to be very clean, and overall this is considered to be a development technology (Bond & Templeton, 2011). The principal benefits of biodigesters for rural energy access, then, are gas for cooking and slurry for fertilizer.

Biodigesters are a simple technology that has been in use as far back as the 10th century BCE as well as in ancient China (Bond & Templeton, 2011). In its simplest form,

[20] See footnote 18.

[21] The WHO warns that slurry produced using human waste is not suitable for use as agricultural fertilizer without pasteurization (Bond & Templeton, 2011).

the digester is merely a sealed chamber—usually a bladder placed in a hole in the ground—into which is placed a mix of organic waste and water. Where biodigesters have been successfully established, they have been shown to provide significant benefits to households by decreasing household expenditures on fuelwood, saving time on the collection of fuel, and decreasing cooking time (M. T. Smith et al., 2014). Biogas is also considered a clean and carbon-neutral fuel, so long as the organic matter is collected sustainably (Bond & Templeton, 2011).

Biodigesters require significant amounts of animal waste and water for their operation. Requirements vary depending on the type of animal waste, which, in turn determines the water requirements. On average, it is estimated that generating enough gas to cook two meals a day for a family of five requires access to the equivalent of 20–30 kg of cattle dung (or four to five head of cattle) along with an equivalent amount of water (Bond & Templeton, 2011; Smith et al., 2014). Biodigesters are only effective in temperatures between 15^{o}C and 40^{o}C. Below these temperatures, there is scope for heating and stirring the slurry using solar energy, but such additions increase the plant's complexity. The labor costs of collecting the waste to feed the digester have proven hard to overcome (Smith et al., 2014); as such, for biodigesters to run effectively, animals generally need to be stabled on concrete floors (Bond & Templeton, 2011). Such requirements mean that biodigesters are generally not suitable for urban households, other than in large-scale facilities (such as next to abattoirs) (Smith et al., 2014).

China has had significant success using biodigesters to improve energy access, with an estimated 26–27 million plants in the country (Bhattacharyya, 2012; Bond & Templeton, 2011). India has also had some success, with about 4 million plants. Biogas, however, is not necessarily a quick solution to energy poverty in sub-Saharan Africa. It took China about 40 years to build its extensive infrastructure, with a great deal of support from the state for research, financing, training for technicians, creation of supply chains, and promotion of the technology. In addition, China had certain advantages, such as its large manufacturing base, that were important in its success (Bhattacharyya, 2012). Overall, it is estimated that China provided a subsidy of $200–$400 per household for biogas plants (Bhattacharyya, 2012), with historic subsidies covering between 30 and 100 percent of plant costs in the 1980s and 1990s (Bond & Templeton, 2011).

Laborious maintenance procedures have been the principal challenge to the successful deployment and use of biodigesters (Bond & Templeton, 2011; Modi et al., 2006). As a result of poor maintenance, only about 50 percent of biodigesters around the world are thought to be operational (Bond & Templeton, 2011). Such challenges even affect China, where only about 60 percent of biogas digesters were estimated to be operating normally in 2006. The number of plants currently operating in any single African country is in the hundreds (Bond & Templeton, 2011).

Given high cattle counts in Africa, biodigesters could potentially have important effects on energy poverty, but to address thermal energy needs completely, biodigesters will need to incorporate crop residues more effectively. Currently, the gas produced using crops residues is too high in carbon dioxide (Bond & Templeton, 2011). In addition, stabling of cattle is uncommon in Africa and access to water is limited in certain areas (Smith, 2011). Adoption of biogas also faces challenges in terms of social norms surrounding the preparation of food using gas generated from human and animal waste. Like LPG, biogas requires the use of a modern stove appliance and as such faces the same barriers as efforts to promote improved cookstoves.

Finally, although biodigesters are a relatively cheap and simple technology, the capital costs are still thought to be high compared with the incomes of rural, energy-poor households in sub-Saharan Africa (Bond & Templeton, 2011). Studies suggest that making the technology financially feasible to low-income rural households in South Africa, for example, would require a subsidy of nearly $2,000 per household (at 2014 prices) and credit structures in which the repayment rate is on the order of 15 years. Despite such high costs, even with subsidies, the welfare benefits of switching to biogas were thought to be significant (Smith, 2011).

Although biogas presents significant opportunities for improving livelihoods, attempts to implement biogas projects in developing countries have had limited success (Terrapon-Pfaff et al., 2014). Overall, “biogas recovery technology has been a failure in many developing countries with low rates of technology transfer and longevity and a reputation for being difficult to operate and maintain” (Bond & Templeton, 2011, p. 347).

6. DEBATES AND ISSUES CONCERNING ENERGY ACCESS

Despite the complexity of the processes shaping household energy choices, as well as the technical challenges involved in providing households with electricity, there has been something of a simplification of the public conversation about energy policy and the need to balance Africa's imperative to develop with the need to address climate change. Some debates have been simplified while other crucial dynamics of effective energy policy have been overlooked. The rest of this report explores the following questions and issue areas: (1) the merits of grid versus decentralized approaches to providing energy access; (2) the challenge of connection fees and last-mile connections; (3) the use of modern versus traditional fuels in addressing energy poverty; (4) how best to address the challenge of setting tariffs and providing energy subsidies, (5) the possibilities for improving the economic benefits of electrification, and (6) challenges in financing increased energy access.

GRID EXPANSION VERSUS DISTRIBUTED TECHNOLOGIES

Recent debate has emerged over whether energy poverty is best addressed by expanding the grid or by providing distributed energy technologies. Within this debate, proponents on both sides have been guilty of playing up the advantages of a particular approach while often overlooking its challenges and limitations. They have contrasted generous appraisals of one technology with equivalently unsympathetic accounts of competing technologies. Proponents of distributed technologies, for example, argue that the grid is expensive and slow to roll out, and that it is run by an unresponsive bureaucracy. Further they note that the grid has failed to provide energy to the poor in sub-Saharan Africa and that it is based on technology that drives climate change. In contrast, they characterize distributed technologies as cheap to deliver, capable of quickly providing electricity access to the poor, amenable to delivery by the private sector (thereby avoiding the problems of the state bureaucracy), and well suited to using renewable energy.

Proponents of expanding the grid point to relatively successful cases of improved energy access through grid expansion, such as in Tunisia, South Africa, and

Vietnam (Khandker et al., 2009b; Modi et al., 2006) (see Text Box 6). They note the higher cost of electricity from mini-grids and the low capacities of SHSs, suggesting that such systems do not provide households with “real electricity” (Wolfram, 2016).

Text Box 6: Expanding access to electricity in South Africa

South Africa is the only mainland sub-Saharan African country to have achieved significant success at increasing access to electricity. Its experience, however, reveals the importance of local contextual factors, as well as the complicated ways in which local political and economic incentives play out in driving and frustrating effective management of the power sector.

The scale of South Africa’s success at expanding access to electricity is notable. In 1993, a year before the end of apartheid, more than two-thirds of South African households lacked access to electricity. By 2001, more than 2 million households (or one-quarter of all households in the country) had been connected, principally through expansion of the grid (Dinkelman, 2011), but also through the provision of solar home systems (Azimoh et al., 2015). This progress took South Africa’s electrification rate from 34 to 70 percent (Prasad & Visagie, 2006). All of these new connections were fully subsidized, and in 2003 electricity access was further supported through the implementation of a free basic electricity allowance (Dinkelman, 2011).

Understanding why such dramatic change was possible requires looking at the political and economic conditions dominant in the country at the time. First, in 1993, unlike other African countries, South Africa had significant excess generation capacity, for several reasons. It had access to abundant cheap coal. It had expertise in electricity generation, driven in part by the large extractive industry activity in the country. Its energy sector achieved high efficiencies by taking advantage of economies of scale and technical innovations. And it had overinvested in generation capacity in the 1970s, based on overly optimistic economic growth forecasts made at the time (Cowan & Mohlakoana, 2005). In addition, Eskom, the sole electricity provider in the country at the end of apartheid, wanted to signal to the new government that it could provide electricity to previously disadvantaged communities without the need to introduce private competition (Dinkelman, 2011). The result of this combination of factors was an ambitious plan to expand access to electricity that was supported by both the state and the utility, which had the generation capacity to support such expansion.

As households have been connected (as of 2012, electrification rates stood at 85 percent (World Bank, 2012)) and the country’s economy has grown, however, the situation of excess generation capacity has changed. As early as 1998 the government reported that increasing demand would lead to electricity shortages. These warnings were ignored on grounds that the utility might be privatized. Plans to increase generation capacity were implemented in 2004, but by 2008 the country was implementing load shedding, after generating reserves reached their lowest-ever levels (Phaahla, 2015a). New production was focused on the construction of 4800MW, to be supplied via a coal-fired power plant at Medupi. Although this project was meant to be completed in four years at a cost of R69 billion ($9.5 billion), seven years later only one of the plant's proposed six reactors is online, providing 794MW of power. The project is now scheduled for completion in 2019, with an updated cost estimate of R159 billion ($12.2 billion) (Phaahla, 2015b). The project has also been mired in claims of corruption. The ruling party, the African National Congress (ANC), owns a 25 percent stake in the company that was awarded the construction contract, an outcome that would net the ANC about R1 billion (Mail and Guardian, 2010).

The power utility, Eskom, currently finds itself in financial difficulty, with sovereign credit-rating agencies having downgraded it to junk status. A proposed 25 percent tariff increase, aimed at remedying the situation, was rejected by the national energy regulator, partly on the grounds that Eskom's books are not transparently available for public scrutiny (Phaahla, 2015a).

The South African story highlights a number of general lessons regarding the technical and political-economic dimensions of energy access. First, the particular factors driving access are unique to the country, and thus calling on countries to simply replicate successes seen elsewhere may be of limited use. Second, the factors driving huge increases in electricity access have little to do with generic features of good governance, such as transparency or accountability. Third, if a country seeks to increase access through grid expansion, it needs to focus heavily on expanding generation capacity and maintaining the grid. Failure to do so will only result in a less reliable grid for all users. Fourth, problems of governance and state capture of utilities remains a threat, and in this respect generic good governance efforts can play a role. Finally, challenges related to the financial viability of utilities and the issue of tariffs are problems even in countries with mature power systems and established supply chains, and even when cheap energy resources are abundant.

Considering all of the evidence, however, it is clear that neither technology is likely to act as a panacea to the challenge of increasing electricity access given the context in sub-Saharan Africa today (not to mention that electricity access is not a panacea to energy poverty). The grid has failed too many people in Africa for too long, providing energy to better-off urban groups while leaving behind poor people in remote rural areas. At the same time, distributed energy technologies face many challenges, including institutional ones that will require support from the state, which will need to take a proactive role in legislation and subsidization (see below). Without these, efforts focused on distributed technology have similarly ended up benefiting relatively well-off individuals and failed to bring access to the poorest members of society (TERI-GNESD, 2014; World Bank, 2008). In addition, the services offered by distributed generation sources are more expensive and often limited in quantity, limiting their capacity to provide people with all of the energy services they need. As such, effectively addressing energy access will require both connecting remote and isolated households through distributed technologies and expanding the grid and increasing access to it.

It is thought that grid extension will be the best means for increasing access in urban areas, while the goal of increasing access to electricity among rural populations will, in most cases, be best met through a focus on distributed technologies. Such an approach will be faster to deploy and cheaper than waiting for grid expansion. Areas with sufficient population density can be connected through mini-grids, and the remainder can be connected using SHSs and solar appliances (Alstone et al., 2015; World Bank & IEA, 2015).

Despite the advantages of distributed technologies in connecting households, the eventual goal should be to connect everyone to the grid, which will provide households with the best-quality electricity at the lowest price (Alstone et al., 2015; Lee et al., 2016). A large grid will also allow for diversity in the energy system and be crucial to supporting the high levels of renewable energy penetration needed to address climate change (see Part 1 of this series). As such, energy policy should focus simultaneously on leveraging investment in distributed energy technologies and on improving the function and scale of the grid, as well as access to it.

Although the specifics of rolling out on-grid and distributed technologies will vary by country, based on factors such as the existing extent of the grid, institutional capacity, economic capacity, geography, demography, topography, and the availability of different resources (Schillebeeck et al., 2012), some common features of energy policy will be necessary. Among other things, policies must (1) increase grid-connected generation capacity, (2) increase grid efficiency, (3) improve demand-side management, (4) ensure the affordability of electricity, (5) ensure the quality of electricity infrastructure, (6) reduce perverse tax incentives on distributed generation components (see below on subsidies), (7) support the creation of effective supply chains (including installation and maintenance), (8) undertake resource assessments, and (9) address uncertainty in the rollout of the grid. The last of these should include making the plans for grid rollout explicit, ensuring that distributed infrastructure will be able to integrate with the grid when it arrives, and putting mechanisms in place to reduce the financial risks to private sector actors regarding the arrival of the grid. All of these actions will be crucial to driving private-sector investment in distributed energy systems. Finally, because the process of rolling out the grid is likely to take many years, policies supporting distributed generation need to include realistic estimates of likely cost reductions in batteries and solar panels.

LAST-MILE CONNECTIONS

If issues of urban energy access are going to be solved via the grid, and if distributed energy is only a stop-gap solution to efforts at electrification, then any comprehensive energy access policy needs to consider how to deal with the costs of actually connecting households to the grid—also known as “last-mile” connections.

Issues of cost

The principal challenge when it comes to last-mile connections is their high cost, which is consistently identified as a major impediment to improving electricity access via grid expansion (K. Lee et al., 2014; Modi et al., 2006; Scott et al., 2003) (see Text Box 7). Specifically, last-mile connections refer to the distribution network for electricity (see Text Box 3). The costs of the distribution network stem from the cost of wire and poles needed to carry the electricity, as well the labor costs of installing this infrastructure. In general, the distribution network comprises a medium-voltage line that carries the current from the transformer linked to the transmission network. Households then connect to this medium-voltage line via secondary distribution lines on which the voltage has been stepped down again in order to deliver electricity to the household. On top of the costs of these additions to the network, there can be costs to the household, which must be wired and metered (see section on tariffs below) before it can receive electricity. The cost of last-mile connections therefore generally depends on how far the household is from the substation, which determines how much wire, how many poles, and how much labor will be required. Last-mile connections are a challenge because they pertain to every household that is to be connected; given the number of households, the cost of connecting all households can get very large very quickly (K. Lee et al., 2014).

The high cost of connecting households to the grid is often cited as grounds for promoting distributed energy technologies ahead of grid expansion. This argument is somewhat misleading. Mini-grid technologies also have costs associated with connecting households; distribution lines must still run from the generating plant to the households. As with the grid, the cost of these connections depends on the distance between the households and the plant. And if the goal is to ensure that the mini-grid infrastructure can later be incorporated into the grid, the infrastructure linking households to the power plant must match that needed to connect households to the grid.

Despite the fact that connection costs are an issue for mini-grids, the cost of distribution infrastructure is often left out of mini-grid discussions, so much so that even the HOMER model (which is the most prominent model for calculating mini-grid sizing requirements) does not include inputs related to distribution costs (Bhattacharyya, 2015). The difference between connection costs for mini-grids and those for the main grid is that grid connection fees are usually standardized, whereas in the case of mini-grids efforts are made to reduce the capital costs of the system through the sorts of bespoke approaches that were described in the section on mini-grids.

Despite the high costs of last-mile connections, however, studies consistently find that the welfare and economic benefits of connecting to the grid far outweigh the costs[22] (Khandker et al., 2009a, 2009b). When large numbers of households live within reach of the grid but are not connected to it—a condition termed living "under the grid"[23] (K. Lee et al., 2014)—the result is not only forgone welfare, but also forgone revenues to the utility, which is unable to charge users and thus unable to recoup on the investments made in expanding the grid. In Kenya it is estimated that as many as 95 percent of households and 78 percent of businesses that are close enough to be connected to the grid remain unconnected (K. Lee et al., 2014). In Nigeria estimates suggest that 31 million people could be living under the grid, accounting for 40 percent of all Nigerians without electricity (Leo et al., n.d.).

To help reduce connection costs, innovations have included privatizing the distribution network or using cheaper materials for the poles. In both cases, however, it should be remembered that maintaining the infrastructure and ensuring the fairness of tariffs are important for long-term sustainability. Another option is to bundle many households so that connection costs are shared between them. This approach has shown to reduce connection costs dramatically (see Text Box 7) (K. Lee et al., 2014; Prasad & Visagie, 2006).

Text box 7: Connection fees and bundling of households

While the actual cost of connecting to the grid varies by country (owing to variations in the costs of materials and labor), it is often prohibitively high. In Kenya, for example, it currently costs about $2,000 to connect a single household to the grid, assuming that the household is located less than 200 meters from the substation (K. Lee et al., 2014). In Botswana in 2002, full cost recovery on connection costs meant that it cost about $1,000 to connect a household to the grid[24] (Prasad & Visagie, 2006). Given that average annual household income in Africa was $762 in 2008 (Lakner & Milanovic, 2013), it is clear why many households remain unconnected even if they are located close to the grid.

One potentially useful option to get around the problem of high connection costs (assuming population densities are high enough) is to bundle households together when connecting them (Modi et al., 2006). Bundling households takes advantage of

[22] Benefits exceed costs by as much as 150 percent in Bangladesh (Khandker et al., 2009a) and are four times greater in Vietnam.

[23] This term was created by K. Lee et al. (2014) to describe households that do not fit into the binary categories of "on the grid" (i.e., connected to the grid) and "off the grid" (too far away to connect to the grid).

[24] In 2002 the exact cost for an individual connection was 10,000 Botswana pula.

the fact that once one house is connected, it becomes cheaper to connect any neighboring house because the necessary low-voltage power line is already in place.[25] Bundling households involves extending low-voltage lines to their maximum distance from the substation and then connecting all of the households that lie within a short distance of that low-voltage line. Instead of connecting only one household at the end of the low-voltage power line, this approach connects multiple households to a single line. This allows the cost of connection (in terms of low-voltage power lines, poles, and labor) to be split among all the connected households, significantly reducing the cost.

This approach has been used successfully in Botswana, where the connection policy was amended after it was found that individual households were unable to afford the full connection cost. In that scheme four or more households had to come together to apply for a connection. Doing so brought the cost of connecting an individual household in 2002 down from about $1,000 to about $200[26] (Prasad & Visagie, 2006). Likewise, theoretical work in Kenya has shown that bundling households that are currently under the grid could bring prices down from $2,000 per connection to $80 per connection.[27] At this price it has been estimated that households would only have to generate $10 a year in terms of improved welfare from their access to electricity in order to make the connection welfare-improving. Furthermore, the same analysis found that households only need to be bundled into groups of six in order to get connection fees to around $200 per household[28] (K. Lee et al., 2014). The low connection costs for mini-grids take advantage of this this bundling approach.

Obviously the process of bundling households creates coordination as well as bureaucratic challenges: households first have to know and understand that a system for bundling them exists, then they must agree to act together and inform the utility of their willingness to connect. Given that challenges around processing paperwork have been shown to be an impediment to connecting individual households that are currently under the grid (Broto et al., 2015), these challenges should not be overlooked, and energy policies must include allowances to deal with them. Notably, however, such challenges are thought likely to be inherent in operationalizing the sort of bespoke energy systems that will be required to make mini-grids cost competitive.

[25] This is, in fact, a classic quality of the grid's economies of scale and its character as an almost perfect monopoly: capital costs of extending the grid are high, but once those capital costs have been paid, the marginal cost of adding one more household to the grid is relatively small.

[26] Under the bundling scheme households paid a Pula 100 down payment of 5%, before paying the other 95% back over a period of 18, 60 or 180 months (Prasad & Visagie, 2006).

[27] This result assumes that the distribution line would be extended 200 meters from the substation and then connected to every household within 30 meters of that line.

[28] Notably, this is the same price as the popular solar kits sold by M-Kopa.

Beyond cost: Tenure and connections

Although discussions and policies about last-mile connections often focus on cost, it is important to recognize that some households remain under the grid because of institutional challenges related to land tenure and the informal nature of settlements in urban areas. Informal dwellings often lack an address, which makes it impossible to receive bills or have a meter installed. Likewise, informal dwellings that are located on land owned by someone other than the dweller, close to other infrastructure (such as roads or railways), or in flood plains can create problems for all manner of service delivery, as the state is usually unwilling, or legally unable, to provide infrastructure or services under such conditions (Cowan & Mohlakoana, 2005; Modi et al., 2006). Since it is often the poorest individuals who occupy such marginal land, efforts to address energy access among poor populations need to include allowances for such challenges. It is possible that distributed energy technologies, which have few permanent infrastructural features (such as solar appliances or SHSs), might play an important role in improving energy access for people living on legally unserviceable land, but no such cases were identified in this research.

Finally, in addition to the above measures, given the low incomes of many unconnected rural households, energy policy will need to include some mechanism for financing the costs, as households are unlikely to have access to capital on the scale required. The most common means for doing this is to include some portion of the connection fee in the electricity tariff, which allows households to pay the connection fee over an extended period. On top of this, in some cases, subsidies will still be required to connect very poor households (Modi et al., 2006; Prasad & Visagie, 2006).

TARIFFS AND SUBSIDIES

Issues of tariffs and subsidies may be the most crucial element of any electricity access effort. If tariffs are too low to allow for cost recovery, then electricity infrastructure will not be sustainable in the long term because there will not be enough resources available for maintenance, replacement of components, and ongoing investment (Africa Progress Panel, 2015; ARE, n.d.; Prasad & Visagie, 2006). At the same time, if tariffs are based only on cost recovery and financial sustainability, the poorest populations are likely to continue to be excluded from, or remain without, the benefits of access to significant quantities of electricity. It is thus widely appreciated that some form of targeted subsidies will be necessary to enable energy access among certain groups (ARE, n.d.; Bhattacharyya & Palit, 2016; World Bank, 2008) (see Text Box 4).

Electricity tariffs

African grid tariffs are much higher than the tariffs paid by consumers in other parts of the developing world—as much as three times higher on average (World Bank, 2013)—but they are not considered sufficient to cover the costs of energy generation. The reason for this seeming paradox is that historically weak tariff collection and an unwillingness to charge the full recovery cost of electricity infrastructure have resulted in financial problems for many African utilities. These financial problems have, in turn, prevented utilities from investing suitably in generation capacity and maintaining the grid. The result is a grid that is inefficient (experiencing high losses) as well as a lack of finance for new generation capacity. Together these problems have left many African countries reliant on leased, emergency generation capacity, which uses expensive fuels such as oil (Africa Progress Panel, 2015; Eberhard et al., 2008). Consequently, although Africans now pay some of the highest tariffs in the world, they are still not sufficient to cover the costs of expensive generation (Africa Progress Panel, 2015; Eberhard et al., 2008). Africans will need to pay higher tariffs in the short run in order to bring tariffs down in the long run. Raising tariffs, however, is politically difficult in Africa (Eberhard et al., 2008), where many countries have displayed strong political opposition to efforts at raising prices in order to make utilities financially sound (World Bank, 2005). In 2008, a survey of 20 African countries identified only 10 that were collecting tariffs sufficient to cover historical operating costs and only 6 that were able to cover all historical costs, including the cost of capital (Eberhard et al., 2008).

Dynamics of this sort show how important it is to get tariffs right, ensure bill collection, and limit theft. In the long run, if the utility is not financially sustainable the cost of electricity will go up. Given the gross mismanagement of African utilities that has led to this dire situation, some advocates of distributed electricity solutions argue that the answer to Africa's energy access challenge does not lie with grid expansion. Furthermore, such high utility tariffs in Africa improve the competitiveness of distributed technologies, which have struggled to be competitive with the utilities in Asia.

Tariff structures can take many forms, each suited to a different context. Possibly the simplest is a flat tariff, whereby all consumers pay the same amount regardless of how much electricity they use. Such a simple structure makes bill collection straightforward. It can also help increase the energy consumption of poor households, which pay the same amount regardless of how much electricity they use. However, flat tariffs will almost certainly be unsustainable as households start to use more energy than they are effectively paying for, resulting in problems for the electricity generator. In addition, a flat tariff can exclude poor households that do not have the income to pay for the regular fee (Prasad & Visagie, 2006).

Excessive consumption of electricity in mini-grids, based on a simple flat tariff system, can be prevented by installing load limiters, which limit how much electricity any one user can consume. Such an approach ensures that the generation capacity of the system is not overloaded (which is important for long-term sustainability in terms of battery use; see Text Box 3), though load limiters increase up-front system costs (Deshmukh et al., 2013; TERI-GNESD, 2014).

An alternative to a flat tariff is a consumption-based tariff, whereby consumers pay based on the amount of electricity they use. This system is much more sustainable because users cover the full cost of their consumption. It also creates an incentive for demand-side management. The downside is that the system requires the installation, maintenance, and checking of meters as part of bill collection—all of which increase the costs and management complexity of the overall system (Deshmukh et al., 2013). In cases where the amount of electricity being consumed is very small, the cost of metering can be hard to justify. The use of meters can also result in unforeseen problems: households have been known to tamper with them in order to steal electricity. One way to address this is to place meters on the outside of people’s homes so that tampering can easily be identified. A final advantage of meters is that they allow for energy to be priced differentially (for example, making it more expansive at peak times). This approach can help redistribute the load on the system, increasing the system’s overall financial viability (see Text Box 3); it is not possible with a flat tariff (Bhattacharyya, 2015).

Progressive tariffs are a final option, whereby the price a household pays for electricity is based on a sliding scale. Users who consume the most electricity pay the highest tariff, whereas smaller consumers pay a lower tariff. This system allows larger (usually wealthier) consumers to subsidize the access of smaller (usually poorer) consumers. It also gives households incentives to manage their demand. Again, such a system requires metering and suffers the associated challenges. While progressive tariffs might seem to be the obvious choice, their suitability can depend on how energy is consumed. In many parts of sub-Saharan Africa it is common for households with a grid connection to provide connections to neighbors who live in informal structures and charge them for the electricity they use. Under this system, because the connected household is consuming a large amount of electricity, it will be subject to a higher tariff, which is then passed on to the informally connected (and usually poor) households, defeating the purpose of the progressive pricing system (Meikle & Bannister, 2003). Progressive subsidies may also overburden wealthy households, causing them to use less energy or replace electricity with LPG (Cook, 2011). In such cases the viability of the overall tariff system can be compromised as the utility loses revenue and the possibility for cross-subsidization is undermined

Finally, for access purposes, it may be necessary to ensure that bill collection schedules coincide with income cycles in the areas of newly connected households. For example, subsistence households do not earn monthly incomes, but rather receive income at the end of the harvest season. Though matching bill collection to periods when households have money can be important for improving access and sustainability, it tends to increase the administrative cost of bill collection (Bhattacharyya & Palit, 2016; Scott et al., 2003). An effective means for getting around such problems has been the installation of pre-paid meters. While there is some cost to install these meters, as well as institutional requirements to ensure they are maintained, pre-paid meters reduce collection costs, and most reports indicate that households are happy to be able to avoid surprise electricity bills (Bhattacharyya & Palit, 2016; Broto et al., 2015; Mushi, 2014). Possibilities for pre-paid meters are also thought to be growing with the advent of mobile money[29] and cell phone technologies, which allow users to purchase electricity on a pre-paid basis using a cell phone. As with regular meters, though, tampering with pre-paid meters has been observed in Tanzania, resulting in theft of electricity and financial challenges for the utility (Mushi, 2014). Innovative models for ensuring bill collection—such as having bills be the responsibility of groups of people in order to create peer pressure for payment—have also been shown to increase collection rates (Bhattacharyya & Palit, 2016).

While tariffs are important for cost recovery, and despite the challenging situation in Africa, researchers have pointed out that simply raising tariffs so that they cover costs would place too great a burden on households (Africa Progress Panel, 2015). For example, where African grid tariffs are as high as $0.25/kWh, for a household consuming as little as 50kWh/month, monthly expenditure on electricity will quickly exceed 5 percent of their income (assuming household income of $260/month) (Eberhard et al., 2008) (see Text Box 4).

In this regard, a singular focus on cost recovery as the basis for setting tariffs (itself a by-product of the privatization of utilities) is thought to have resulted in skewing energy access heavily toward urban areas and nonpoor groups who have the ability to pay (Mostert, 2008; Scott et al., 2003). In Botswana, for example, such an approach is thought to have prevented 40 percent of rural households from accessing the grid (Prasad & Visagie, 2006). Since consumers usually pay for their connection to the grid through an additional cost on the tariff, it is clear that simply pushing for full cost recovery on tariffs will not be a viable solution to improving energy access, especially among the poor. Energy access efforts must include targeted subsidies to support both connection fees and electricity tariffs, for both on-grid and distributed technologies (Africa Progress Panel, 2015; Deshmukh et al., 2013; Eberhard et al., 2008).

[29] Mobile money creates opportunities for novel financing of distributed energy infrastructure as well as possibilities for improving bill collection, but the exact degree to which access to mobile money can be advanced across the continent is debated; see for example (McLeod, 2016).

Electricity Subsidies

Electricity subsidies can take a number of different forms. Geographic targeting, whereby people in a certain area all receive a specific subsidy, is straightforward to administer, but it allows leakage to the nonpoor as income does not always correlate neatly with geography. Means testing (or tariff setting based on household wealth) is more effective for targeting, but it is expensive and time-consuming to administer because it requires finding a way to continuously assess household wealth. As with the progressive tariff system mentioned earlier, subsidies can also be provided based on consumption (Prasad & Visagie, 2006), and again prepaid meters have an advantage in that subsidies can simply include a basic amount of free electricity each month (Bhattacharyya, 2012). Consumption-based, or metered, subsidies are thought to be an effective and cost-effective means of targeting subsidies (once the cost of the meter and its maintenance are factored in), but they are not useful for energy forms other than electricity (see below).

It is important to note that unless the issue of last-mile connections is addressed, any subsidy on electricity consumption will end up benefiting the relatively wealthy who have been able to get a connection (Eberhard et al., 2008; World Bank, 2005). In this way, electricity subsidies can be regressive in the same way that fossil-fuel subsidies have traditionally been (see below). The same can be said when subsidies are provided only to grid-connected consumers, while tariffs for mini-grids are negotiated in an unregulated environment with the provider. Such cases present a bias toward the grid which, given the barriers to connecting, likely results in a regressive subsidy.

Whatever system of subsidy is considered, the cost of targeting should stay low—certainly lower than the benefit any household might receive from the subsidy (Prasad & Visagie, 2006). Beyond subsidies delivered directly to the consumer, electricity subsidies can also include loans for energy infrastructure at below-market rates or without conditions or security, tax breaks on components, state investments in capacity building, removal of import tariffs on electricity components, and support for capital costs (ARE, n.d.; Bhattacharyya, 2015; Deshmukh et al., 2013; Prasad & Visagie, 2006).

The desire for the private sector to play a significant role in the delivery of mini-grids, as well as the high cost of energy delivered by these systems, means that subsidies of some variety are thought to be essential for determining their scalability, equitability, and long-term viability (Deshmukh et al., 2013; Mostert, 2008; TERI-GNESD, 2014). There may be some low-hanging fruit in this respect around tariffs and duties. For example, duties cause PV systems to be three times more expensive in Ghana than they are in Bangladesh and make small hydropower twice as expensive in African countries as it is in Sri Lanka (ARE, n.d.). Addressing such issues is a simple way to bring down the costs of capital on these systems and increase their attractiveness to the private sector.

Despite such potential reforms, however, and regardless of the declining costs of technology, subsidies for mini-grids may need to be substantial (Bhattacharyya & Palit, 2016). In Bangladesh, for example, even when all the capital costs of (PV-diesel hybrid) mini-grids were covered, costs could still not compete with grid prices (Bhattacharyya, 2015) (see Text Box 4). Thus, for a system to be sustainable, subsidies might be needed to cover not only capital costs, but also operation and maintenance costs, as well as the costs of replacing components in renewable energy systems (Bhattacharyya, 2015; TERI-GNESD, 2014).

Fossil-fuel subsidies

In light of the relatively limited role electricity will play in meeting thermal needs, there is also a need to discuss fossil-fuel subsidies. Advocates concerned with climate change and energy access frequently criticize fossil-fuel subsidies (Africa Progress Panel, 2015), but from an energy poverty perspective, fossil-fuel subsidies are simply another form of energy subsidy. To this end, some authors argue that fossil-fuel subsidies have played an important role in advancing the adoption of modern fuels (kerosene and LPG) in low-income households (Eberhard et al., 2008).

Despite such gains, the major challenge with fossil-fuel subsidies is that they are frequently consumed by people who are not poor, and only small proportions of subsidies end up supporting poor people. The IEA estimates that of the $409 billion in fossil-fuel subsidies that are paid globally, only $35 billion (or 8 percent) reached the poorest income groups[30] (IEA, 2010). Since nonpoor groups use more energy than poor groups, blanket subsidies on fossil fuels end up benefiting the wealthy far more than they do the poor—essentially making them highly regressive (Bacon et al., 2010; Meikle & Bannister, 2003).

Compared with electricity, efforts to target fossil-fuel subsidies have met with limited success. Fossil fuels can be transported, which allows for theft and black market sales, and with some tinkering on the internal combustion engine, many fossil fuels are relatively substitutable. For example, subsidized kerosene—a fuel used predominantly by the poor and therefore not susceptible to consumption by wealthy households—has been used to adulterate diesel, which is then used in far greater quantities by wealthy groups (Bacon et al., 2010). In India, even when means-testing was used—Indian households had to carry cards qualifying them to receive subsidized kerosene—the relatively high price of diesel soon saw a black market develop around kerosene, so that it again entered the automotive

[30] These groups are defined as the poorest 20 percent of a country's population.

sector[31] (Bhattacharyya, 2012). Likewise, poor targeting of LPG in India has resulted in policies benefiting the wealthy, as poor groups could not afford the appliances necessary to capitalize on the LPG subsidies. In addition people modified their cars to run on LPG (Bhattacharyya, 2012). Problems of leakage can be partially addressed by ensuring that subsidies are supported with policies that allow households to purchase appliances and by dying kerosene blue to prevent adulteration with diesel (Bhattacharyya, 2012).

Fossil-fuel subsidies can also place a significant strain on the national budget, especially if fuel prices fluctuate and the fuel is imported. Further complicating such dynamics is the fact that once fuel subsidies are in place, political pressure makes them very difficult to remove (Bhattacharyya, 2012).

Overall, it is simple to note that tariffs need to cover costs, but the imperative for cost recovery should not inhibit people's access to energy. Implementing effective tariff structures and subsidies in particular African contexts however will likely prove extremely challenging. Given that utilities are currently unsustainable, that grid tariffs are currently high, and that distributed energy tariffs will be even higher, the challenge of managing the balance between access and sustainability is significant, especially if one considers the weak economic base of many African countries. On top of this, the potential for graft is an obvious concern regarding subsidies—whether they are for fossil fuels or electricity access. Subsidies therefore need to be accompanied by a strong regulatory environment, with strong provisions for transparency and accountability, to ensure that they are fiscally sound (Modi et al., 2006). Any serious policy on energy access needs to include some account of how to resolve these challenges, based on realistic appraisals of state capacity, poor people's current reliance on fossil fuel subsidies, the imperatives around energy access, and any expected price changes in electricity generation capacity and energy prices. Finally, if subsidies are meant to allow people to gain access to energy on a temporary basis until such access allows them to increase their income to the point that they no longer need the subsidy, then energy access policies need to include some realistic account of the likely impacts of energy access on economic development. This last issue is a point to which the report now turns.

"ELECTRICITY FOR DEVELOPMENT" OR "ELECTRICITY AND DEVELOPMENT"

Investments in electricity infrastructure have long been justified on the grounds that they will drive important improvements in economic development. Further to

[31] Such leakage creates further problems because adulterated diesel generates more emissions when burnt in car engines (Bhattacharyya, 2012).

this, proponents of energy access in particular have argued that improving access will have more profound impacts on human development than providing large-scale industries with electricity and hoping that trickle-down economics will play their part. Hopes that access to electricity will drive local economic development are also crucial given the challenges around the cost of energy and the scale of subsidies required, as discussed above. Unless electrification drives an increase in incomes, and therefore an increase in people's ability to pay for modern energy access, electrification efforts may well become unsustainable.

However, as discussed earlier empirical evidence on the impacts of electrification on economic development has been somewhat ambiguous, showing broad generalizable impacts in some cases and no noticeable effect in others. Furthermore, where impacts have been observed they tend to accrue disproportionately to the wealthy (Bhattacharyya & Palit, 2016; Prasad & Visagie, 2006; World Bank, 2008) and to women (Dinkelman, 2011). Although it remains the case that electricity is necessary for the sorts of increased productivity that characterize rich industrialized (and post-industrialized) economies, access to electricity is also an insufficient condition for driving economic gains. It seems that simply providing electricity will not drive the kinds of economic development that are so desired and so necessary (Khandker et al., 2009b).

To explain the relative lack of economic impacts of electrification, authors have pointed out that economic development has rarely been included as an explicit goal of electrification efforts. As such, investment in increasing access to electricity has usually not been accompanied by policies aimed at driving economic development (Schillebeeck et al., 2012; Terrapon-Pfaff et al., 2014). To generate economically viable small businesses, however, households need a range of other resources beyond electricity. For example, a household that wished to start up a cottage woodworking industry would find it impossible to do so without access to the credit required to make investments in heavy-duty woodworking equipment, regardless of whether it has access to electricity or not. Likewise, the impact of electricity access on households' income diversification will be limited if those households do not get better access to markets through improved road infrastructure (ARE, n.d.; Practical Action, 2014). Such considerations are especially important given that the populations most likely to suffer from poor electricity access are also likely to be remote from other necessary resources, such as roads, schools, hospitals, and markets (Prasad & Visagie, 2006).

Thus while the provision of electricity is an important factor shaping development outcomes, policies aimed at achieving energy access should not assume that economic development will be an inevitable outcome (Terrapon-Pfaff et al., 2014). Instead, efforts at improving access to electricity need to be located within the context of broader development policies and integrated with other supportive development infrastructure (Schillebeeck et al., 2012). In this respect some authors have specifically pointed out the need to ensure that efforts to promote energy access need to be located within the larger context of an energy transition, which links energy for thermal needs, electricity for lighting, and electricity for national industry. In this conception, addressing energy poverty needs to be linked with addressing Africa's disproportionately small generation capacity (Sokona et al., 2012).

MODERN VERSUS TRADITIONAL FUELS

Given that access to electricity is unlikely to completely address energy poverty, particularly for thermal services, it is important to consider how to provide energy for cooking and heating while reducing the harm caused by the use of "traditional," or solid biomass, fuels.

Countries' efforts in this area have reflected the dominant concerns about the impacts of solid biomass fuel use on health and the environment (mainly deforestation), as well as the associated drudgery. The result has been a push to move individuals up the "energy ladder" and away from such fuels. As mentioned, much of this focus has fallen on electrification, or encouraging the use of modern, petroleum-based fuels. Policies on biomass have historically been neglected (Owen et al., 2013), and where they exist they have been criticized for being incoherent and disjointed (Zulu & Richardson, 2013). In 2013, for example, 35 governments in sub-Saharan Africa had strategic targets to increase access to electricity, 13 had targets related to promotion of modern fuels (kerosene, LPG, and natural gas), and only 7 had policies related to improved wood or charcoal stoves (Zulu & Richardson, 2013).

More recently, however, some researchers have come to question the simple rejection of biomass fuels. New work has made clear that households cannot easily replace biomass, and its use is in fact expected to increase in sub-Saharan Africa through 2030 (Malla & Timilsina, 2014). In addition, studies have revealed that biomass supply chains are extensive. The process of producing, distributing, and selling charcoal provides a significant number of jobs (see Text Box 8) (Clancy, 2008; Lambe et al., 2015; Nissing & von Blottnitz, 2010; Owen et al., 2013) and is a potentially important source of livelihood diversification among women (Jones et al., 2016) and a social safety-net for rural populations (Zulu & Richardson, 2013). Such extensive supply chains also mean that wood and charcoal are readily and reliably available across sub-Saharan Africa in quantities that suit the income characteristics of poor households (Broto et al., 2015; Zulu & Richardson, 2013).

Text Box 8: Charcoal and livelihoods

Because of the informal (and sometimes illegal) nature of charcoal supply chains, their economic impacts are frequently overlooked in policy research. Studies of biomass supply chains have revealed, however, that they support a significant number of livelihoods and that the transport, processing, and retail of charcoal are worth hundreds of millions of dollars annually (Mwampamba et al., 2013a). In Rwanda, for example, the charcoal sector is estimated to generate $77 million annually while in Kenya it is estimated to be about $450 million— equivalent to the country's tea industry. The story is similar in Tanzania, where charcoal is estimated to contribute $650 million to the economy—more than 5.8 times the combined value of tea and coffee production in the country (Zulu & Richardson, 2013).

In terms of jobs, charcoal production in Malawi was estimated to employ 120,000–140,000 people in 2008. A study from Addis Ababa points out that on a single market day in 1984, 42,000 suppliers were found to be transporting traditional fuels. After the government put in place a strategy to limit the use of fuelwood in the city (which successfully reduced fuelwood use from 70 to 13 percent), that number had dropped to 3,500 suppliers. Although about 2,000 jobs were thought to be added in the small business sector through the manufacture of electric, kerosene, and improved biomass cookstoves, the Ethiopian government was reluctant to acknowledge the problem of lost livelihoods as a result of a shift away from charcoal fuelwood as a primary household energy source (Shanko & Rouse, 2005).

Finally, the idea that the collection of biomass drives deforestation has come to be heavily contested (see Text Box 9), and the impacts on climate have come to be viewed potentially favorably when compared with improved, petroleum-based fuels. To this end, some authors have pointed out that while countries in Africa are generally attempting to reduce their use of biomass, countries such as Germany are working to increase the use of biomass in grid-scale energy generation through the use of wood pellets (Owen et al., 2013). Overall, authors have begun to point out that rather than viewing biomass as a fuel to be avoided, developing countries should focus on how to best manage biomass in households in ways that exploit its advantages while limiting its damaging effects.

Text Box 9: Rethinking environmental concerns about biomass

Environmental concerns about the sustainability of biomass as a source of household energy have their origins in the environmental writings of the 1970s (e.g., Ekholm, 1975), which focused on problems of population growth and forecast that increasing demand on wood stores would soon decimate forests, with significant impacts for society (Clancy, 2008). Despite the fact that such predictions clearly did not come to pass, the narrative they spawned remains common. Some authors and policy makers still describe the imminent dangers of severe environmental degradation, and even desertification, as a result of poor households' reliance on solid biomass for energy (Owen et al., 2013). This concern has sparked associated worries about the impacts on water runoff and climate change.

Some contemporary researchers have begun to question this view. Concerns about fuelwood have largely been dismissed; it has been found that fuelwood is usually collected from dead trees and its impacts on forest stocks and climate change are therefore negligible (Bailis et al., 2005; Modi et al., 2006). Concerns about charcoal, however, remain, as charcoal is produced from forest stock. Charcoal has been identified as contributing to deforestation (Lewis & Pattanayak, 2012; Malla & Timilsina, 2014; Modi et al., 2006) and driving carbon emissions (Bailis et al., 2005; Bailis et al., 2015).

However, the exact impact of charcoal collection on forest stocks is also now contested (Bailis et al., 2015), with numerous studies questioning the link between deforestation and charcoal production (Mwampamba et al., 2013a). Reviews of the literature looking at the impacts of charcoal production on deforestation have found that the impact is both relatively minor and reversible (Chidumayo & Gumbo, 2013; Clancy, 2008; Owen et al., 2013). In terms of scale, charcoal production is estimated to account for only 2–7 percent of global deforestation (including cases of charcoal production for industrial use, as in Brazil) (Chidumayo & Gumbo, 2013). More recent analysis notes that only 4 percent of land across the world's tropics constitutes regions in which the majority of traditional fuelwood is harvested unsustainably. Within sub-Saharan Africa, the vast majority of traditional fuelwood is thought to be harvested sustainably (Bailis et al., 2015).

The impacts of charcoal collection vary across sub-Saharan Africa depending on particular practices of forest cutting. West Africa is characterized by selective forest clearing, while in East and southern Africa clear-cutting is prominent (Chidumayo & Gumbo, 2013). The largest contiguous area of concern is thought to be a particular swath of East Africa (Eritrea, western Ethiopia, Kenya, Uganda, Rwanda, and Burundi). Southern Africa contains areas of concern, but none of them large and contiguous (Bailis et al., 2015).

Even where clear-cutting is taking place, authors note that forest regrowth has been observed (Mwampamba et al., 2013a; Ribot, 1999) over periods of 9–30 years, depending on the region (Chidumayo & Gumbo, 2013). How land is managed after being cleared has been shown to matter more than the fact that land was cleared at all (Bailis, 2009; Chidumayo & Gumbo, 2013).

Overall, the idea that forest clearance for charcoal production drives deforestation has come to be questioned. Authors now suggest that its impact seems to more closely resemble degradation, particularly when compared with other drivers of deforestation, such as commercial tree felling or the conversion of land for agricultural use (Chidumayo & Gumbo, 2013; Clancy, 2008).

Charcoal production also raises questions about impact on runoff and climate change. Impacts on runoff are thought to be quickly undermined by forest regeneration, while wetland clearance and reservoir construction are thought to have much greater effects on runoff dynamics than forest clearance for charcoal production (Chidumayo & Gumbo, 2013). With regard to climate change, carbon that is released in charcoal burning is thought to be eventually sequestered in new forest growth (Chidumayo & Gumbo, 2013). Even at these lower levels, though, the impacts of traditional fuel use can generate relatively large proportions of the carbon emissions produced in countries with few industrial emissions (Bailis et al., 2015). Thus, efforts to reduce emissions by promoting and using improved cookstoves remain important.

While felling trees for charcoal use is thought to have only local and temporary effects, kiln sites have been found to have more permanent effects owing to the high temperatures that permanently damage soils. Although kiln sites are relatively small, forest recovery in such sites is limited, because forests do not recover in the medium term but are replaced instead by shrubby plant species (Chidumayo & Gumbo, 2013).

Among the damaging effects of traditional biomass, none is more severe than the impact on people's health. Further, while the impacts on deforestation may be limited and time bound (see Text Box 9), forest clearance still temporarily undermines access to forest services, while the drudgery of collecting fuelwood represents a welfare cost to the women and children to whom this task frequently falls. Moreover, in the future increased demand from growing urban centers may weaken the sustainability of this practice. This is especially the case in semi-arid areas, where the relative impacts of charcoal production on forest cover change may be greater than those of land clearance for agricultural purposes (Sedano et al., 2016). Under such circumstances, even if forest degradation is temporary, combustion of biomass produces carbon immediately while regrowth takes time. Under conditions of increased future demand, this will result in increases in the total carbon dioxide in the atmosphere. Efforts to promote improved cookstoves, which might serve to limit these pressures are, therefore, crucial.

As mentioned earlier, efforts on this front have been bolstered by the creation of the Global Alliance for Clean Cookstoves (Africa Progress Panel, 2015; Agbemabiese et al., 2012; Practical Action, 2014), which has a goal of providing 100 million cookstoves by 2020. Considering that there are expected to be 3 billion people in rural Africa and Asia by that time, the Alliance for Clean Cookstoves will reach only about 16 percent of the needy population (assuming 5 people per household) (Bhattacharyya, 2012). This suggests that although the current focus on cookstoves is an improvement on historical neglect, there is a need to put even greater resources into the project.

Although there is a strong case for acknowledging the extent to which the supply chains around solid biomass support livelihoods, such supply chains are thought to be characterized by high levels of inequality. Middlemen and wholesalers are able to capture most of the value, while individuals involved in production and retail are relatively exploited (Zulu & Richardson, 2013). Efforts to support the creation of inclusive and sustainable supply chains for solid biomass are therefore an essential element of any energy access effort.

Finally, regardless of the benefits of improved cookstoves, the use of solid biomass for cooking will result in excessive drudgery and unacceptable health impacts, most of which will be borne by women, who are usually responsible for these tasks. Although it is unclear exactly how to address these problems, a concerted effort needs to be dedicated to solving such problems, while acknowledging the likely persistence of solid biomass fuels in the home.

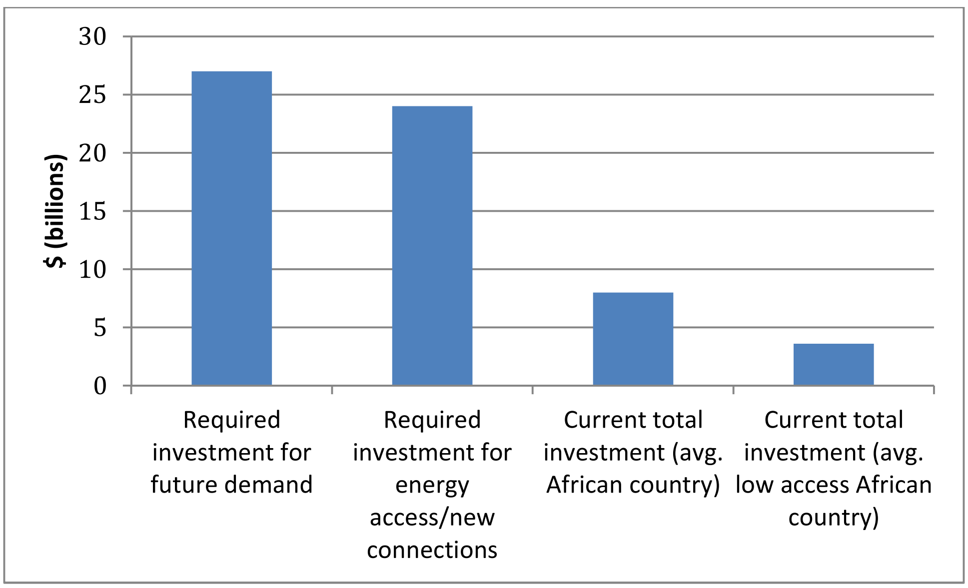
Overall, considering the question of modern versus traditional fuels, the intention here is not to promote a single fuel or approach over another. Instead it is to point out that different fuels have different impacts involving complicated trade-offs. Petroleum-based fuels are more efficient and have important health advantages over solid biomass, but they also drive climate change (Alstone et al., 2015; Bailis et al., 2005; Clancy, 2008) and have made only limited inroads into the household energy economies of the poor. On the other hand, biomass fuels provide important access to energy and sustain livelihoods. The use of traditional fuels is also not simply going to go away. In sub-Saharan Africa, the number of people reliant on biomass fuels is expected to increase between 2014 and 2030 from 793 million people to 823 million (IEA, 2016). As such, a simple view that treats biomass as a “traditional” or “backward” fuel, with no place in development policy will undermine efforts to address energy poverty.

Any serious policy aimed at addressing energy poverty needs to engage with the complexity of factors determining how households choose their fuels. This will need to include an explicit focus on the role of biomass in households. Important dimensions of such policy will include the promotion of improved cookstoves, including standards for their construction, tax incentives for their manufacture, subsidies and credit systems to support their purchase, awareness raising about their value, and investments in the infrastructure needed for their manufacture (such as electricity) and their supply (such as roads) (Agbemabiese et al., 2012). Likewise, policies will need to include plans for community-based sustainable forest management, and the creation of policies that ensure the effective distribution of wealth within the charcoal value chain (Clancy, 2008). Finally, efforts that seek to improve the efficiency of charcoal use or provide effective biomass substitutes, such as briqueting, can also play a role in alleviating the impacts of degradation or address concerns in cases where charcoal production is unsustainable (Mwampamba et al., 2013b).

FINANCING

It is clear that finding the financing to tackle energy poverty will be a major challenge. This financing will need to cover increased generation capacity, upgrades to the grid, connection fees, and subsidies both to cover basic energy consumption and to reduce the barriers to the private sector. Looking at universal energy access alone, reports suggest costs of the order of $17–$24 billion annually (Africa Progress Panel, 2015; IEA, 2012; IEG, n.d.). About 65 percent of that money is needed to support new generation, and approximately 25 percent is needed for transmission and distribution (IEG, n.d.). In addition, an estimated $3.8 billion per year is required to achieve universal access to clean cooking facilities (IEA, 2012). On top of this an estimated $20–$35 billion needs to be invested annually in plants (67 percent) and transmission and distribution (23 percent) to meet current and future demand in Africa (Africa Progress Panel, 2015; IEG, n.d.). These large sums of money dwarf current investment in the sector: about $8 billion annually (Africa Progress Panel, 2015). The picture looks worse in in countries with low levels of energy access, where public and private investments have been only about $3.6 billion annually (IEG, n.d.).

Figure 8: Comparing required annual financing for electricity infrastructure in Africa with current financing



Source: Africa Progress Panel, 2015; IEG, n.d.; World Bank Group, 2012.

It is unlikely that the international financial institutions will be able to solve this financing challenge alone. Consider that between 2000 and 2014 annual investments in energy from the World Bank Group were around $1.5 billion annually, with most of that money going to countries with relatively high levels of energy access and being invested mainly in improving the quality, reliability, and efficiency of supply to already connected consumers (IEG, n.d.). Countries with low levels of electricity access received disproportionately small investments, attracting only 8 percent of total investment in generation capacity (in terms increasing GW capacity), 7 percent of investment in connections, and 3 percent of T&D network investments. World Bank projects lasted around nine years on average. Unless something changes on this front, countries will only receive a little over two project cycles before 2030, meaning that energy access goals are unlikely to be met (IEG, n.d.).

The possibilities for official development assistance (ODA) are expected to be similarly limited. ODA has stagnated since 2011, and while estimates for financing Africa's infrastructure needs are estimated at around $93 billion, total aid to the continent is about half that, with only around $18 billion being available for infrastructure investment (Africa Progress Panel, 2015).

Despite these challenges, however, the financing problem for energy infrastructure may well be surmountable. African domestic taxes are thought to be able to cover about half the financing gap for electricity infrastructure. On top of this, Africa is estimated to spend about $21 billion on poorly targeted fossil-fuel subsidies every year (though most of this is dominated by spending in North Africa, with South Africa, Nigeria, and Angola being the only sub-Saharan countries paying significant subsidies (IEA, 2011)). The continent is also estimated to lose around $69 billion annually through illicit financial flows. Finally, while holding out hope for ODA might be a limited option, it should be noted that if rich countries met their longstanding goal of contributing 0.7 percent of GDP to ODA, this would free up an estimated $178 billion in extra financing for Africa (Africa Progress Panel, 2015).

Given these conditions, the challenge of mobilizing finance for investments in energy infrastructure is believed to be one of the principal barriers to achieving universal energy access (Bhattacharyya & Palit, 2016). Solving this problem will likely require using public finances to leverage private finance and generating policies that create a conducive environment for private investment (Africa Progress Panel, 2015; Bhattacharyya & Palit, 2016). Important channels for public expenditure will be investments in increasing the efficiency of the grid (Eberhard et al., 2008) and subsidizing last-mile connections and basic electricity consumption (Bhattacharyya, 2015; Bhattacharyya & Palit, 2016; Deshmukh et al., 2013). Policies will need to focus on reducing taxes, tariffs, and import costs on renewable energy components, supporting the creation of supply chains for distributed renewable energy technology, and reducing uncertainty around the expansion of the grid (see below).

On top of financial support, there is a need to increase access to credit (to both consumers and local entrepreneurs) through efforts at financial inclusion and increase the periods over which loans can be paid back (Africa Progress Panel, 2015; Turman-Bryant et al., 2015). Efforts in this regard should pay particular attention to the new financing possibilities being created as a result of new technologies such as cellphones and mobile money (Alstone et al., 2015).

7. CONCLUSIONS AND WAYS FORWARD

With a clear sense of the nature of energy poverty, and the opportunities for improving energy access via different technologies and approaches, the report moves to consider the important ways forward for energy policy in countries with low levels of energy access. Overall the emphasis should fall on (1) leveraging financing, (2) reforming institutions, (3) addressing the challenge of solid biomass, (4) making explicit plans for grid expansion and distributed energy integration, (5) balancing different generation technologies and approaches to access, (6) supporting the whole supply chain across generation technologies, and (7) placing efforts at electrification within broader development strategies.

FOCUS ON THE FINANCING

Financing presents a fundamental challenge for addressing energy poverty in sub-Saharan Africa. Public finance will not be able to cover these costs and thus it is imperative that public finances, along with donor and non-governmental support, be dedicated towards efforts that leverage private finance in the sector. At the same time, it is imperative that opportunities for increasing public finance must be pursued by reducing wasteful and regressive expenditures and addressing illicit financial flows. Public and donor support should go toward reducing taxes, tariffs, and import costs on renewable energy components; undertaking resource assessments; subsidizing basic electricity allowances and connection fees; and creating and supporting institutions focused on promoting learning around new technologies.

To help promote investment in technologies that increase energy access, it will be important to develop policies that reduce risk for private investors, such as making grid expansion plans transparent, and to create institutes to train the relevant technicians. Finally, there is a need to promote financial inclusion and increase access to credit for both potential consumers and local entrepreneurs.

Despite these opportunities for improving financing, in very low-income countries it will likely be exceptionally challenging to find the finances to ensure that low-income groups can gain access to electricity and shift their cooking to improved cookstoves. Appreciating the scale of this challenge is central to generating realistic efforts to tackle it.

FOCUS ON INSTITUTIONS

Recent advances in renewable technologies have created new possibilities to advance energy access at a rate and cost that would not be possible if grid expansion was the only option available. Important as such advances are, however, they create a risk that advocates will focus solely on the technology and overlook the importance of the institutional context in which that technology is being delivered. In particular, there is a risk of believing that distributed technologies can simply be provided by the private sector and that challenges associated with unresponsive and corrupt utilities are no longer an issue.

To reduce this risk, it is worth keeping in mind that distributed energy technologies are not all new and neither are efforts at improving energy access (Agbemabiese et al., 2012; Sokona et al., 2012). For example, straightforward technologies such as windmills have long been promoted in Africa as a means to provide power for irrigation without resounding success (Sokona et al., 2012). Likewise, diesel generators have long been able to provide electricity at prices comparable with what is currently possible using solely PV systems (Bhattacharyya, 2015) and with much lower up-front costs (World Bank & IEA, 2015), and yet the private sector has not simply capitalized on the latent demand and provided electricity via mini-grids.

To this end, the literature on energy access repeatedly observes how “weak institutional structures and organizational systems contribute to the poor performance of projects.… economically viable projects can fail simply because of an inadequate appreciation of the importance of appropriate organisational structures and institutional arrangements. Past experiences also show that a large number of off-grid electrification projects have had limited success… because of the disproportionate focus on technical installation without adequate attention to the long-term sustainability of the projects” (TERI-GNESD, 2014, p. 26). As mentioned above, “no electrification project has ever succeeded without significant government backing and strong political will” (Schillebeeck et al., 2012, p. 7), and achieving countrywide rural electrification through the efforts of small-scale private companies alone is impossible (Mostert, 2008, p. 12). As such, policy and regulatory environments will matter, as will financial support to enable supply chains and cover subsidies. The public sector will therefore remain a crucial part of this process, with the utility likely playing a central role.

There is, therefore, an absolute need to maintain core advocacy work on creating public energy institutions that are responsive and accountable. It would be an error, for example, to assume that the private sector can resolve the challenge of energy access and that debates over the privatization of state utilities can now be neglected. If this occurs, the ongoing failure of power sector reform to benefit the poor is likely to continue (Prasad & Visagie, 2006). Further, given the role of subsidies and the scale of tenders that will likely be involved in increasing energy access, the scope for misuse of funds is significant. Given that utilities are already cited as sites of patronage in Africa, the focus on energy access could well result in a greater need to ensure institutional accountability.

A note of caution on this front is that the political and economic dynamics shaping institutional responsiveness might be more complex than is often portrayed in the literature on good governance and institutions. For example, efforts that have sought to explain energy access by looking at governance metrics and corruption indicators have been found to lack any power when it comes to explaining electrification rates across countries (Wolfram et al., 2012). Such findings mirror a larger trend in the development literature toward questioning the relationship between both democracy and governance, and human development outcomes (Nelson, 2007; Ross, 2006; Truex, 2015). Findings such as these point to the need for institutional reforms to go beyond cookie-cutter approaches to improving governance and engage with nuanced accounts of power and political economy analysis when seeking to drive improved institutional responsiveness. See Text Box 6 for an example of how these complex processes play out.

DO NOT NEGLECT TRADITIONAL FUELS

Although electricity is a unique source of energy that creates unique opportunities for improving people’s standard of living, the empirical evidence is clear: use of solid fuels will remain prevalent regardless of whether households are connected to electricity and regardless of whether they are connected via the grid or distributed energy sources. The use of biomass is actually expected to increase, not decrease, in sub-Saharan Africa (Malla & Timilsina, 2014). Since as much as 90 percent of household energy needs come from cooking and heating (Bhattacharyya, 2012), any serious policy on energy poverty needs to dedicate significant effort to ensuring that such needs can be met safely and sustainably. Policies must account for managing the use and collection of solid biomass rather than simply trying to replace such fuels and ignoring the conditions of their use. To this end the challenges and opportunities around promoting petroleum-based fuels, such as kerosene and LPG, need to be weighed against the challenges and opportunities of meeting energy needs through solid biomass fuels such as fuelwood and charcoal.

In terms of charcoal and fuelwood, policies need to focus on creating standards for, and ensuring access to, improved cookstoves. While the creation of the Global Alliance on Clean Cookstoves represents important progress on this front, given the scale of the challenge of energy poverty, it is clear that still more needs to be done (Bhattacharyya, 2012). Efforts in this respect include removing taxes and duties on imported cookstove technologies, raising awareness about the benefits of using improved cookstoves, creating access to capital for private-sector cookstove development and purchase, and ensuring that likely users of improved cookstoves are engaged throughout the design, manufacture, and retail process to ensure that cookstoves are culturally appropriate and support local poverty alleviation efforts (Lambe et al., 2015). On top of such actions, as with electricity access, efforts around cookstoves need to be supported by the larger infrastructural context so that, for example, roads exist to allow for stoves to be distributed and grid electricity is cheap and sustainable to allow for stoves to be manufactured affordably (Agbemabiese et al., 2012).

In addition to promoting improved cookstoves, efforts should be directed toward encouraging the appropriate drying and storage of fuelwood as well as the soaking of grains to reduce cooking times (Modi et al., 2006). Finally, policy needs to focus on creating the conditions for the sustainable harvesting of fuels. To this end, much can be done to improve efficiency of charcoal kilns (Bailis et al., 2005). Likewise community management of forests and acknowledgment of the importance of fuelwood and charcoal production as forms of employment will be central to ensuring sustainability and poverty reduction. Calls for biomass collection to be made illegal should be resisted, as this tends only to result in elicit transactions that are likely to undermine sustainable management (Clancy, 2006). Supply chains for both biomass fuels and cookstoves should be made more equal and less exploitative. Policy could also play a role in increasing access to solid fuels by creating fuel depots, which can reduce drudgery, lower costs, and ensure the sustainable supply of solid biomass (Modi et al., 2006).

Focusing on biomass fuels does not mean excluding attention to improved, petroleum-based fuels or the uptake of electricity for cooking. The push for clean cookstoves is not an end in itself, but rather an important interim measure that can improve health, reduce drudgery, maintain access to forest services, and mitigate the emission of greenhouse gasses as well as other pollutants, while access to modern fuels is achieved. It is thus also important to promote the use of modern fuels; encourage the use of, and create finance for, low-cost appliances; address bottlenecks in the supply chain of modern fuels; ensure that fuels are available in small quantities; and ensure that transport infrastructure is in place to support supply chains (Modi et al., 2006). A focus on education, especially among women, is also a key way to ensure that households' fuel use is rational and not simply determined by the low opportunity cost of women's time. In addition, countries need to carefully weigh their support for fossil-fuel subsidies; they may have been effective in driving the uptake of improved fuels, but they are highly inefficient and regressive owing to problems with targeting and leakage.

Finally, complementary actions can be taken to reduce the risks associated with kerosene, including setting standards that prevent it from being resold in drink containers, dying kerosene a color so that it does not look like water, and using childproof caps on containers, which has been shown to significantly reduce unintentional poisoning[32] (Meyer et al., 2007; Tshiamo, 2009). Some of the risks associated with energy poverty, such as fire risk, are located in larger social contexts associated with substance abuse, land tenure, and urban planning (Morrissey & Taylor, 2006). In South Africa, for example, despite improvements in both energy access and the availability of spill-proof kerosene stoves, the number of informal settlement fires has continued to rise (Kimemia et al., 2014). Efforts to address energy poverty therefore need to be rationally located within a larger policy environment that addresses these larger developmental challenges as well.

ADDRESS UNCERTAINTY AROUND GRID EXPANSION

Debates about the merits of centralized, on-grid approaches versus distributed energy technologies for addressing energy poverty are overstated. Both strategies will need to be deployed simultaneously. Electricity will best be introduced to most rural households through distributed technologies, but this will likely be a temporary solution. The eventual goal should be grid expansion, which will achieve the lowest cost of electricity for any household and allow for high rates of renewable energy penetration (see Text Box 3).

As a result, it is essential that plans for grid rollout are transparent and that the government sticks to those plans. This sort of certainty will be necessary for the private sector to invest in distributed energy technology. Given that plans for grid rollout can involve time scales of 25 years (Eberhard et al., 2008), staying the course on policies made today will involve resisting intense political pressure to change those plans and connect certain constituencies. To this end, an effective means for planning the rollout of the grid is on the basis of least-cost. Also needed are policies that detail what will happen when grid expansion meets privately owned, distributed generation projects that have not yet recovered their costs and generated a return on capital.

MIX TECHNOLOGIES FOR ACCESS

In balancing expansion of the grid with distributed energy technologies, as well as identifying roles for the state, the private sector, and community-led efforts, every country context will be unique. This context will depend on factors such as

[32] Certain graphics, such as the skull and crossbones on kerosene containers, have actually been discouraged by the US National Committee for Injury Prevention and Control because they have been shown to attract children rather than deter them (Meyer et al., 2007).

the size of the economy, the distribution of the population (and the distribution of wealth across the population), the nature of the terrain, the availability of different energy sources and fuels, and the current quality of infrastructure. Despite such variation, in general, decisions on technologies should include the following principles:

1. Policies should be in place to connect “under the grid” populations and be complemented by polices to ensure that there is sufficient generation capacity to meet the extra demand. Such policies need to consider the particular challenges faced by the urban poor; economic trickle-down will not automatically meet these groups’ needs (Clancy, 2006), especially when connection problems stem from their interaction with compromised access to serviceable land.

2. Income density will be an important guide to determining where grid expansion should be a priority. The grid should be expanded to areas where its considerable economies of scale can be exploited.

3. Where incomes densities are relatively high yet population centers are remote, mini-grids will be the best solution. They will provide the cheapest form of energy with the additional possibility of being scaled up to meet future growth in demand.

4. Where remote populations are scattered into small homesteads, SHSs will likely be the best choice.

5. Among very poor households, solar appliances might be the best option. Policies to support this should focus on awareness raising, the removal of taxes and tariffs on solar appliances, and creation of product quality verification standards (Turman-Bryant et al., 2015).

6. Plans to expand energy access through biodigesters should be modest given the barriers experienced in other countries when it comes to effectively integrating them into household energy consumption.

Efforts at grid expansion are likely best undertaken by a centralized state body owing to the fact that the grid represents an almost prefect monopoly. Beyond grid expansion, a mix of private and public approaches can productively generate and sell electricity. Likewise, the provision of distributed energy technology can take place through a variety of hybrid arrangements involving the state and the private sector (Mostert, 2008). Establishing a dedicated government department, focused on increasing energy access, within the utility has proven useful in cases where access to electricity has been successfully expanded[33] (Eberhard et al., 2008). In all cases, policies aimed at achieving energy access should include

[33] It should be noted that having such a dedicated body does not always result in improved energy access.

provisions for flexibility so that it is possible to learn from successes and amend policies as new problems arise. The process by which Africa is electrified will not parallel experiences from other countries. With few blueprints for best practices, learning must be a central feature of policy.

SUPPORT THE WHOLE DISTRIBUTED ENERGY SUPPLY CHAIN (NOT JUST UP-FRONT COSTS)

As mentioned, the state and the utility will likely matter a great deal in efforts to increase energy access and address energy poverty—even for distributed energy technologies. Policies should focus not only on addressing challenges related to the costs of generation, storage, and distribution, but also on the entire supply chain. This will include creating institutions that train technicians, installers, construction staff, economists, and engineers (Modi et al., 2006; Mostert, 2008). It will require ensuring that parts for servicing and replacement are available and affordable, undertaking resource assessments, and creating institutions for financing for both entrepreneurs and consumers. Without such conditions in place, projects are likely to prove unsustainable (Terrapon-Pfaff et al., 2014) and the subsidies covering initial capital costs could well be wasted as projects fail or are abandoned.

Because distributed renewable energy technologies are new, the state will also play an important role in overcoming first-generation technology barriers. Activities will include providing data and promoting learning about the creation of effective supply chains and viable business models (Bhattacharyya & Palit, 2016).

PLACE ELECTRICITY ACCESS WITHIN THE BROADER CONTEXT OF DEVELOPMENT

Although access to abundant energy is clearly a precondition for the levels of economic productivity and well-being experienced in industrial and post-industrial economies, simply providing households with electricity is unlikely, by itself, to drive the large development outcomes that are possible. As such, while improving electricity access is an important development imperative in and of itself, it must be conceived of within a broader development agenda that focuses on the provision of other infrastructure such as roads, markets, and sanitation, and the availability of other services such as credit, education, health, and policing. In this respect it will be important to integrate energy poverty alleviation into efforts to close the energy gap in sub-Saharan Africa. Such a large-scale integration of development efforts is challenging because it will involve many different government departments and ministries, but this integrated planning is likely to be necessary to realize the development opportunities made possible by electrification.

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