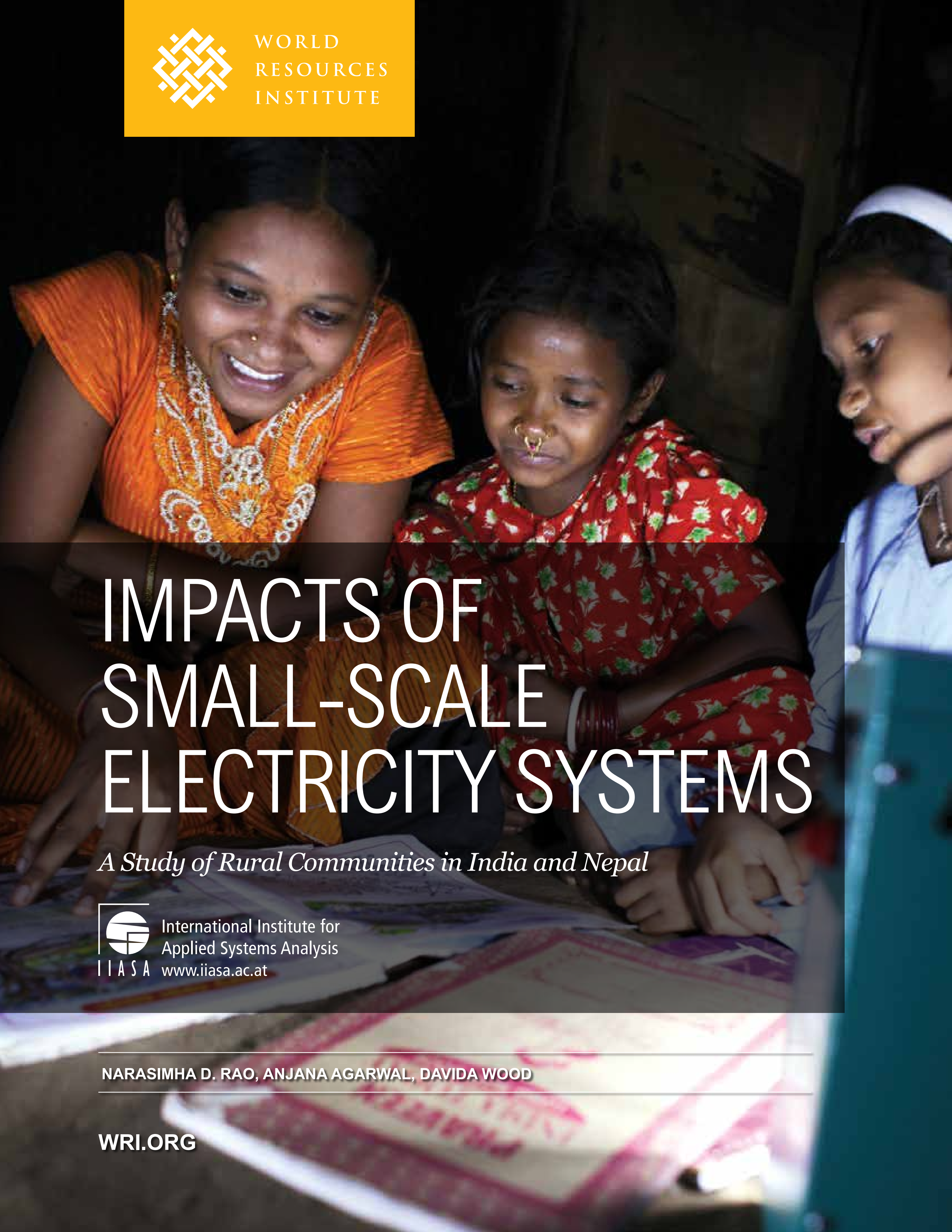

WORLD RESOURCES INSTITUTE

IMPACTS OF SMALL-SCALE ELECTRICITY SYSTEMS

A Study of Rural Communities in India and Nepal

IIASA International Institute for Applied Systems Analysis www.iiasa.ac.at

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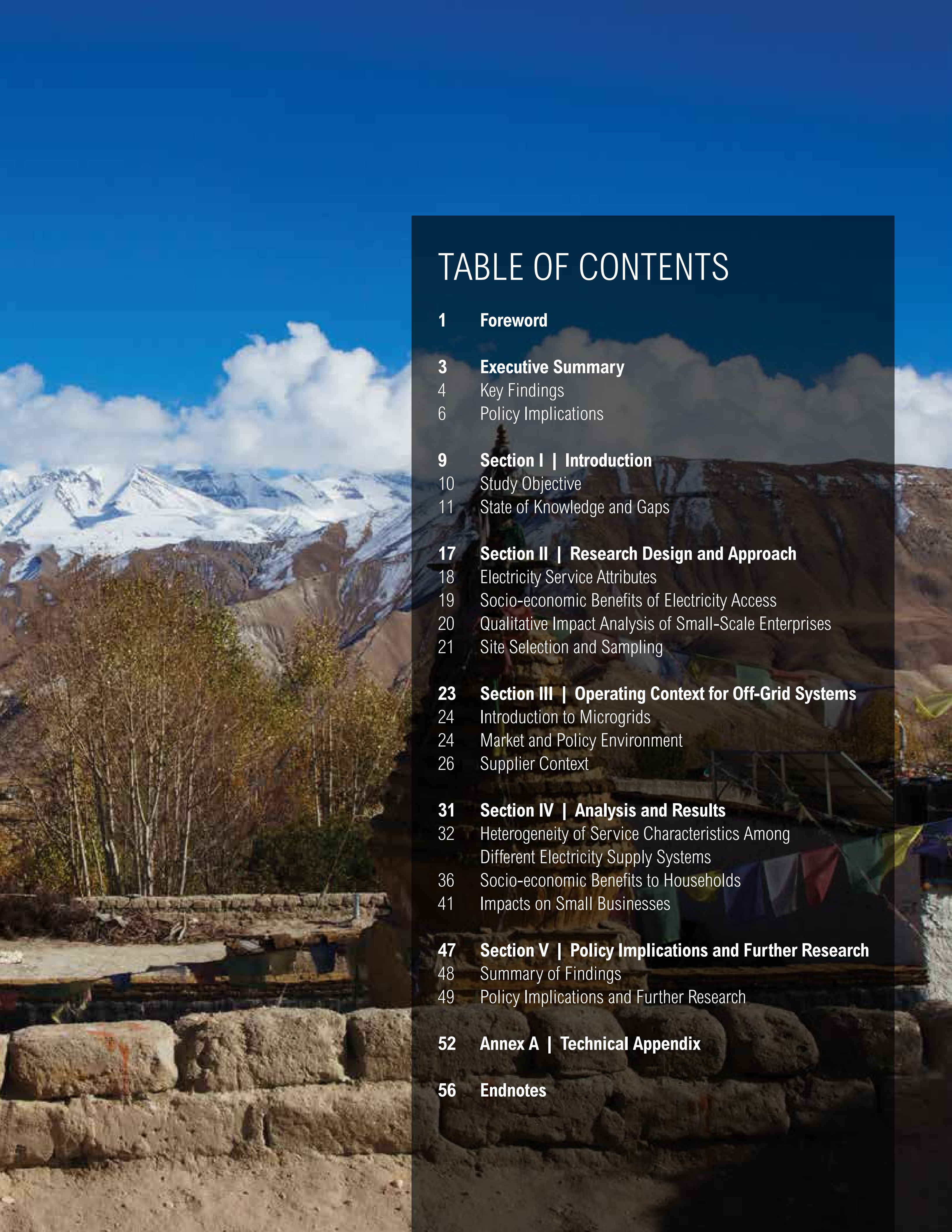

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FOREWORD

The year 2015 represents a milestone in international development policy, with the launch of the Sustainable Development Goals (SDG) and the Paris negotiations on climate change. The development of a global sustainable energy system is central to both achieving the SDGs—not just the specific energy goals but also energy as an enabler of poverty eradication—and in tackling climate change. The fast changing landscape of technology, private sector involvement, and policy in the energy sector necessitates research to understand how these facets interact to influence basic human development. Therefore, it gives me great pleasure to read the research results of this collaboration between the International Institute for Applied Systems Analysis (IIASA) and the World Resources Institute into ongoing electrification efforts in South Asia.

Researchers at IIASA are already assessing the energy needs for development in Asia and sub-Saharan Africa, including the provision of electricity and modern clean cooking energy, and the impact of this transition on climate change and other development objectives. This study enables new data to be collected, and emerging trends in technology, electricity systems and markets to be systematically analyzed, yielding new insights for how policy can guide such trends toward sustainability. As the SDGs and new strategies for climate change stabilization are put into place in the coming years, research findings such as those in this report provide invaluable input into developing practical solutions that take a holistic view of development and help eradicate energy poverty.

Pavel Kabat
Director General and Chief Executive Officer
IIASA

More than 600 million people in South Asia lack access to electricity. Millions more are "under electrified", i.e. they have electricity connections but receive limited and erratic supply. This means opportunities to set up new businesses remain limited, there is no respite from the sweltering heat, children cannot study after dark, and people continue to have to rely on small, flickering kerosene lamps for light.

As technologies for delivering decentralized energy services have emerged, clean energy enterprises have proliferated in many parts of the region. Increasingly, unconnected and underserved households are relying on microgrids and solar home systems for reliable electricity supply. Yet very little is known about the socio-economic impacts of such decentralized solutions.

This report, the product of collaboration between WRI and the International Institute for Applied Systems Analysis, attempts to fill that information gap. By analyzing primary data from a survey in rural India and Nepal, it is one of the first efforts to quantify and assess the performance of these decentralized solutions in terms of reliability, affordability and development impacts.

Impacts of Small-Scale Electricity Systems: A Study of Rural Communities in India and Nepal finds that the poorest of the poor often pay the highest rates for basic electricity services, and regulation of off-grid markets is needed. It also finds that erratic supply offsets the full economic benefits of electrification programs. Finally, the report identifies areas of research that will help design electrification programs that meet local needs and maximize rural economic development.

We hope you find this report useful as you develop or influence electrification plans to result in true economic development benefits.

Andrew Steer
President and CEO
World Resources Institute

EXECUTIVE SUMMARY

This study assesses and compares the benefits of electricity service to households and small enterprises from microgrids, solar home systems (SHS), and the national grid in select rural communities in India and Nepal. Electricity access, in general, leads to reduced kerosene use, more time spent by women on income-generation, and the acquisition of home appliances. However, different types of systems have distinct differences in electricity service conditions. These conditions partly explain why households with SHS exhibit the greatest reduction in kerosene use; why grid-connected households own more appliances; and why electricity access benefits small businesses, but seldom drives key business decisions. The developmental impacts of rural electricity access may benefit from supply standards, greater policy support for investments in productive uses, and further research into the cost-effectiveness of electrification from different supply systems.

More than 600 million people in rural South Asia lack access to electricity. National electrification efforts have made steady progress, but remote regions remain inadequately served. In recent times, off-grid systems, particularly those developed by private entrepreneurs, have proliferated in remote areas of India and Nepal, raising hopes of accelerated electrification. These off-grid systems include microgrids supplied by various technologies and stand-alone solar home systems (SHSs). National grid expansion has proceeded in parallel, often in competition with off-grid systems.

How has this recent proliferation of small-scale electricity systems in rural South Asia affected the lives of communities that they serve? Has the provision of electricity led to higher incomes among households and small business enterprises? Has electricity access improved health and educational outcomes? Do different types of systems and technologies deliver similar services with similar benefits? This study assesses the socio-economic impacts of electricity from off-grid systems and compares them with the services offered by electricity from the national grid in select communities in India and Nepal. The study confirms that the technical characteristics of different types of systems can influence the services offered; the term "electricity access" does not imply a homogenous set of services.

We surveyed households and small businesses in three districts in India and Nepal: Araria and West Champaran in the Indian state of Bihar, and Kavre in Nepal. We compared households with and without electricity but also made comparisons, where possible, of the relative benefits provided by different types of supply systems. We followed a comparative approach that assessed differences in outcomes across these systems, ensuring their robustness through statistical techniques, such as Propensity Score Matching (PSM). We also made a qualitative assessment of how electricity supply from different systems impacts the income and business decisions of small- and medium-sized enterprises (SMEs).

This study contributes to a growing understanding that access to electricity is not binary (access/no access), but multi-dimensional: Communities' experience of electricity is shaped by attributes such as reliability, affordability, and capacity for powering different services. This multi-dimensionality has been captured in the Global Tracking Framework developed by the UN Sustainable Energy for All (SE4All) program. We confirm the importance of this multi-dimensionality, and assess the utility of the framework in categorizing services to the households surveyed in this study.

Key Findings

In many villages, different types of off-grid systems co-exist, sometimes in competition with each other, and occasionally even with the national grid.

The microgrid markets in this study have operated with limited government oversight in Nepal, and virtually none in India. Diesel-based microgrids often co-exist with biomass-based microgrids, which are in some cases transitioning to solar power. In the chosen sites, SHSs were common, using a wide range of system sizes and costs. Households and SMEs sometimes purchase SHSs on the open market.

Service conditions surrounding electricity supply, including availability and reliability, differ across different technologies and systems.

Households served by the biomass-based microgrids in Bihar receive 3-4 hours of service per day, typically during evening hours, while those served by micro-hydro systems in Nepal receive 15 hours. The business model of biomass-based microgrids partly explains the low availability to households: system owners prioritize service to commercial customers in daytime hours to keep utilization high enough to ensure system viability. Grid service, on average, tends to be available for more hours, but with lower predictability.

No single system is cheaper by all affordability metrics. Electricity costs and effective per-unit rates vary significantly across supply systems.

Other than grid customers in Nepal, most households, including grid customers in India, lack meters and pay flat monthly rates. Service costs are best understood through a combination of monthly costs, per-unit rates, and share of total household budget. Sampled customers pay between INR 60 and 200 (US$ purchasing power parity ($PPP) 3-10) per

month. Biomass-based microgrid customers in Bihar pay the highest rates when assessed on a per-unit basis, of up to $PPP 4.5/kWh, due to low usage. The poorest consumers in Bihar spend 7–10 percent of their monthly household budget on electricity. Metered customers in the sample, in general, pay lower rates than flat-rate customers. Households in Nepal typically pay lower rates, but higher connection fees, than households in the Indian cases.

Off-grid systems have connection limitations that inhibit appliance purchase and use, but unreliable grids also constrain investment in appliances.

In comparison to households connected to the grid, households supplied by microgrids and SHSs have 26 percent and 39 percent lower appliance ownership rates, respectively, after controlling for income. This is likely due to the absence of connection restrictions with grid supply. Grid customers in Nepal had distinctly higher appliance ownership, probably because of greater availability of supply.

Household kerosene use is significantly lower for households with SHSs and moderately lower for microgrid customers, when compared with grid customers.

While 80 percent of the households with access to electricity continue to use kerosene, only about 25 percent of homes with SHSs use kerosene. The reliability of SHS supply may partly explain these differences.

Households perceive electricity access as beneficial for children's education.

About 82 percent of grid customers and over 90 percent of the remaining households agreed with the proposition that electricity benefits both children's studying, and their school attendance.

No discernable differences in income levels were found between households with and without electricity access.

Many factors may explain this finding. Most households have obtained supply recently, well within the last decade, which may not have allowed enough time for benefits to manifest. Sample size, poor supply conditions, and the absence of other enabling factors, such as market access, may also influence this outcome.

Women with electricity access spend more time on income-generating activities than those without.

Women in households with electricity access spent, on average, almost an hour a day on income-generating activities, which is more than double the amount of time spent by women in unelectrified households. No differences were found in leisure time.

Electricity is not the primary determinant of business choice or location, but the more reliable and predictable the supply the better the environment for business.

SME owners are, for the most part, reluctant to make electricity-dependent investments because of erratic supply. Fewer hours of more predictable supply is generally considered preferable to more hours of erratic supply. Depending on the type of business, some SMEs are able to cope with poor reliability without significant income losses, while others pay high costs for diesel or solar backup.

Policy Implications

Given the rapid proliferation of off-grid systems in South Asia, further research of the kind undertaken in this study is required to understand how both grid and off-grid systems can deliver electricity services that support broader development goals. We cannot claim that the findings from this study are generalizable. The following lessons should therefore be taken as initial evidence that can suggest areas for further exploration.

Electricity service from off-grid systems in India may require regulation

Electricity supply, whether from off-grid or grid systems, should have minimum standards of service. Households currently face poor supply conditions and high costs, and regulation and related enforcement mechanisms may be necessary to correct the situation. The rates paid for microgrid supply in many areas are comparable to the cost of electricity from diesel, and they are higher than the regulated (and subsidized) rates paid by other rural households in India.

In addition, metering may confer benefits on both suppliers and households. For suppliers, metering offers a means of preventing theft and violation of load restrictions. For some households with low usage, metering could lower their costs if accompanied by per-use rates instead of flat rates.

Electricity supply for rural development should be incentivized

This study indicates that off-grid systems, particularly in India, provide limited services, mostly lighting and phone charging. However, systems are evolving. Solar is increasingly being adopted, both as a gradual replacement for traditional biomass-based microgrids and in the form of SHSs. The more these systems can be encouraged to support a broader set of services, particularly productive uses, the greater the potential for off-grid systems to serve as a mechanism for rural development.

The multi-tier framework for electricity access metrics should be refined

The multi-tier framework of metrics was developed by the World Bank to characterize energy access. While the framework captures the multi-dimensionality of energy access, its application leads to internally inconsistent tier assignments for many households. For example, many households are assigned to "low use" tiers but these tiers include both poor households with minimal demands and wealthier households, with several appliances, whose use is constrained only by available supply. Aggregating different dimensions into single scores, therefore, can yield inconsistent results. Separating energy poverty metrics related to consumption, such as connected load, from those related strictly to supply characteristics would reduce this inconsistency. The issue of energy affordability is also complex and a single affordability metric is insufficient to differentiate households with different cost characteristics.

SECTION I

INTRODUCTION

This study starts to fill several gaps in the literature on electrification benefits. By examining service attributes, including reliability, and the comparative benefits of electricity from grid supply, biomass-based microgrids, micro-hydro systems, and solar home systems, this study advances our understanding of the complex relationship between supply systems and social benefits.

Study Objective

This study is motivated by the following overarching question: how has the recent proliferation of small-scale electricity systems in rural South Asia affected the lives of communities that they serve? Our goal is to assess the benefits of electrification from these systems in comparison to the conditions of communities without electricity, and where possible, to assess the relative benefits from different types of electricity supply. We focus on four types of supply: the national grid, village-level biomass-based microgrids, village-level micro-hydro-based microgrids, and stand-alone solar home systems (SHSs). Technical characteristics of different types of systems can influence the services offered, which are not homogenous under a single definition of "electricity access."

The study has three components:

1. We assess and characterize actual service conditions for households across the three systems, including service availability and cost of service.
2. We quantify and compare the following benefits of electricity access to households: appliance ownership, income, children's education, health (reduced kerosene-related injuries), and women's use of time.
3. We qualitatively assess the impacts of electricity supply on small- and medium-sized enterprises (SMEs), including their choice of location, income, and future plans.

To our knowledge, there are no data available to enable such a comparative analysis, particularly where households with access to the national grid, to off-grid systems, and with no access are located in close proximity. We designed and implemented a survey of households (859 households) and small-businesses (74 SMEs) in order to inform the research objectives.

We conducted the surveys in two districts of Bihar, India, and one district in Nepal, where such co-located systems were known to exist.

In the rest of this section, we describe the state of knowledge and our understanding of the socio-economic benefits of electrification, particularly from off-grid systems. We then explain our objectives in more detail and describe our research design. In Section 2, we establish the real-world context of this study, by introducing microgrids, the market and policy environment for off-grid systems in India and Nepal, and the relevant background of the suppliers that have established microgrids.

While the supply-side issues surrounding viability, competition, and business models, among others, are intimately tied to and influence the attributes of supply and the resulting benefits to customers, a detailed examination of these issues is beyond the scope of this study. The focus is on the perspectives and experiences of customers—of households, in particular and, to a lesser extent, of SMEs.

State of Knowledge and Gaps

More than 600 million people in rural South Asia lack access to electricity. According to the Global Energy Assessment (GEA 2012), investments of over $2.5 billion per year will be needed to provide universal access in South Asia by 2030. Both public- and private-sector investments, as well as national policies and private entrepreneurship, will be required to meet this goal. In order to make effective investments, however, we need to better understand peoples' needs, and better exploit the range of benefits that different energy systems provide.

Robust studies, data, or ground-level assessments that quantify the types of benefits that accrue from clean energy enterprises are growing (Rao 2013; Khandker et al. 2012). Recently, an increasing number of assessments have been conducted of minigrids and microgrids (Frearson and Tuckwell 2013; Schnitzer et al. 2014; Yadoo and Cruickshank 2012), and of SHSs (Samad et al. 2014). Qualitative studies of the benefits of electrification from small-scale enterprises are also numerous. However, grid, microgrid, and SHSs offer different benefits, and these differences have been insufficiently researched. Systematic quantifications of the benefits of microgrids are few, and comparative studies of different systems are non-existent. Even with regard to known benefits such as income growth, causal pathways and other enabling conditions that link the provision of energy access to these benefits are not well understood.

We have identified three types of gaps in the literature on impacts of energy access:

- Impact studies involving privately owned distributed generation systems
- Quantitative impact studies, and
- Impact studies that take into account levels of service

This report begins to bridge these gaps. Studies that are focused on distributed generation tend to explore the status of microgrids from the perspective of the enabling environment—identifying the barriers to successful operation and scale-up (e.g. Prayas 2012; ADB 2013; Schnitzer et al. 2014; Bhattacharyya and Palit 2014). On the other hand, literature studying the impact of electrification tends not to differentiate between grid and decentralized power. Recent inquiries into the level of access needed to enable poverty reduction do not pay particular attention to the access levels provided by mini- or microgrids versus grid power in rural areas (e.g., Pueyo and Hanna 2015). Where quantitative studies do exist, most are not focused on private energy enterprises. Finally, most studies treat access to power as a binary variable, without accounting for the reliability or quality of supply, or customer service. Nevertheless, as we will show below, this binary approach is starting to be eclipsed.

Multi-dimensional metrics to represent energy access

The development of multi-dimensional metrics to represent energy poverty has gained traction. Practical Action's Poor People's Energy Outlook (2014) proposes an "Energy Supply Index" to categorize quality of energy access, based on tiers of end-use (Figure 1). The World Bank's Global Tracking Framework (GTF), which has been adopted by the UN Sustainable Energy for All (SE4All) program, also uses the concept of tiers to define access in terms of seven service characteristics (Bhatia and Angelou 2015). However, while both studies aim to capture the advantages of energy access for households in terms of end-use needs (lighting, cooking, space heating, Information and Communications Technology (ICT)), livelihood generation (agriculture, Micro, Small and Medium enterprises (MSME), energy entrepreneurs), and community (healthcare, education, institutions, infrastructure), the suitability of these metrics has only begun to be tested (Groh et al. 2016). The data collected in this study verify the heterogeneity of access characteristics across the different types of supply systems, and can thus inform the development of some of these metrics.

Figure 1a | **GTF Multi-Tier Matrix for Access to Household Electricity Supply**

			TIER-0	TIER-1	TIER-2	TIER-3	TIER-4	TIER-5
ATTRIBUTES	1. Peak capacity	Power		V. Low Power Min 5 W	Low Power Min 70 W	Medium Power Min 200 W	High Power Min 800 W	V. High Power Min 2 kW
		Daily capacity		Min 20 Wh	Min 270 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
	2. Duration	Hours per day		Min 4 hrs		Min 8 hrs	Min 16 hrs	Min 23 hrs
		Hours per evening		Min 2 hrs		Min 2 hrs	Min 4 hrs	Min 4 hrs
	3. Reliability					Max 3 disruptions per day	Max 7 disruptions per week	Max 3 disruptions per week of total duration < 2 hours
	4. Quality					Voltage problems do not prevent the use of desired appliances		
	5. Affordability					Cost of a standard consumption package of 365 kWh per annum is less than 5% of household income		
	6. Legality					Bill is paid to the utility / pre-paid card seller / authorized representative		
	7. Health and Safety					Absence of past accidents and perception of high risk in the future		

Note: The tier structure has undergone many subsequent changes. See Groh et al. (2016).
Source: Bhatia and Angelou (2015) Global Tracking Framework report.

Figure 1b | **GTF Multi-Tier Matrix for Access to Household Electricity Services**

		TIER-0	TIER-1	TIER-2	TIER-3	TIER-4	TIER-5
	Tier Criteria	-	Task Lighting AND Phone Charging	General Lighting AND Television AND Fan (if needed)	Tier-2 AND Any Medium-Power Appliances	Tier-3 AND Any High-Power Appliances	Tier-2 AND Any Very High-Power Appliances

Source: Bhatia and Angelou (2015) Global Tracking Framework report.

Broader understanding of electrification benefits

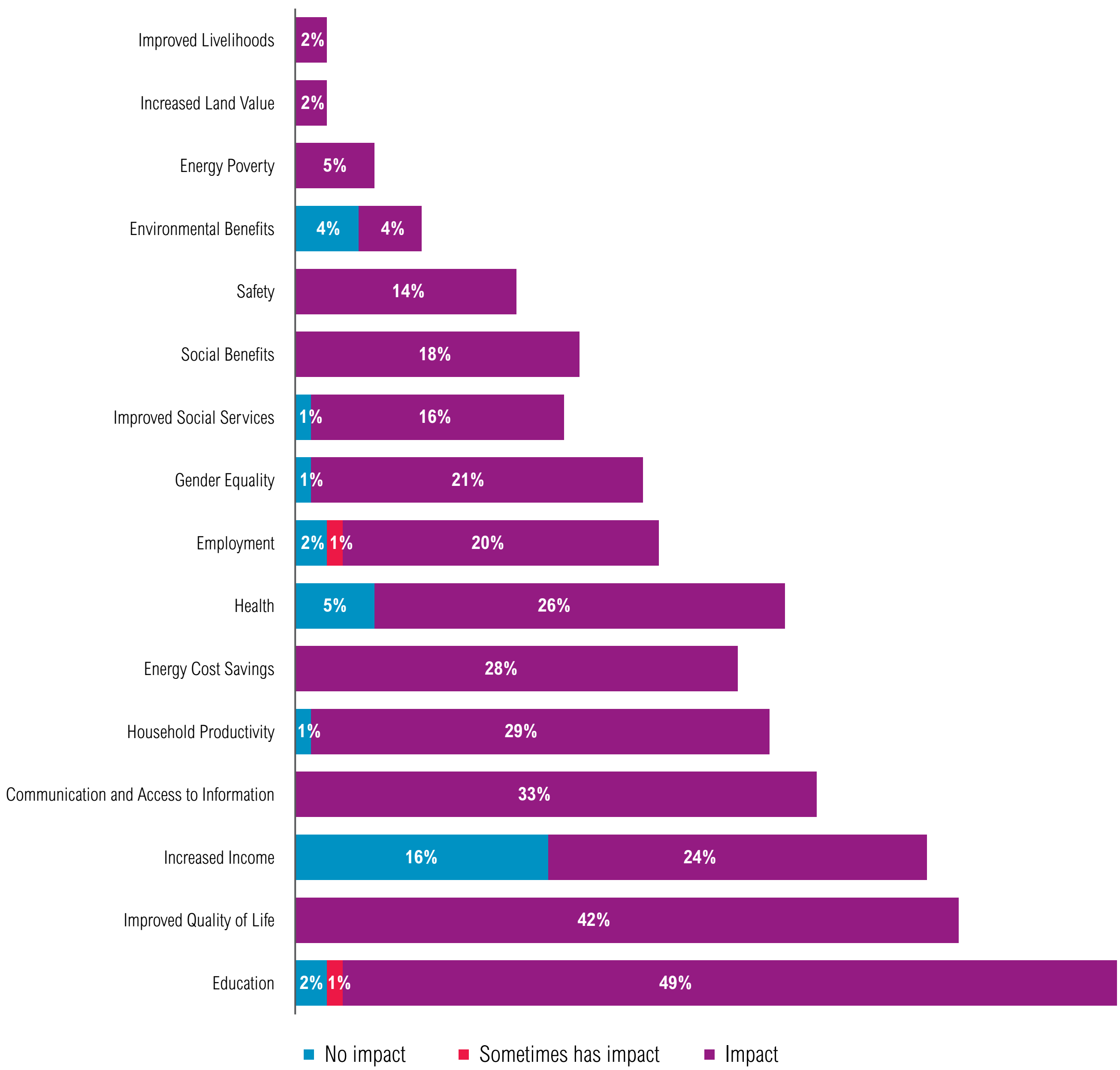
The shift toward understanding the impact of access to energy through a non-binary, multi-tiered lens can also be seen in the literature. Two comprehensive reviews by Pueyo et al. (2013) and Pueyo and Hanna (2015), conducted only two years apart by the same author and institution, demonstrate the shift in how energy access is defined and impacts are evaluated. In 2013, Pueyo et al.'s approach to reviewing studies of the impact of access to electricity did not distinguish between studies that were binary in their approach to energy access and those that captured more specific attributes of energy access. In 2015, the review deliberately organized studies with respect to the attention given to the multi-dimensionality of energy access. This more nuanced approach enabled the authors to make sense of what had previously appeared to be contradictory findings reported in the literature, and to be more specific about the levels of energy access that can lead to improved livelihoods and poverty reduction.

In this section, we review the main findings of the literature reviewed by Pueyo et al. (2013), the emerging evidence pointing to the need for increased attention to the attributes of energy access, and the findings of this more nuanced approach to reviewing the evidence for the impact of energy access on poverty reduction.

The literature review conducted in Pueyo et al. (2013) analyzed the evidence, more qualitative than quantitative, on the income, education, and gender benefits of electricity access. Non-income related impacts are the most widely reported for households. Improvements in education are the most widely and consistently reported, as measured by years of schooling completed, study time, and school enrolment (see Figure 2).

The literature is inconclusive as to whether electricity has a positive effect on income generation for households and SMEs. Longer hours of business operation cannot be linked to increased revenues. Similarly, evidence of impacts on employment, wages, and creation of enterprises is mixed. The most strongly reported impact with respect to potential poverty reduction is a shift in time use, especially for women. Women in households with electricity lead a life more balanced

Figure 2 | **Impacts of Electricity Consumption for Households Reported in the Literature**



Source: Adapted from Pueyo et al. (2013).

between work and leisure. They spend less time collecting fuels, fetching water, and cooking, and more time on earning an income, reading, and watching television. However, the jobs that are created are generally unskilled, obtained through self-employment rather than formal employment, and are of a precarious nature with limited potential to generate income for the community as a whole. In general, non-income benefits for households are more strongly reported in the literature than income-related outcomes. For businesses, the literature review found indications that sufficient and reliable service is necessary to improve performance—more important even than the price of electricity (Pueyo et al. 2013).

Quality of supply, however, is rarely measured or described in impact studies (Attigah and Meyer-Tasch 2013; Karekezi et al. 2012). It is, therefore, not surprising that the literature on productive uses is highly country- and context-specific, and therefore inconclusive. There is growing recognition that studies that treat electricity access as binary are not sufficiently nuanced to capture the ways in which different levels of access can enable different uses and hence achieve different poverty impacts. Although some binary studies do recognize the role of the quality of electricity supply, they discuss this in general terms without quantifying the actual impacts.

In the review by Pueyo and Hanna (2015), the authors are able to disaggregate the development impacts reported at different levels of access and map them on to the tiers of energy access defined by the multi-tier framework. Most papers reviewed refer to electricity access levels equivalent to Tier 2. With respect to household income generation, the higher quality papers—those that take into account confounding variables and provide statistical analysis—conclude that impacts on household income were minimal or non-existent. Lack of impact is attributed to low electricity consumption levels, equipment malfunction, and lack of productive uses for electricity. With regard to the impact of electricity on business income, the studies referring to Tier 2 show an increasing variety of electric equipment used by SMEs, but only those SMEs indicating Tier 3 or higher report higher revenues, better product/service quality, increased production, and higher productivity.

The studies that explicitly quantify different levels of access to electricity show that increased service reliability encourages households to consume more electricity and to engage in non-farm enterprises (NFE). Increasing availability at the village level by an average of one hour per day increases the rate of household adoption of electricity by 2.7 percent and consumption by 14.4 percent (Khandker et al. 2012). Households in villages that never suffer blackouts have an average of 1.3 more NFEs, and their share of rural income from NFEs is 27 percent higher (Gibson and Olivia 2008). Rao (2013) suggests that better supply is associated with higher incomes of household-based NFEs, with gains observed predominantly at availability up to 16 hours of supply per day and to a lesser extent at higher levels. Increasing load capacity or investments in infrastructure is found to have a positive relationship with poverty reduction (Cook et al. 2005; Yang 2004).

Despite increased attention to reliability and quality of supply, very little of this evidence sheds light on the particularities of service from microgrids. Rao (2013) quantifies the impact of variable quality of service on household enterprises. However, the study is limited to grid-connected service, and addresses only income benefits. The compilation of case studies by Yadoo and Cruickshank (2012) is one of the few studies to focus on the impacts of microgrid projects undertaken by clean energy entrepreneurs, with some comparisons made to grid supply. Still, very little is known about the comparative impact of grid connection, particularly where power outages are chronic, and where alternative systems, such as microgrids, have sprung up to compensate for inadequate supply.

SECTION II

RESEARCH DESIGN AND APPROACH

We select three sites in Bihar, India, and Nepal, which have in close proximity villages without electricity, those served by different types of off-grid systems, and those served by the national grid. We collect data through a household survey and interviews with small-business owners. Using quantitative techniques to control for confounding factors, we compare electricity service benefits related to income, women's time use, kerosene use, and perceptions of education across households. We qualitatively assess the influence of electricity access on key decisions of small businesses.

In this section, we describe the research objectives introduced in Section 1.1 in more detail, and introduce our research approach for each component.

As mentioned, our goal is to quantify the socioeconomic benefits to households of electricity service from off-grid systems (microgrid and SHS) in comparison to those from the grid, and qualitatively assess the same benefits from the perspective of SMEs. First, however, we analyze the service conditions under each system, in keeping with our belief that the implicit assumption that the provision of electricity access confers homogenous benefits has been shown to be largely false.

Electricity Service Attributes

The two matrices of multi-tier metrics developed by Practical Action and the World Bank (Figures 1a and 1b) aim to capture the multi-dimensionality of energy access. These dimensions include reliability, affordability, quality, voltage, and support for productive power (power that enables economic production), among others.

Our focus in the household survey is on two attributes: reliability (which includes availability) and cost of service. The rationale is that these two factors critically affect household benefits, and are possible to characterize from survey responses (unlike voltage, for example). We indirectly address productive power based on triangulation from a number of sources, including interviews with SMEs, microgrid owners, and households.

The World Bank's framework includes connected load as one of the multi-tier attributes. We do quantify appliance ownership, but view it as a service benefit (see below), rather than an attribute of supply, since it also depends on household attributes, such as income, education, and other factors that influence purchase decisions (Groh et al. 2016).

Service availability

We ask respondents to recall the average hours of supply per day in the last 30 days. While respondents' recall is subject to measurement error, we learned beforehand that outages followed certain patterns, which were relatively consistent and well-known in villages. Furthermore, this type of survey question has been asked before on a national scale in the India Human Development Survey, 2004-05.

Cost of service

There is no single appropriate measure of cost of service, for purposes of comparison across a diversity of households. In the literature, electricity is treated largely as a commodity. The (often implicit) purpose of comparing rates is to assess the cost with respect to a common benefit, which is assumed to be the commodity itself. However, this benefit is not directly equivalent to electricity service, because electricity powers a number of different end uses, such as lighting, refrigeration, and others. Costs of service may be compared on an absolute monthly expenditure basis, per-unit rate basis, or as a share of income or household

expenditures. A comparison across income groups of absolute monthly costs would mask the relative burden (of affordability), and mask differences in costs of service for different amounts of usage (actual benefit). A per-unit rate may overstate the difference in burden for households with very low, but different levels of, usage. An expenditure share masks actual usage and per-benefit costs.

Therefore, we measure and present all three cost measures: per month, per unit, and expenditure share, for all systems. For completeness, we also discuss connection costs/fees for grid and microgrid customers. We don't present these alongside costs of SHSs because SHSs present altogether different challenges for comparisons. Because operational costs are negligible, and costs are "lumpy" (upfront plus battery replacements), one has to know the life of the components. However, this is almost impossible to gauge, given that most installations are very recent. We therefore separately discuss SHSs and their varying costs.

Socio-economic Benefits of Electricity Access

The study examines five types of household impacts: appliance ownership, income, women's use of time, children's education, and health impacts (in terms of kerosene avoidance). Aside from the first benefit, all others have to be measured against a "counterfactual," or household conditions without access. Because we did not have the opportunity in this study to examine households before and after they obtained electricity, we instead compared them to households without electricity access. Below, we first describe how we interpret and measure each benefit, and then describe the common analytical approach for the comparative assessment.

Appliance ownership

Appliance ownership can be influenced by service conditions, such as physical restrictions on connected load (that prohibit certain appliances from being connected), the availability of service (that can constrain the use of appliances), and cost (that can make operation of appliances unaffordable). As noted, the World Bank's Global Tracking Framework includes connected load as one measure of the multi-tier access measurement metric. We survey and count the number of appliances owned by households and relate them to the type of system and related characteristics, both descriptively and quantitatively, using regression analysis (see Technical Appendix for details).

Income

Income benefits can manifest through many channels. Electricity can provide direct income benefits to households by enabling productivity gains in mechanical tasks and providing opportunities for expanding or setting up new businesses. For instance, lighting allows longer working hours. Or mechanical power can allow households to sell the

service of grinding flour. We measure the benefit simply as the total income earned by households, and reported in the survey.

Women's use of time

We survey women's time spent on daily activities, including daily chores and leisure, and compare the data from electrified and unelectrified households. Having access to electricity and consequently to mechanical power may reduce the time that women spend on chores, which would give them the option of engaging in leisure, remunerative, and educational activities.

Health impacts of kerosene

Kerosene use can cause adverse health effects resulting from the emissions that accompany combustion, or injuries sustained in accidents. Our focus is on the latter. Long-term health effects are relatively well understood, and in any case long-term use is difficult to capture in a one-time survey. We ask households about their kerosene consumption, and kerosene-related injuries and associated costs.

Children's education

Studies that find measurable benefits of electricity to children's education usually examine proxies, such as study time or school attendance, because it is difficult to relate school performance to electricity. However, information on both study time and attendance is more appropriately obtained from direct observation than from a survey, because survey respondents typically aren't children. Respondents may not be aware of children's activities, particularly while children are away from home. So, instead, we add to this literature by assessing the perception that survey respondents have of educational benefits, which is a reflection in part of the quality of supply, and their observation of children's behavior.

Analytical approach to benefits estimation

Our approach is comparative. Rather than determine the causal effect of electricity access on the outcome variables, we want to learn whether there is a statistically significant difference in the observed outcome variables across different "treatment" groups (electricity supply from the grid, microgrids, and SHSs) in comparison to the "control" group (households without electricity). This would suggest a causal effect, but not establish it.[1] In order to make a fair comparison among these groups, we need to compare "apples to apples," and not include income differences that may result from other influential attributes that differ across groups. We first tested whether there were statistically significant differences in the benefit outcomes among the groups. If there were, we used a technique called Propensity Score Matching (PSM) to refine this comparison. PSM selects for comparison only those observations that have a "common support" of characteristics among compared households (see Rao 2013). The common support set of variables includes: assets, education level of the head of household, distance from paved roads, distance from a water source, and the size of household. (See Technical Appendix for more details.)

Qualitative Impact Analysis of Small-Scale Enterprises

The economic impact of electricity on livelihoods is best captured in the proliferation and income of small- and medium-sized business enterprises (SMEs). Newly electrified regions enable new business startups and can also attract migrants who run businesses. Further, existing businesses relying on mechanical power, for example, agro-processing, can improve their productivity and expand their output through mechanization.

However, isolating and quantifying the benefits of electricity for SMEs is challenging in a cross-sectional study of this kind, where inferences have to be drawn from differences among businesses, rather than from observations of individual businesses over time (i.e., a longitudinal study). This study does not have such a scope.

Instead, we interview a number of SMEs to gain qualitative insights into the role played by electricity in their business decisions and income levels. As with the household analysis, the insights here are intended to be suggestive of electricity's impact, not conclusive. We pose a specific set of questions to all interviewees related to:

- their choice of location, whether they are migrants, and the role of electricity in their choice;
- their dependence on electricity for their revenues; and
- the key opportunities and challenges they have faced with their particular conditions of electricity supply.

As with the household surveys, we also ask questions about the preference for electricity supply, if relevant.

Site Selection and Sampling

We selected three districts for the surveys, two in Bihar (Araria and West Champaran), India, and one in Nepal (Kavre and part of Sindhuli). The rationale for their selection and the sampling procedure are presented in the Technical Appendix. The survey questionnaire can be found at http://www.wri.org/publication/small-scale-electricity-systems. We surveyed 859 households and 74 SMEs. The breakdown of the number of households and SMEs surveyed at each site is shown in Tables 1 and 2.

Table 1 | **Breakdown of Household Survey Sample**

LOCATION	NO ELECTRICITY	GRID CONNECTION	OFF-GRID SYSTEMS			
			BIOMASS/ DIESEL	MICRO-HYDRO	SHS	TOTAL
Nepal	14	81	-	90	53	238
West Champaran	77	99	94	-	45	315
Araria	134	95	77*	-	-	306
Total	**220**	**280**	**171**	**90**	**98**	**859**

Note: *Sample includes 60 households that used to have a microgrid connection, but at the time of the survey either had none, or had grid access.

Table 2 | **Small- and Medium-Sized Enterprises (SMEs): Sample Distribution by Type**

LOCATION	TOTAL	RETAIL	MECHANICAL	ELECTRICAL	SERVICE	OTHERS
Nepal	42	12	10	3	7	10
Bihar	34	18	1	6	5	4

SECTION III

OPERATING CONTEXT FOR OFF-GRID SYSTEMS

Both India and Nepal have promoted stand-alone, off-grid systems. Technical characteristics of different systems significantly influence hours of supply, rates, and supported uses. Solar home systems have proliferated with and without government support. In many regions, different types of off-grid systems compete with each other and the national grid.

Introduction to Microgrids

Microgrids can be thought of as a subset of a broader universe of small power producers that may be defined as independently operated electricity providers selling electricity to retail customers, or to the national utility operating the main grid, or to both.[2]

While there is no universally accepted definition that distinguishes microgrids from minigrids, the term microgrid typically refers to systems of a smaller scale. For example, the European Union Energy Initiative defines minigrids as small-scale electricity generation from 10 kW to 10 MW, and microgrids as 1 kW to 10 kW systems, while SE4All's High Impact Opportunity seeks an inclusive definition, which simply differentiates the minigrid sector from stand-alone household systems and grid-extension approaches.

For the purposes of this study, we define microgrids as off-grid networks between 1 kW and 100 kW that serve retail customers using any technology, including biomass, diesel, or hydro. The type of technology can have a significant influence on the characteristics of microgrids and the services they provide, which we explore below.

Market and Policy Environment

The market for off-grid systems in South Asia

Off-grid systems (using various technologies to provide power) are being deployed by companies and communities across South Asia, the Philippines, and Africa. The IFMR Power to the People report (Bairiganjan et al. 2010) assessed the off-grid market (referred to as Distributed Renewable Energy (DRE) systems) at about US$2 billion and the SHS market at about US$27 million annually, for India alone. The recently released IFC report From Gap to Opportunity (IFC 2012) has also noted the increase in the market for community minigrids, along with household-level devices for extending energy access.

In India, the Ministry of New and Renewable Energy (MNRE) (as of November 2015) reports about 18 MW of rural biomass gasifiers and 17 MW of micro-hydro. In addition to microgrids, almost 280 MW of solar photovoltaic (PV) has been installed.[3] Notably, grid-connected systems for biomass, hydro, and solar in India each total more than 4 GW. In Nepal, there are three million off-grid systems, including solar home systems (SHSs), almost entirely in rural areas, which serve 9 percent of rural households. In total, about 19 MW of micro-hydro (~1,000 systems of 5–100 kW) and 4 MW of micro-hydro (~1,500 systems of <5 kW) capacity, and 12 MW of solar PV schemes have been installed in Nepal (Sarangi et al. 2014). Ninety-five percent of the micro-hydro projects are community-run.

Both India and Nepal have promoted stand-alone, off-grid systems as part of their respective national rural electrification policies. However, the regulatory environment for off-grid systems differs considerably in the two countries, which has influenced the types and ownership of systems that have proliferated.

Off-grid policy environment in India

India has the largest number of poor and energy-poor people of any country in the world. According to the World Bank, over 700 million people earn less than $PPP 2 per day, and over 300 million still lack electricity access. The government claims to have extended electricity to more than 95 percent of villages,[4] indicating that a significant "last mile" gap exists in electrification. The Electricity Act of 2003 encouraged the entry of the private sector into rural electrification.[5] It stipulates that certain rural areas, as determined by the State Governments, may be exempt from licensing and regulation, though they have to meet basic safety standards. The Rural Electrification Policy of 2006 explicitly encourages the establishment of stand-alone systems below 1 MW, particularly those that utilize local resources such as biomass. These projects obtain automatic permits for land use, pollution, and a number of other requirements, including "self-certification" for safety standards.[6]

At the same time, the Rural Electrification Policy reinforces the "Universal Service Obligation" on grid distribution licensees within their service jurisdictions, within which these notified areas fall. It is no surprise that there are areas—including parts of the sites of this study—where the grid has been extended into villages where private entrepreneurs operate minigrids, or where SHSs are common. For instance, Desi Power in Baharbari lost many customers to the grid, many of whom came back because of grid unreliability.[7]

The Ministry for New and Renewable Energy (MNRE) provides limited financial support for off-grid systems.[8] Suppliers of biogasification-based electrification projects, in particular, get INR 15,000 per kW ($PPP 750), which amounts to 10–15 percent of project costs.[9] Households that purchase and finance SHSs through NABARD (National Bank for Agriculture and Rural Development), get a capital subsidy of up to 40 percent.[10]

Certain state laws and policies are applicable to the state of Bihar specifically. The Bihar Standards for Performance of Distribution Licensee, 2007 exempt stand-alone systems, non-conventional energy systems, and local distribution systems in rural areas from licensing regulations, in accordance with the provisions of the Electricity Act, 2003. Equipment for new and renewable energy sources is exempt from entry tax, and electricity generated from new and renewable sources is exempt from electricity duty. Furthermore, in Bihar, the government offers Below Poverty Line customers a full capital subsidy for connection fees.[11] Assistance is also provided to obtain clearances for land use, water allotment, etc., for electricity generation through renewable sources.

In those regions without licensing requirements, the free market has reigned. In the districts visited in this study, a multitude of systems was found in single villages, including SHSs, multiple microgrids, including diesel- and biomass-based, and (in one case) the grid as well. This type of unregulated competition increases the business risk faced by private entrepreneurs.[12] Of more pertinence to this study, the absence of regulations has resulted in a diversity of electricity service conditions, price structures and levels, and customer responsiveness on the part of suppliers.

Off-grid policy environment in Nepal

Nepal is a poverty-stricken country, with a Human Development Index of 0.46; one-quarter of its 30 million inhabitants were without electricity in 2011 (IEA 2012). Some 10 million people live in remote regions—defined as more than five days' walk to a road (in 2006)—which will not be reached by the national grid for decades, if ever (Zahnd and Kimber 2009). It is no surprise that Nepal has a long history of supporting off-grid energy systems. As of 2013, about a quarter of the 60 percent of rural households with electricity were served by off-grid systems (Bhattarai and Willcox 2015).

The government has given particular emphasis to micro-hydro systems, due to the high availability of water sources in the regions inhabited by mountain communities in the lower highlands of Nepal. The development of alternative energy systems such as micro-hydro in Nepal can be traced to the 1970s (Sarangi et al. 2014). Prior to 2000, donor agencies funded the bulk of micro-hydro projects. Since 2001, the government's hydropower policy has permitted the private sector to generate and distribute power through micro-hydro projects up to 100 kW in capacity. The UNDP's Rural Energy Development Programme (REDP), launched in 1996, combines support for micro-hydro and social mobilization in rural communities. Subsequently, through various initiatives such as the Water Resources Strategy of 2002, the government also actively encouraged communities to establish and operate micro-hydro systems.[13] Through the Alternative Energy Promotion Centre (AEPC),[14] the government provides subsidies, technical assistance, tariff recommendations, and quality assurance to ensure the success of micro-hydro systems. In terms of finance, the government typically provides 40 percent of the capital outlay for a community-run micro-hydro project, and another 40 percent is raised through soft loans from financial institutions. The Village Development Committees put up 20 percent equity obtained from customers through fees and in-kind contributions (e.g., labor).[15] Government support for off-grid systems in Nepal extends to SHSs as well. SHS owners receive subsidies of up to INR 6300 ($PPP 315), depending on size and technical assistance (Government of Nepal 2013).

Overall, government support for off-grid systems in Nepal is significantly greater than in Bihar, India. This support, akin almost to regulation, results in more regularized conditions of operation (from the providers' perspective) and service (from consumers' perspective) in Nepal.

Supplier Context

In this section, we provide some background on microgrid suppliers, their history, the evolving marketplace, and other related factors that influence the prevailing supply conditions. We also briefly describe the market for SHSs in South Asia. In India, microgrids are operated by Desi Power and Husk Power, while the Nepali microgrids are community-run. The description that follows is based on published materials; interviews with the CEO of Desi Power, Dr. Hari Sharan; interviews with representatives of the NGO REMREC in Nepal; site visits; and information obtained from company websites. Corporate representatives from Husk Power could not be reached.

Biomass-based microgrids in Araria District, Bihar, India (Desi Power)

Desi Power is the oldest microgrid electricity supplier in India. The company now has about 343 kW of total system capacity serving 14 villages in Araria, Bihar. It was established in this district in the 1990s, where the founder, Dr. Hari Sharan, has his roots. Indeed, the choice of location was driven in part by his familiarity with the location, people, and

conditions.[16] In addition to commercial aims, Desi Power was committed to promoting rural development through the establishment of biomass-based power production, which would provide employment in the development of feedstock, operation of the power plant, and the provision of electrically pumped groundwater for agriculture as its main commercial product.

For the purposes of this study, the salient feature of this company's approach to microgrid-based electrification is that commercial use of electricity, particularly for pumping water, was the primary motivation and the necessary revenue stream to justify establishment. Desi Power extracted and sold groundwater, using electricity generated by its facilities. Water sales still comprise an important revenue contributor, along with sales to agro-processing industries in village markets. Without these commercial customers, the supplier could not achieve the minimum load factor of 60–65 percent that enables profitable operation of its biogasification-based power plant.

Desi Power introduced household electricity supply in Baharbari only after 2007, with a financial contribution from the International Copper Association that covered all (copper-based) grid extension costs. Initially, the microgrid extension to households was established solely to provide lighting. Households were provided with a lighting connection for a fixed monthly fee. The national grid was subsequently extended to Baharbari, leading many customers to switch over to grid supply and purchase many appliances. However, due to poor reliability of the national grid, some consumers switched back to Desi Power. To power other appliances, such as additional lights, fans, radios, and televisions, people began to steal electricity or violate their connection restrictions. Desi Power decided to change its model to allow multiple appliances, and started charging a monthly tariff on a "per-watt" basis. More recently, Desi Power has selectively introduced a smart metering system in villages where the company has expanded service (outside the geographical scope of this study).

Originally, two biomass systems, of 11 kW and 50 kW, served Baharbari. In 2014, Desi Power ended its operation of the 50 kW system and introduced solar PV and battery banks to supply some households. This switch was motivated by the inability to sustain the high load factor (65%) needed to make the biomass system viable.

Desi Power has made use of the MNRE subsidy for biogasification technology (see Section *Off-grid policy environment in India*) for a few of its systems. However, of greater importance to the long-term viability of the microgrid business has been the low number of credit-worthy commercial customers who can finance the equipment that would run on electricity. Notably, according to the Desi Power CEO, it is not the financing of the electricity connection fee itself, which is typically only a few hundred rupees (according to the household survey), but the

cost of electro-mechanical equipment (higher by several orders of magnitude) that inhibits commercial entrepreneurship, and in turn limits the exploitation of electricity for livelihood development.

Biomass-based microgrids in West Champaran, Bihar (Husk Power)

Like Desi Power, Husk Power was set up in West Champaran because of the connections of its founders to the region, and with the intent to support rural development. According to the company's website, it has 84 plants serving over 200,000 households in 300 villages across Bihar. Unlike Desi Power systems, Husk Power does not provide its own feedstock, choosing instead to purchase rice husk from rice mills in Bihar. According to some local employees in West Champaran, the supply of husk has never been a problem, though the commercial price has increased steadily over the years. Like Desi Power, in at least one site, Husk Power replaced its biogasifier with solar PV supply. As mentioned, due to our inability to contact and interview Husk Power representatives, we do not have additional insights on the supply side of operations to inform this study. Further historical information on Husk Power can be found in other publications (IFMR 2010).

Hybrid/competing microgrid penetration

Solar PV/battery systems have replaced biogasifiers as the microgrid supply source in a number of villages. This is likely driven by the need for biogasifiers to maintain a 60–65 percent load factor if they are to remain profitable. It is interesting that both Desi Power and Husk Power replaced the biomass supply source with solar PV/battery banks in low load-factor conditions. However, it is too early to determine whether this shift has proven commercially viable.

In some villages in both districts in Bihar, diesel-based microgrids were found to be operating, sometimes in competition with larger microgrids. For example, in the village of Gayari, where Desi Power serves commercial but not residential customers, we surveyed 60 households that were served by local diesel-based microgrids. In one of the sites supplied by Husk Power, we found that its PV microgrid was competing with a diesel-based microgrid in the same market place.

It may have been the case, therefore, that households selected in the random sampling process received power from either a PV or a diesel-based microgrid. While the survey questions cannot reveal the technology supplying the microgrid, they do differentiate grid service from microgrid service. The latter differentiation is critical for this study, while the technology isn't a particular focus. Undoubtedly, however, the technology has an influence on service conditions, as this section aims to reveal. This study is therefore somewhat restricted in its attribution of findings to biomass-based microgrids, due to these confounding cases.

Micro-hydro systems in Kavre, Nepal

The Nepali case stands apart from the Indian cases in many ways: microgrids are powered by a different technology (hydro), with lower operating costs than biogasification (but not as low as SHSs); microgrids are typically community-owned and operated; and they have been promoted with the highest subsidy (as a share of total costs) among the three cases, from both government and international donors.

Micro-hydro plants have been a critical element of the Nepali government's efforts to electrify Nepal, because the remoteness of many mountain villages has meant that extending the national electric grid is often not an option. With strong government support for establishing these plants and the (conventionally) free and year-round nature of the resource, the constraints on supply imposed by profitability that are faced by private owners of biomass-based microgrids typically do not apply in Nepal. Furthermore, due in part to the distance from roads and markets, in many villages commercial activities are restricted to a flour mill and a few retail shops.

Micro-hydro units in Nepal appear to face the obverse of the challenge faced by microgrid operators in India, who rely on daytime commercial sales for their commercial viability. Without the need to recover capital costs from sales, Nepali micro-hydro plants often have idle capacity. This situation was encountered during field interviews conducted for this project, and echoed by AEPC. Even in villages with access to markets and willing commercial customers, micro-hydro plant owners are often unwilling to sell power during the day. Though only anecdotal, field interviews suggest that, in some locations, villagers fear that such commercial sales/

use would “over-use” the generator equipment, thereby reducing its lifetime and its long-term benefit to households. This study did not have the scope to systematically explore this issue.

The specific size of the micro-hydro systems deployed in the villages that were surveyed is not known. However, most systems are likely in the range of 12 kW—35 kW.

Solar home systems (India and Nepal)

The households with SHSs surveyed for this study were selected through random sampling.[17] As a result, the survey was not designed to capture details of the solar home system, other than what was reported in the open-ended questions on general electricity supply issues. Although some of these answers provided insights that are shared in subsequent sections, the data that were revealed in these questions on SHSs must be considered anecdotal, rather than representative of the region.

Our survey discovered 98 households with SHSs (45 in India and 53 in Nepal), representing more than 10 percent of our sample. This high number is indicative of the wide proliferation of SHSs. In Nepal, all SHSs were found in villages that either had no electricity, or had only SHSs. However, in India, SHS-owning households were found in villages that were also supplied by microgrids and the grid. In India, therefore, one can assume that SHSs were selected from among multiple options, whereas, in Nepal, they may have been households’ only option for electrification. In both countries, most SHSs were 20 W–160 W systems.

While we were not able to capture systematically the reliance on government subsidies to purchase SHSs, in several cases systems were purchased directly from the market. Interviews with electronics store owners who sold such systems in both Nepal and India indicate that the “package” of a Chinese-manufactured solar panel (usually 20 W) with a battery (the size of a car battery) was a common purchase, both among small businesses and households. The implications of this market trend are potentially far-reaching and worthy of further investigation.

Summary

The main insights from the supplier context are the following:

- In the case of privately run biomass-based microgrids, household electricity supply is an “ancillary” service; alone, this service is not a viable basis for microgrid establishment. Households are therefore a lower priority than commercial customers. By contrast, in the case of micro-hydro plants in Nepal, households dominate use of microgrid power production.

- In all supply systems (as is fairly commonplace in rural areas generally) (Tenenbaum et al. 2014: 232), households benefit from electricity primarily in the evenings, whereas commercial customers, if any, utilize the grid during the day.

- Financial barriers to electrification apply beyond the electricity connection itself, and relate also to the capital cost of end-use equipment that would mechanize small-scale businesses. These capital costs can restrict the potential commercial customer base for off-grid systems, and consequently their viability.

SECTION IV

ANALYSIS AND RESULTS

Electricity is typically used for basic services such as lighting and phone charging, and less frequently for fans, televisions, and refrigeration. Supply availability varies widely, more across villages and types of systems but also within them. Costs of service differ widely, partly due to rate structures, metering, and typical uses. Electricity access, in general, leads to reduction in kerosene use, more time spent by women on income-generating activities, and the acquisition of home appliances. Electricity access benefits small businesses, but seldom drives key business decisions.

Heterogeneity of Service Characteristics Among Different Electricity Supply Systems

We find that the nature of service provided by different electricity supply systems varies widely, in terms of both availability and cost.

Availability

Table 3 shows respondents' estimates of the daily supply availability during the previous 30 days.[18] We exclude SHSs, since they are stand-alone systems with storage.[19] A few observations stand out. All the differences noted are statistically significant at the 95 percent confidence level.

- *Average grid supply availability is higher than that for the microgrids in the same region.* The difference is 18 hours/day versus 15 hours/day between grid and micro-hydro systems in Nepal, and 4-6 hours/day versus 3-4 hours/day between the grid and biomass-based microgrids in Bihar.

- *Supply is erratic, but the variation differs by system.* Micro-hydro supply in Nepal is more erratic (as reflected in the standard deviation of average supply) than grid supply. The biomass-based microgrids in India have lower average availability but are less erratic than grid power.[20] The heterogeneity in grid supply availability in India, however, is higher among villages than within them. The mean grid supply by village ranges from 1.5–8.5 hours/day.

- *Among the microgrids, daily power availability from micro-hydro plants in Nepal is significantly higher (15 hours/day) than that from biomass-based microgrids in India (3-4 hours/day) and the variation in supply seems lower as well.* Since both systems are dispatchable and, as far as we were able to determine, unencumbered by supply shortages, this could reflect suppliers' choice of operation, rather than a resource limitation.[21] As discussed earlier, in both the Indian cases household supply was set up for lighting and evening supply only.

- *Grid supply in Nepal has significantly higher availability than grid supply in Bihar.* However, this could be a function of conditions in the survey locations at the time the survey was conducted. Chronic outages are a phenomenon in Nepal as well as in India.

Key Findings

- Supply availability varies widely, both within and among different types of systems, including grid and microgrid systems.

- Supply is as erratic as it is scarce, particularly in Bihar, from both biomass-based microgrid systems and the national grid.

Table 3 | **Household Estimates of Daily Power Availability (Hours/Day)**

MEAN (STD DEV)	GRID	BIOMASS-BASED MICROGRID	MICRO-HYDRO-BASED MICROGRID
Nepal	18 (2)	-	15 (5)
West Bihar	6 (5)	4 (2)	-
East Bihar	4 (4)	3 (2)	-

Note: SHSs excluded due to assumed storage capability.

Cost of service: grids versus microgrids

All microgrid customers and many grid customers in our study are unmetered, and pay fixed rates per month. Rates are often determined by the connected load (e.g., total bulb wattage in the case of households with lighting connections only).

Interviews with microgrid suppliers revealed a recent trend toward metering, in order to reduce the abuse of connection terms, where households connect more appliances over time than originally agreed. The extent of this trend is unclear. No metered households served by microgrids were encountered in our survey, because we deliberately chose villages with old systems, as described earlier in the report.

In addition to a monthly cost, households typically also pay one-time connection fees. These fees are very dependent on individual household locations relative to the closest point of supply. We present them separately, because they are relatively arbitrary and unrelated to household benefits.

The electricity rates in Table 4 show some expected trends, and some surprises. Given that demand is so constrained by supply availability, it is not surprising that monthly expenditures for electricity are relatively comparable across income groups (and therefore that the share of energy in household expenditure decreases sharply with rising income). For the poorest income group in India, however, 7–10 percent of total expenditure is a lot to pay for just lighting and phone charging. This level of share-of-expenditure cost falls in the category of low affordability (>5%) in the World Bank's recent multi-tier energy access indicators. Notably, only one other group—grid customers earning INR 250–500/cap/month (~$PPP 12-25)—fall in the same category. Grid customers incur higher monthly costs than microgrid customers in both India and Nepal, which is likely due to their higher rates of appliance ownership and the fact that grid customers are metered, and therefore pay for their actual usage. Low-usage grid customers could, on the other hand, pay less with metering than with flat rates.

There is an interesting trend in the effective per-unit rates (in terms of per kWh), which were calculated by assuming common usage characteristics of appliances (see Technical Annex, Table A3). These per-unit rates rise with income, but then fall, so that people earning INR 500–1000 per month ($PPP ~0.8-1.6/cap/day, assuming $1 PPP=INR 20) pay the highest rates. This is a function of both progressive rates (which rise with growing connected load) and appliance ownership patterns. Suppliers in the study typically charge higher rates for more connected load, and in the case of grid customers, tariffs are explicitly pegged to usage. However, the highest income groups observed in this sample can afford many more appliances that have higher load factors (e.g., televisions), and therefore get more service for the same cost. In the case of grid customers, the higher income households apparently don't consume enough to fall into a higher rate category, making their average rates lower than that of households with lower incomes/usage.

The (effective) per-unit rates of service in the Indian cases may seem unusually high, particularly microgrid service rates, which are double those of grid service, at between $PPP ~2 and 4.5/kWh. Note that customers have low usage, so this high rate doesn't mirror their absolute burden. These rates are also comparable to the highest minigrid rates observed for diesel-based minigrids in other countries such as Cambodia, of $PPP~3/kWh.[22] Furthermore, these rates may not even reflect real costs of service,[23] and customers apparently have paid (and are therefore willing to pay) higher rates for lower quality alternatives, such as kerosene and diesel gensets.[24]

However, another perspective on fairness would suggest that comparable customers (in terms of usage characteristics) ought to pay the same rate, regardless of where they are located. In this view, the more appropriate comparison is with rural poor in other parts of Bihar. The regulated South Bihar Power Distribution Company Limited (SBPDCL) is supposed to charge unmetered rural customers INR 160 per month, unmetered Below Poverty Line (BPL) customers INR 50 per month (with service restrictions), and all metered residential customers well below INR 3/kWh.[25] From this perspective, the monthly costs of unmetered customers are in line with SBPDCL regulations, though it is unclear whether SBPDCL's customers get more service for the same cost.

Table 4 | **Cost of Service under Grid and Microgrid Systems**

(A) INDIA

PER CAPITA EXPENDITURE	MEAN HOUSEHOLD EXPENDITURE	ELECTRICITY EXPENSES					
		EFFECTIVE PER-UNIT COSTS (INR/KWH)		EXPENDITURE SHARE (%)		HOUSEHOLD MONTHLY COSTS (INR)	
		GRID	MICROGRID	GRID	MICROGRID	GRID	MICROGRID
0-249	*1,858*	20.8	44.0	7	10	146	122
250-499	*3,489*	21.9	56.1	6	4	184	107
500-999	*5,084*	40.5	94.1	5	2	218	111
1,000-1,999	*8,695*	29.3	67.2	3	2	234	136
2,000+	*22,703*	36.6	53.1	1	1	198	139

(B) NEPAL

PER CAPITA EXPENDITURE	MEAN HOUSEHOLD EXPENDITURE	ELECTRICITY EXPENSES					
		EFFECTIVE PER-UNIT COSTS (INR/KWH)		EXPENDITURE SHARE (%)		HOUSEHOLD MONTHLY COSTS (INR)	
		GRID	MICROGRID	GRID	MICROGRID	GRID	MICROGRID
0-249	*1,276*	-	8.4	-	3	-	63
250-499	*2,306*	4.1	15.4	5	4	102	74
500-999	*3,488*	4.5	12.3	2	3	77	78
1,000-1,999	*4,996*	4.1	13.1	1	2	78	80
2,000+	*17,112*	4.0	10.8	1	1	119	79

Note: Monetary units: INR. See text for Nepal tariff schedule. $PPP 1=~INR 20. Please see Technical Appendix Table A4 for average household size by expenditure group.

While the above analysis applies to both India and Nepal, there are a few notable regional differences. Overall, Nepali costs and rates are far lower, by an order of magnitude for grid service, and by a factor of five for microgrid service. However, these rates are misleading in the case of micro-hydro systems, because their costs are front-loaded in the connection fees (see Table 5). Operating costs are relatively low and capital costs dominate the cost of supply. Grid customers in Nepal actually pay higher rates than regulated grid customers in Bihar.

This discussion suggests that both households and suppliers may be better off with metered service, at least in Bihar. In comparison to grid-connected metered customers, it would seem that unmetered

customers, regardless of whether they are served in regulated or unregulated areas, pay a much higher unit price. Suppliers find it cost-effective to meter even the poorest households, because they avoid the problem of free riders, and households typically pay lower per-unit rates. Supply-side issues, including technology, may explain differences in rates between the biomass- and hydro-based microgrids, though that investigation is beyond the scope of this study.

We now examine the connection fees of all the systems. Connection fees are a one-time expense for obtaining a connection. The different systems have different costs for specific reasons. As indicated earlier, Desi Power in Araria had a partner that subsidized grid extension to households from the market centers. This may explain the lower connection fees in comparison to Husk Power. Nepali connection fees are higher by up to a factor of five, because of the terrain and remoteness of the surveyed region, among other things. Grid connection costs in Nepal are much higher than for microgrids, because microgrids do not need to connect to a distant grid.

It is notable that, for a given system, the distance from paved roads is not statistically correlated to connection fees.[26] In the specific case of grid customers in Bihar, customers closest to paved roads seem to pay higher connection fees, which is counter-intuitive. One possibility is that rates are relatively ad-hoc, and negotiated, rather than driven solely by actual costs of connection, or that costs other than those for distribution lines dominate total costs.

Table 5 | **Connection Fees (One-Time) for Grid and Microgrids in India and Nepal**

PAVED ROAD DISTANCE	INDIA-ARARIA		INDIA-ARARIA		NEPAL-KAVRE	
	GRID	MICROGRID*	GRID	MICROGRID	GRID	MICROGRID
<1km	1,547	239	1,195	403	4,763	1,813
1–2km	578	200	961	417	3,409	1,786
2–5km	800			158	3,326	2,649
>5km					4,000	2,733

Note: Monetary units: INR per household connection. *In Araria, microgrid lines were subsidized. See text for details.
Source: Primary household surveys.

Solar home system costs and characteristics

Households with SHSs were not identifiable a priori. Rather, we came across such households by chance. As such, the survey did not allow for a detailed assessment of SHS characteristics. However, we were able to piece together anecdotal information about these systems.

Among the 16 SHSs (out of 98) where system data were available, system sizes ranged from 20 W–160 W, with a median of 60 W. Most systems provided just lighting, for multiple bulbs (almost exclusively compact fluorescent), though a few households also had fans and even TVs.

Interviews with small businesses that had SHSs led to a number of interesting observations regarding system costs. First, solar costs depend very much on when customers invested. The cheapest systems found were Chinese-made systems (PV/battery) that were purchased in 2014 and cost INR 80/watt in India. Systems sold by Tata Power (an Indian company), however, seemed to be in the range of INR 120/watt. In Nepal, system costs are higher, at a minimum of INR ~180/watt. This is partly because the systems in Nepal were older. Some systems that were installed between 2000 and 2002 cost ~INR 225–250/watt.

Although SHSs are supposed to need relatively little maintenance, anecdotal evidence from some surveys and interviews with SHS suppliers in India indicate that the use and maintenance of the batteries has been a major concern. The primary issue is that customers reduce the life of the battery. For instance, they may drain the battery by leaving appliances on, or unintentionally damage equipment.

Another notable observation is that, where information was available, systems seem grossly oversized. Systems of 80–160 W were common, even if they were used only for two light bulbs and phone charging. We found many customers that used a 20 W panel to serve the same load.

It is not clear why households invested in SHSs, and to what extent they took advantage of the government subsidy. However, in several interviews, including those with SMEs, it was apparent that greater control over power supply was essential, for which customers were willing to pay a high price.

If there is one certainty, it is that SHSs are a fast-growing option for the poorest people in the country, due in no small measure to falling panel prices, and that there is significant heterogeneity in the systems and prices that customers are adopting. Certainly, the need for more systematic investigation of market trends in SHSs is an important lesson from this study.

Key Findings

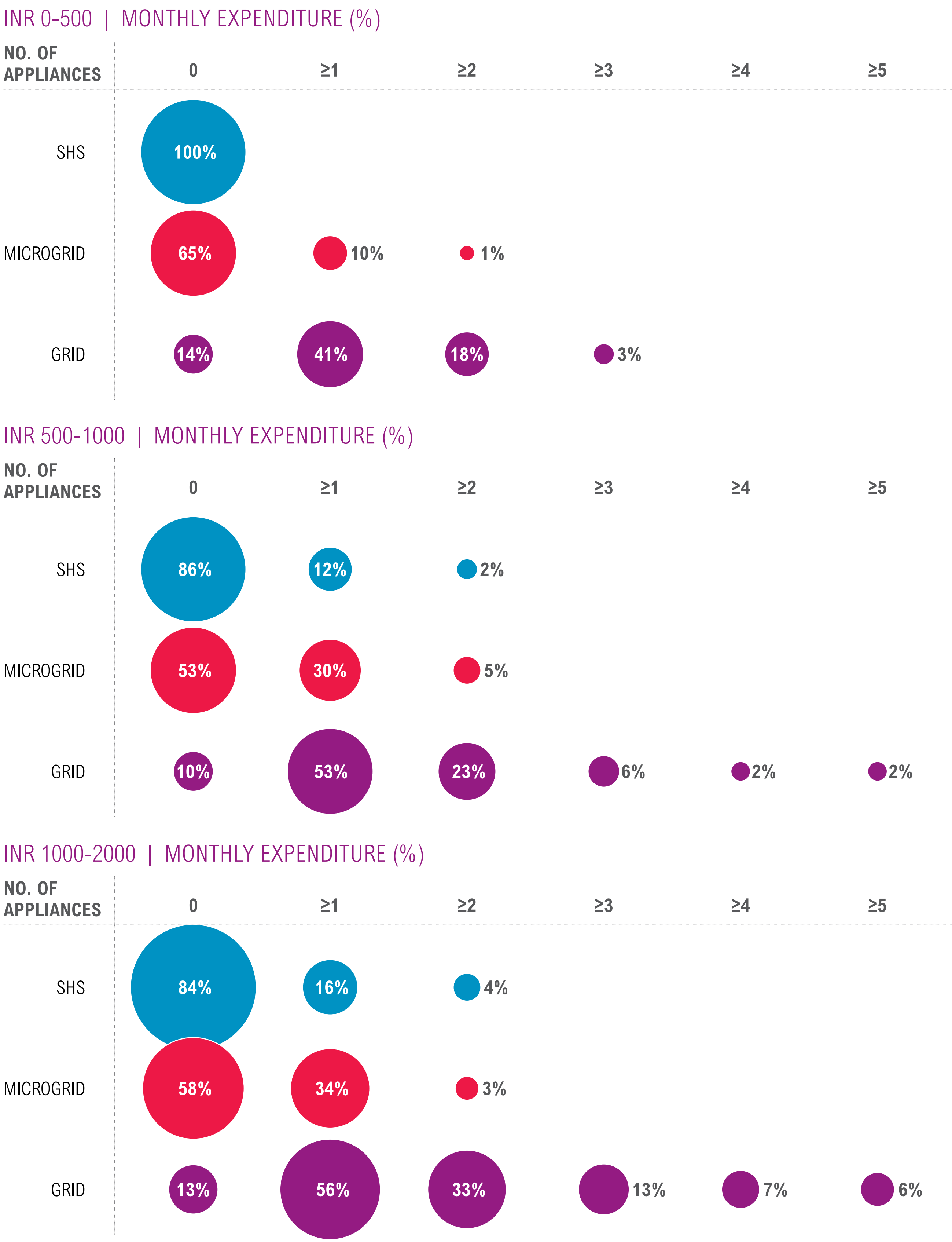
- Most surveyed households paid an initial connection fee followed by a flat monthly payment (based on connected load) of INR 100–200 ($PPP 5–10) in Bihar, India and INR 60–100 ($PPP 3–5) in Kavre, Nepal.
- Constrained supply has meant that monthly expenses for electricity are relatively comparable across expenditure groups.
- For the levels of electricity service being provided, effective per-unit rates are high, particularly for microgrid customers.
- Micro-hydro customers in Nepal pay lower rates but higher connection fees than customers of biomass-based microgrids in India.
- SHSs are increasingly penetrating the market and costs are coming down.
- Battery replacement and system size, however, continue to remain concerns.

Socio-economic Benefits to Households

Appliance ownership

Appliances enhance people's quality of life, and can therefore be thought of as a benefit of electricity supply. Connected capacity is one of the attributes of the multi-tier framework proposed to measure energy access in the UN SE4ALL program, which reflects the importance of appliance ownership as

Figure 3 | **Appliance Ownership by Service Type and Average Household Expenditure**



Note: Data are based on 52 percent of sample (447 households, India and Nepal). Bubble size indicates share of households with indicated total number of appliances. The sum of columns 0 and >=1 indicate share of households in each group that answered the question. For example, among SHS owners spending INR 0–500 per month, none have appliances.

a measure of progress toward eliminating energy poverty. The conventional wisdom is that income is the primary determinant of households' appliance ownership, particularly in India (Letschert and McNeil 2007). Notwithstanding the strong supporting evidence, this understanding is based on a body of knowledge that has little, if any, consideration of actual supply conditions (Rao 2013). Logically, it might be expected that households would not purchase electricity-intensive appliances if they could not rely on a dependable supply of electricity.

Indeed, we find that households with similar incomes have different levels of appliance ownership for different types of systems (Figure 3). Appliances counted include TV, refrigerator, iron, rice cooker, AC, and washing machine. Grid customers consistently have higher numbers of appliances at every income level (we use total consumption expenditure as a proxy, henceforth, when referring to income) than both microgrid customers and SHS owners. This difference increases with income, because households can afford more appliances in the first place. Overall, in comparison to grid-connected households, appliance ownership rates among microgrid and SHS households are 26 percent and 39 percent lower, respectively. This phenomenon was observed equally in the Nepali and Indian samples.

Different supply systems also create different incentives for appliance ownership because of their varying supply characteristics. Appliances require higher connection capacities, and availability of supply when used. Grid supply, though unreliable, has no systematic restriction on capacity or time of use. Microgrid suppliers typically offer limited hours and restrictions on connectable load (see Section *Supplier Context*). SHS customers are physically restricted in the extent of load they connect (depending on panel and battery size). This argument is consistent with the fact that households in the Nepali sample have higher rates of appliance ownership, where, as shown earlier, grid supply availability is far higher.

The type of system may also be a proxy for other factors that happen to align with system location. For instance, the presence of commercial markets in villages may be strongly correlated with the type of supply system. It is plausible that grid-connected villages may have better infrastructure, and thus may have lower prices and better support for appliance markets.

Though factors related to both system characteristics and location are plausible, there are a number of other factors that likely influence households' appliance purchases, such as education level, how long households have had electricity, and proximity to markets, among others. We therefore quantitatively tested the significance of supply attributes after controlling for all other explanatory factors (see Technical Appendix). The results show that almost all the factors mentioned above have a statistically significant influence on appliance ownership. Among them, education has the highest influence. However, the magnitude of the effect is relatively small for all the variables, in comparison to that of the type of system and the country.

Key Findings

- Appliance ownership is unsurprisingly correlated to household income.
- Grid customers consistently report higher levels of appliance ownership, after controlling for income. This may reflect higher supply availability and capacity.

Impact on health

Our main metric for health impact is injuries caused by kerosene-related accidents. The use of kerosene is also associated with exposure to particulate matter and black carbon emissions, which have severe health consequences, but this issue has been examined by Lam et al. (2014). We find that kerosene-related accidents are a minor issue, overall. Only 29 households out of 859 reported any accidents. Of those accidents that were reported, some resulted in serious injuries.

Kerosene use is significantly lower in households with SHSs, and moderately lower among microgrid customers, in comparison to grid customers. Almost all households with grid electricity continue to use kerosene, while about half the households with either SHSs or microgrid access use kerosene as a backup. Furthermore, the quantity of kerosene

Table 6 | **Kerosene Consumption (Monthly) by Electricity Access Type (Liters/Mo)**

COUNTRY	NO ELECTRICITY	GRID	MICROGRID	SOLAR
India	3.3	3.3	2.5	2.1
Nepal	1.4	1.0	0.7	0.4

Note: Data based on households using kerosene.

consumption by users is lowest among SHS owners (see Table 6). Kerosene use is far greater in India, due to the lower reliability of both the grid and microgrid in comparison to those systems in Nepal. Further, grid customers in India use as much kerosene as people with no electricity, reflecting the erratic supply at night.

Despite regional differences, the finding that households with SHSs have the lowest kerosene use is consistent in both countries. We did not find any characteristics that distinguish these households other than their type of access. If the system is indeed an influential factor, this implies that lower kerosene use is one concrete positive impact of an off-grid system, and particularly a stand-alone system with (well-functioning) storage. This finding would also confirm the work of Obeng et al. (2008).

Key Findings

- Kerosene use is significantly lower in households with SHSs and moderately lower among microgrid customers.
- Grid supply (particularly in India) has minimal impact on kerosene use.

Children's education

We focus on the perceived benefits of electric lighting for children's education, by asking respondents to agree or disagree with a statement asserting that electricity benefits: (a) children's studying; and (b) school attendance (Table 7).

The overwhelming majority of households see benefits. Of those with access to electricity, grid customers had the least confidence in the benefits of electricity access for children's studying (82% agreed). The high unpredictability of night-time grid supply may explain this difference.

Table 7 | **Survey Responses to Assertion that Electricity Benefits Children's Studying**

ELECTRICITY SUPPLY	DISAGREE	AGREE	AGREE (%)
Grid	42	196	82
Microgrid	4	164	98
Solar	2	67	97
None	27	244	90

Key Findings

- Most households believe that electric lighting has a positive impact on children's education, but this belief is weaker among grid customers.

Women's time

In the survey, we asked respondents how all women in the household spend their waking time, offering them choices of cooking, household chores, income-generating activities, watching TV, collecting firewood or water, and other miscellaneous activities. We present results for all women about whom we have data.[27]

We find that when comparing like households (i.e., using Propensity Score Matching (PSM)) there is no discernable difference in how much time women spend watching TV. However, the amount of time women spend on income-generating activities (IGA) among like households is higher among women in India with electricity access. Women with any level of electricity access, on average, spend 46 minutes per day on IGA, while those without access spend 20 minutes. Notably, a quarter of households with access reported some IGA, while only 4 percent of those without access reported women spending time on IGA (see Technical Annex, Table A5). Since the income from women's IGA is not the primary household income source, and this difference in time is small, the potential income increase from electricity use is not discernable (see sub-section on income). In Nepal, we don't have a large enough sample of households without access to make any claims.

Predictably, for both cooking and fuel/water collection, there is no discernable difference in women's time. Anecdotally, several female respondents also cited the benefit of TVs and fans in terms of distracting children and keeping them comfortable, thereby giving the women more free time.

Key Findings

- Electricity access is associated with women spending more time on income-generating activities.

Income

Overall, we find no discernable difference in income between households with and without electricity access. Part of the reason is that the standard deviation of income/expenditure across households is high (equal to the mean). In cases where we did find

statistically significant differences (e.g., in Nepal, between households with and without access, and between grid and microgrid customers), these differences vanished with the adjustment using PSM (see Section *Socio-economic Benefits of Electricity Access* and the Technical Appendix).

This result is not surprising, and is consistent with many previous studies (see Section *State of Knowledge and Gaps*). Besides the difficulty of discerning differences in a small sample when there is high variability in incomes, the result is likely due also to the low prevalence of home-based SMEs. The productivity differences between small businesses with and without electricity, particularly those that use mechanical power, could markedly alter incomes. Most SMEs are retail shops, whose main benefit is to stay open for longer hours at night, but this is the time when most markets are closed, and customers are few. Further, even though the sample includes relatively old systems, most are less than a decade old. The growth of income and businesses due to electrification is known to grow with time (Khandker 2009).

Key Findings

- No discernable differences in income were found as a result of electricity access. This is likely a function of the study context and limitations.

Impacts on Small Businesses

We surveyed 42 SMEs in Nepal and 34 SMEs in Bihar across five primary categories—retail, mechanical (largely mills), electrical, services, and other miscellaneous businesses (Table 8). The survey of small businesses in Bihar and Nepal demonstrates that electricity access is not binary, and that often unreliable and poor quality supply is only marginally better than no supply. Small businesses rarely locate themselves based on electricity availability, but they suffer high opportunity costs from poor supply. Access to electricity seems to ease the conduct of ongoing businesses (through improved lighting and cooling, for instance). In most cases, respondents preferred limited but more reliable supply from microgrids to erratic supply from the grid.

Average business income in Nepal and Bihar is around INR 12,000–13,000 per month, with maximum reported income being INR 50,000 per month. Income also tends to fluctuate rapidly depending on factors such as the weather, festivals, school holidays, etc.

Our findings for several parameters, including business location and migration, electricity use, and choice of electricity supply source are detailed below.

Business location, migration, and the role of energy access

Electricity access is not the primary driver for business location among the surveyed SMEs in either Bihar or Nepal, regardless of type of business. Factors such as access to roads, presence of a market, and familiarity with customer base seem to play more of a determining role.

Proximity to a highway, particularly in Nepal, not only increases the customer base but also makes it easier for businesses to procure supplies and repair any defective machinery. Respondents reported increased sales after construction of a highway close to their businesses, and also identified ready markets, such as a school, as a reason for selecting their present business locations.

Table 8 | **Small Business Interviews: Breakdown of Sample**

COUNTRY	RETAIL	MECHANICAL (MILLS)	ELECTRICAL	SERVICES	OTHER MISC.	TOTAL	AVERAGE MONTHLY INCOME
Nepal	12	10	3	7	10	42	INR 12,000
India	15	2	4	5	7	34	INR 13,800

None of the respondents in Bihar or Nepal had migrated from other places to the survey areas to set up businesses. Thirteen Nepali respondents had, however, worked elsewhere—either in other countries or in urban Nepal—and returned to their native villages to set up businesses (usually with the help of accumulated savings). These respondents reported declining health, wanting to look after their family, and agricultural land as key reasons for moving back home. Interestingly, two respondents also reported that they were not earning enough money working in urban towns and cities. In Bihar too, four respondents had moved back to their villages from electrified towns and cities. These respondents then used training they received outside (such as in electrical appliance repair) to set up businesses in their village.

Migration out of the surveyed areas was naturally difficult to capture. When asked whether they would consider moving to areas with better electricity access, however, most respondents replied in the negative. In India, most respondents are also engaged in agricultural activities and need to remain close to their ancestral villages and lands. While migration is more common in Nepal, the risk appetite for setting up a business in a new area is relatively low and, typically, migration to electrified areas is to seek employment. Social networks and reputation seem to be key drivers for business success, thus motivating business owners to remain close to their villages. Rent and cost of living are other factors that some respondents reported having considered. There are some instances of migration within village development committees (VDC)[28] in Nepal (from one ward to another) typically due to the opening up of a new market or construction of a new road. Another factor that might increase migration to more urban (and therefore better electrified areas) is the shrinking market base in rural Nepal. Several SME owners reported decreased profit levels due to declining village population and growth in competing businesses.

Electricity supply choice

While most businesses in Nepal rely primarily on the grid and microgrids, Indian businesses seem to rely on various other types of sources including diesel gensets (either individually owned or community owned), batteries, and even gas cylinders. Table 9 breaks down the type of electricity connection among surveyed SMEs in India and Nepal.

Table 9 | **SME Electricity Connection**

	INDIA	NEPAL*
Grid connection (only)	0	12
Microgrid connection (only)	12	9
SHS (only)	2	5
Diesel genset (only)	10	0
Other sources	2	0
Multiple connections	7	13

Note: *Excluding three surveyed businesses that currently receive grid supply but will revert back to micro-hydro supply once the micro-hydro plant in their village is repaired.

What stands out is that none of the surveyed SMEs in India rely on the grid alone. While at least three businesses have a grid connection (and some others are in the process of trying to get one), all these business owners feel the need to supplement this connection from another source of supply, most commonly diesel gensets (either individually or communally owned). In Nepal, on the other hand, 12 businesses rely on grid supply alone (though this might be on account of the smaller market potential). Unlike Indian respondents, respondents from Nepal with multiple connections typically have an SHS to supplement grid supply. In at least three cases, the SHS was bought before grid supply reached the respondent.

What is also interesting about Nepal is that respondents were open to admitting that they had access to the grid through a loose line or hook-up connection. This might be because their own villages are not yet electrified and such connections are usually from electrified villages nearby. Loose-line connections also seem more institutionalized in Nepal with respondents reporting a uniform tariff structure for their use.

Availability of grid supply is reportedly higher in Nepal than in India; however, it continues to be erratic in both countries and supply during business hours is not guaranteed. In addition to reliability, some other factors that respondents take into consideration when choosing among supply options are cost and quality of supply (for instance, what appliances the connection can handle).

Microgrids are a preferred option for many business owners in both countries. Particularly in Nepal, all business owners who have access to the grid and a microgrid prefer the microgrid. This is partly on account of more reliable supply, and partly because most microgrids charge a flat rate. One interesting case was Katike Deurali VDC where the micro-hydro plant is undergoing some repairs and the village is temporarily receiving supply from the grid. All three respondents from this village reported that they preferred the microgrid and would switch back (irrespective of the new tariff structure) once it resumed supply.

Several respondents in both countries who now have microgrid connections used kerosene/gas lanterns and stoves prior to the setting up of the microgrid plant. They find microgrids cheaper, more convenient, and safer. In Nepal, particularly, not having to buy kerosene is a huge saving both in terms of the cost of kerosene and the time involved in procuring it. With one exception, microgrid users reported that supply was extremely regular. They also found microgrid suppliers helpful and easy to deal with. Indian respondents who rely on the microgrid for irrigation of agricultural land also reported that service providers offer flexible payment schedules, which they find attractive. In Nepal, microgrid supply hours are determined by the community. In some places, this means that the plant supplies electricity only in the evening and at night because water is needed for irrigation purposes during the day. Several business owners complained that this timing is inconvenient for them.

In India, almost all businesses that have a high reliance on electricity run on a generator. Various factors, including relatively inexpensive diesel and expensive microgrids, have meant that community gensets are competitively priced vis-à-vis microgrids, and in many cases also able to take on a higher load. Unlike India, where diesel gensets are quite popular (and often considered the most reliable source of supply), 11 respondents in Nepal said that diesel gensets are not an option because of their high costs. Apart from the cost of diesel itself, the time, effort, and money required to transport diesel from the nearest town/market also seem to make it an unviable option.

In Nepal, the small market also limits the need for alternative or backup sources of electricity. Several business owners reported that the existing hours of supply (either from the grid or a microgrid) are sufficient to cater to present demand, and longer hours of supply would not immediately translate into more business (however, this may not be the case with businesses that need a constant supply of electricity such as restaurants with refrigerators). While consumers are inconvenienced in that they don't always get services when they want (such as grain milling), most business owners report that customers understand the situation and come back when there is electricity. Irregular supply hours do, however, restrict business owners' flexibility in terms of when to carry out electricity-dependent tasks. One impact of this is seen in the increased incidence of injuries among mill owners in Nepal, who sometimes have to work late at night because that is the only time when grid supply is available.

Though grid customers in the surveyed Indian villages did not seem very familiar with the tariff structure, there is a perception that the grid is the cheapest source of power. Despite its unreliability, Indian SME respondents (and a few Nepali SME respondents) expressed their desire to get grid connections once supply to their area begins. However, several of these respondents also want to retain their existing connection as a backup option. Overall there seems to be a greater willingness among Indian SME customers to pay for electricity than among their Nepali counterparts. What appears to restrict electricity consumption in India is limited hours of supply, not costs. This could, however, be the case only in the surveyed areas and is not necessarily representative of the larger SME community in Bihar.

Business expansion plans

Overall, Indian respondents were more upbeat about the possibility of improved business through better electricity supply. This could be attributed to the limited market base in rural Nepal that has already been discussed.

Respondents in both countries (12 in Bihar, 10 in Nepal) did, however, express interest in expanding their existing businesses through the purchase of more appliances such as refrigerators or mechanical equipment. Seven respondents in Bihar and four in Nepal also hoped to start a completely new, more electricity-reliant business if they could be assured of better supply.

However, several respondents in both countries also noted that they had no significant business expansion plans and a few (owners of fertilizer sales shops, for instance) also observed that, besides basic lighting and cooling facilities, electricity has no significant impact on their existing business.

There is a general perception that, apart from impacting individual businesses, access to electricity will open up the market to new business opportunities and expand consumer choices. Some business owners, for instance, were of the view that improved electricity access in nearby villages could lead to a higher demand for purchase and repair of electrical appliances and agricultural pumpsets. Interestingly, some businesses are likely to suffer with greater electrification. One Nepali shopkeeper observed that candle sales increased by 50 percent during the dry season, while another who used to sell SHSs reported that saturation of the village market had led to reduction in sales.

Key Findings

- Electricity access is not the primary determinant of business location or nature of business, and many other factors, such as access to roads and proximity to agricultural land, play a bigger role.
- Business owners suffer high opportunity costs due to lack of supply or unreliable supply and, for the most part, are reluctant to make electricity-dependent investments because of unpredictable supply.

SECTION V

POLICY IMPLICATIONS AND FURTHER RESEARCH

Households in the study sites face poor supply conditions and high costs. Solar home systems are a fast-growing option, due in large part to their falling costs and relative reliability. Standards of service for electricity, if developed and enforced across systems, may improve service conditions. Further research is required to understand how both grid and off-grid systems can deliver electricity services that support broader development goals. These research needs include understanding commercial customers' infrastructure needs, their barriers to investment, and monetary benefits from electricity use under different service conditions.

This study revealed some noteworthy characteristics of electricity service offered by different supply systems, which influence the benefits they provide. We first summarize these characteristics and some of their drivers. We then summarize the assessed socio-economic benefits of electricity access to households and Small and Medium Enterprises (SMEs). Lastly, we discuss the policy implications for the future regulation of off-grid system markets, and the design of access metrics, and we provide pointers for further research.

The sample of 859 households and 74 SMEs observed in this study spanned three districts in Bihar and Nepal. The geographic region was chosen based on the condition of observing households served by different types of grid and off-grid systems of highest vintage and in close proximity.

Summary of Findings

Electricity service in the study sites are largely unregulated

- The microgrid markets studied in this report have operated with limited government oversight in Nepal, and none in India. Conditions of electricity service, including price, have been determined by the market (or by the community in Nepal). This can even be said, to some extent, of grid customers in Bihar because, in most of the villages, households are unmetered and effectively outside the control of the Bihar electricity regulator.

- In Bihar, and to a lesser extent in Kavre, Nepal, many types of off-grid systems compete and coexist, even in the presence of the national grid. Electricity supply can include some combination of diesel-based microgrids, solar home systems (SHSs), biomass-based microgrids, and the grid.

- SHSs are a fast-growing option in both Nepal and Bihar. Households and SMEs appear to purchase these systems on the open market, which offers a wide range of system sizes and costs.

- Biomass-based microgrids are not commercially viable if they have to rely only on household demand because households cannot sustain the high load factor necessary for profitability. (Microgrids receive significant capital subsidies in Nepal.) In India, the need to secure commercial customers to make projects viable has adversely affected the service conditions, costs, and priority given to household supply.

- These market conditions help to explain the heterogeneity in service conditions observed among different types of supply systems, and between India and Nepal.

Different systems of electricity supply provide customers with different levels and quality of service

- Most off-grid systems are designed to provide a limited set of household electric services, primary lighting and phone charging though, over time, some households appear to add more appliances, despite restrictions. In contrast, grid supply supports more services with few or no capacity restrictions, but service is limited by poor reliability.

- Customers pay for electricity according to varied rate structures, most typically a flat monthly rate pegged to connected load. Metering is an emerging trend among off-grid suppliers in India, in response to households' increasing appliance demands.

- Service costs are best understood as a combination of monthly costs, per-unit rates, and the share of electricity in the total household budget. Sampled customers pay INR 60–200 ($PPP 3–10) per month. Biomass-based microgrid customers in Bihar pay the highest rates when assessed on a per-unit basis, of up to $PPP 4.5 /kWh, due to flat monthly rates and low usage. The poorest households in Bihar spend 7–10 percent of their monthly household budgets on electricity. Metered customers in the sample generally pay lower rates than flat-rate customers. Customers in Nepal typically pay lower rates, but higher connection fees, than Indian customers.

- There is significant heterogeneity in the characteristics and quality of electricity service across different supply systems and income groups, particularly in India. Grid service, on average, tends to be available for more hours than microgrid service, but with lower predictability.

Regional differences are also stark: in Bihar, households receive an average of 3–6 hours of service per day while, in Nepal, households receive 15–18 hours. Average grid availability varies among villages, and much less within them.

Electricity access provides diverse socio-economic benefits to households

- Households with electricity access use less kerosene for lighting, saving both money and time, but kerosene use varies widely according to the type of electricity supply. Households with solar home systems consume less kerosene than microgrid customers, who in turn consume less than grid customers. This is likely due to the higher reliability of SHSs as a stand-alone system for lighting, and the more erratic night-time supply from the grid. Since kerosene use has significant health impacts in terms of indoor air pollution, reduced reliance on kerosene brings the greatest health benefits to off-grid electricity customers.

- Grid connected customers have higher appliance ownership, and so do those with better supply reliability on any system, after controlling for household expenditure.

- Women with electricity access spend almost twice as much time on income-generating activities as women without access. However, the time spent on income-generating activities remains below one hour per day on average.

- Access to electricity does not lead to any discernable differences in household income. This finding is likely a function of the study's context and limitations. Income effects manifest over a long period of time and in conjunction with other enabling factors, such as market access. Further, electricity access can reduce energy costs (e.g., SHSs replacing kerosene), which does not increase income but does provide households with the flexibility to re-allocate expenditure and increase welfare.

Small businesses are held back by poor electricity service

- Electricity access is not the primary determinant of business choice or location. In mountainous Nepal, access to roads is considered more important. In Bihar, the choice and location of small businesses is primarily determined by family roots and the dominance of ancillary agricultural enterprises.

- Reliability of electricity supply is essential for most SMEs. Unreliable supply is only marginally better for business than no supply at all. Some SMEs are able to cope with poor reliability without significant income losses, but others are obliged to pay high prices for diesel or solar backup.

- Electricity is perceived as a service that enhances the customer base of small businesses, primarily because of improved lighting that allows extended hours of operation. Businesses report (but can't quantify) the high opportunity costs of poor electricity availability and reliability, primarily in the form of lost market opportunity and lost customers. Poor supply is a significant disincentive to expanding their business.

- Limited but more predictable supply from microgrids was generally considered preferable to more available but erratic supply from the grid.

Policy Implications and Further Research

By viewing electricity access through the lens of its attributes—that is, the context, characteristics, and quality of service—rather than as a binary condition (access/no access), this study reveals that different supply systems deliver different services. Heterogeneous levels and quality of service, in turn, have a significant influence on the benefits they deliver to customers. Given the rapid proliferation of off-grid systems in South Asia, further research of the kind undertaken in this study is required to understand how both grid and off-grid systems can deliver electricity services that support broader development goals. We cannot claim that the findings from this study are generalizable more broadly across other areas of India and Nepal where off-grid systems have more recently proliferated in competition with

the grid. The following lessons should therefore be taken as initial evidence that can suggest areas for further exploration.

Electricity service from off-grid systems in India may require regulation

The presence of multiple supply options in some villages suggests that poor supply conditions may risk stranding assets in the future. Electricity supply, whether from off-grid or grid systems, should have standards of service. This may necessitate regulation and related enforcement mechanisms. Households currently face poor supply conditions and high costs. SHSs are a fast-growing option for the poorest, due in large part to their falling costs and relative reliability. However, the rates paid for microgrid supply in many areas are comparable to the cost of electricity from diesel, and they are higher than the regulated (and subsidized) rates paid by other rural households in India. Rate structures vary widely, as do reliability and customer service.

Metering may confer benefits on both suppliers and some households. For suppliers, metering seems to be a development that prevents theft and violation of load restrictions. For customers with low usage, metering may lower their costs if accompanied by per-usage rates instead of flat rates.

Electricity supply for rural development should be incentivized

In India, this study indicates that off-grid systems provide limited household services, mostly lighting and phone charging. At the same time, they are evolving. During the course of the study, we found that solar was increasingly being adopted, both as a gradual replacement for traditional biomass-based microgrids and in the form of solar home systems. Further research is required on the services offered by these newer systems and their impacts. This study did not quantitatively assess the benefits that these off-grid systems do provide to commercial customers. The more these systems can be incentivized to support a broader set of services, particularly productive uses, the greater the potential for off-grid systems to serve as a mechanism for rural development.

In Nepal, the experience of off-grid systems appears more favorable than in India. In part, this is due to their longer history and the remoteness of many villages from the grid, which inhibits grid extension. In part, it is due to the relatively more reliable conditions of micro-hydro supply. However, micro-hydro systems could be better utilized to serve rural development objectives. The barriers to expanding their use should be investigated.

Further research in understanding demand patterns and consumer needs would inform and guide policymakers as they develop support mechanisms to promote further growth in off-grid solutions. Our findings in the Bihar case studies may be particular to biomass-based microgrids, which are known to face specific operational challenges. Further systematic investigation is needed of the service conditions and socio-economic impacts of off-grid systems based on different technologies, different levels of service, and in different localities. Considerable savings to consumers might be realized through further research into the use of solar home systems. SHSs need to be better aligned in terms of capacity and consumer usage; this study found evidence of significant overcapacity in some installations. The potential cost savings associated with obtaining electricity service, or shifting from one type of service to another, are important components of rural development strategies.

The multi-tier framework for electricity access metrics should be refined

Measuring attributes of electricity access and supply systems is a complex process. Metrics for access measure both the extent of energy poverty and electricity supply characteristics. The current multi-tier framework conflates the two. For example, connected load reflects not only supply characteristics, but also household income/wealth. In this study, all households fall within Tier 1 or 2. Some higher-income households would qualify for Tier 3 from the perspective of connected load but, of those, many in Bihar would not qualify because of limited supply availability, among other differences. This would suggest that metrics related to consumption, such as connected load, be separated from those related strictly to supply characteristics.

This study also demonstrates the complexity of affordability and the inability of a single metric to capture all aspects of service costs. For example, supply conditions might result in households paying very high per unit rates for electricity, while still spending a reasonably small fraction of their total household budget. This nuance would be lost in the current framing. Multiple affordability metrics could provide a more complete picture of supply costs to consumers.

Lastly, the current method of combining multiple attributes into a composite score can lead to bias toward particular attributes. For instance, a decision rule that takes the lowest tier score among all attributes as the composite score would, in this study, lead to most households' score being driven entirely by supply availability (the lowest tier). A method that either uses multiple decision rules or avoids aggregation altogether could prevent such bias.

ANNEX A | TECHNICAL APPENDIX

Sampling and Site Selection

Site selection

Electricity benefits manifest over time (Khandker et al. 2009), and the proliferation of energy entrepreneurs is a recent phenomenon. We therefore selected sites that were served by the oldest microgrid systems we could find, and where grid access and unelectrified villages are in relatively close proximity, so as to ensure similar external conditions as far as possible. We identified these sites by first selecting energy suppliers whom we knew to have some of the oldest microgrids in operation in India—Desi Power and Husk Power. This search resulted in a selection of two districts in the Indian state of Bihar, namely, West Champaran and Araria. We also wanted to select a site in Nepal, to take advantage of the country's long history with micro-hydro-based electricity supply in villages. We selected two districts in Nepal, Kavre and Sindhulli (Kavre was the main target, but geographic proximity to targeted microgrids led us to survey some villages in a neighboring district) for their convenience: we knew of relatively closely located villages with grid access and no electricity. Henceforth, we refer to these two areas as Kavre because Sindhulli households comprised only 16 percent of the Nepali sample (Figure A3).

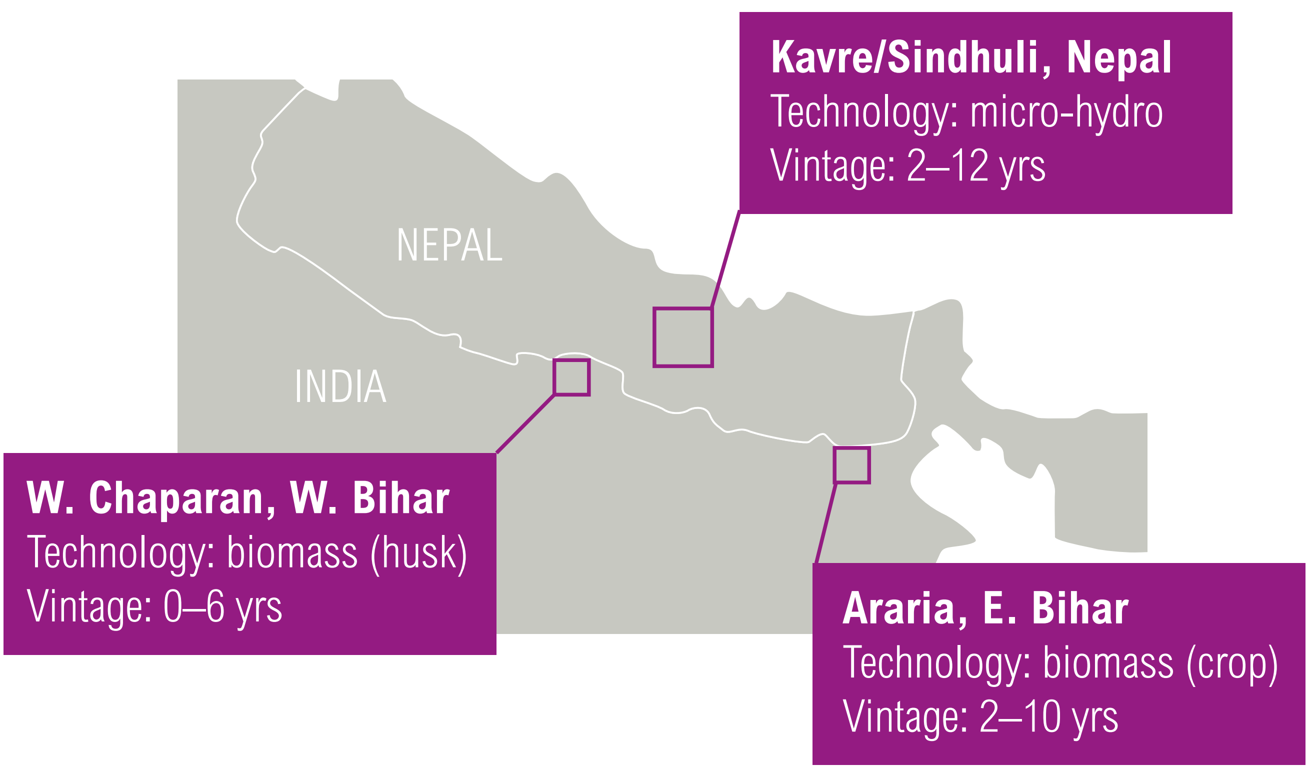
The microgrids in West Champaran are run by Husk Power, and those in Araria by Desi Power. Note, however, that in the eventual random sampling we often came across households that were served by microgrids run by other private suppliers, most often from diesel suppliers. The microgrids in Nepal are typically community-run, but their installation is heavily subsidized by the Nepali government.

Sampling

We initially aimed for a 900-household survey, based on the rationale described below, but after quality control we ended up using 859 household surveys. The total number of households (900) was determined using standard power calculations, with the intent of discerning a difference between treatment (electricity) and control (no electricity) of 25 percent, with a 95 percent confidence interval. We aimed for a 10 percent margin of non-response, thus targeting a total survey size of about 1,000 households.

For households, we adopted a two-stage random sampling process. Within each district, villages and houses were randomly sampled. For effective comparison, the sampling design aimed at an equal distribution between households that: had access to the grid; had access to a microgrid; and had no electricity access. Households with solar home systems (SHSs) were dispersed through the sample,

Figure A1 | **Site Selection**



but not identifiable a priori. We aimed to sample 300 households per district, 100 in each of the three categories. We knew to some extent a priori whether villages were electrified by the grid, microgrids, or unelectrified, so the sample selection of villages from which we selected particular villages to survey was purposeful. Then, in the first sampling stage, in each of these groups, four villages were selected at random. In the second stage, 25 households were selected from each village at random. However, there was uncertainty from the random household selection whether we would meet the sample target, because households in electrified areas may not have had a connection, or conversely in unelectrified villages households may have purchased an SHS.

In the case of SME interviews, due to the absence of reliable data on the number, type, or location of SMEs, we had to conduct interviews on a relatively ad hoc basis. We aimed to conduct four to five interviews in as many of the 36 targeted villages (four in each category of access, per district), and with a view to selecting a range of business types. Business types were primarily mechanical, electrical, retail, and service shops, such as restaurants, and other miscellaneous business categories. Of the more than 100 interviews conducted, we selected 74 that had sufficient information and quality to inform all our research questions.

Survey Method and Questionnaire

Survey Description

The household survey consisted of approximately 50 questions, which were primarily closed (multiple choice), with a few open-ended questions to solicit more general comments on issues with electricity supply, household-based income-generating activities, and any other special circumstances. The questionnaire was designed by the authors of this report. Local firms in India and Nepal were selected to conduct the surveys based on their experience with market research and local presence in the surveyed sites. The authors trained the surveyors and accompanied them on initial surveys. Questionnaires were translated into Hindi and Nepali respectively. In India, Sahaj e-Village Limited, a firm with an extensive network of village-level entrepreneurs across Bihar, conducted interviews in local dialects. In Nepal, Square One, a survey and marketing company with prior household survey experience did fieldwork. The questionnaire can be found at http://www.wri.org/publication/small-scale-electricity-systems.

The SME interviews were open-ended interviews, the majority of which were conducted by the same market research firms (and a minority by the authors in their presence), with guiding questions corresponding to the research questions.

Appliance Ownership

This section describes the regression analysis used to explain the total appliance ownership of households (including light bulbs). Because this outcome (the dependent variable in this case) is a count variable, it doesn't exhibit a normal distribution, and is therefore better suited to a Poisson regression, rather than the usual linear regression. The Poisson regression conceives of the dependent variable as a frequency rather than as a probability. We select as explanatory variables the available data related to the electricity service, including type of system (grid, microgrid, SHS); age of connection; supply availability (hours per day); and market access. These variables were used to address appliance availability, including location (India, Nepal) and market proximity (distance from paved road); education, which serves to reflect knowledge of appliances (years of schooling); and household income (proxied by consumption expenditure), which reflects ability to pay. Table A1 below summarizes these variables, and Table A2 shows the regression results.

Table A1 | **Summary of Variables – Households with Electricity**

VARIABLES	INDIA		NEPAL	
	MEAN	STD. DEV	MEAN	STD. DEV
Total number of appliances	3.2	3.6	7.9	3.9
Explanatory Variables				
Connection vintage (Yrs)	3.4	5.0	6.3	3.9
Total expenditure (INR/month)	838	975	1,221	1,510
Education (1=None; 2=Primary; 3=Secondary; 4=Tertiary)	1.8	0.9	1.8	0.8
Market proximity (km)	0.5	0.6	8.3	8.2
Supply availability (Hrs/day)	5.7	5.4	16.8	4.0

Table A2 | Determinants of Total Appliances per Household: Poisson Regression Results

DV: TOTAL APPLIANCES PER HOUSEHOLD (HH)	COEFFICIENT (IRR)[1]	Z-STAT (-)
Microgrid Dummy[2]	0.74***	(6.63)
SHS Dummy[2]	0.61***	(4.98)
Nepal Dummy[2]	1.4***	4.67
Age of Elec. Connection (Yrs)	1.03***	10.06
HH Exp. ('000 Rs/cap)	1.04**	2.59
Head of HH Education (1–4 yrs)	1.09***	4.35
Market Proximity (km)	0.99**	(1.44)
Supply Availability (Hrs/day)	1.02***	6.17
Pseudo R^2	0.20	
N	498	

Note: * p<0.1; ** p<0.05; *** p<0.01

[1] IRR: Incidence Rate Ratio: For a one unit increase of the explanatory variable, the coefficient is the change in the expected rate of appliance ownership. For example, Nepali households have 40 percent higher appliance ownership (relative to Indian households), while households with SHSs have 39 percent lower appliance ownership (relative to grid-connected households).

[2] Reference Country is India, Reference supply system is grid.

We found no multicollinearity between any of the variables or any error disturbances that would invalidate the significance of variables.

The coefficients indicate that all but market proximity have a significant effect on appliance ownership at the 95 percent confidence level (z-stat of 1.96 or higher). However, the magnitude of the effect is relatively small for all the variables, in comparison to that of the type of system and the country. That is, households in the Nepali sample have 40 percent more appliances. In comparison to grid-connected households, microgrid and SHS households have 26 percent and 39 percent fewer appliances, respectively.

Table A3 | Appliance Usage Assumptions Used in Cost-of-Service Calculations

FINAL ENERGY HOUSEHOLD	RAT-ING (W)	USE (HRS/DAY)	KWH/YR	KWH/MO
LED	5	4	7.3	0.6
CFL	10	4	14.6	1.2
Tube-light	20	4	29.2	2.4
Incandescent	40	2	29.2	2.4
Radio	1	2	0.7	0.1
Fan	15	4	21.9	1.8
Refrigeration	300	8	876.0	73.0
Cell Phone	1	2	0.7	0.1
Television	20	3	21.9	1.8
Rice Cooker	1100	1	401.5	33.5
Iron	1100	0.3	120.5	10.0
AC	1100	2	803.0	66.9
Washing Machine	500	1	182.5	15.2
Mixer	200	1	73.0	6.1
Computer	60	0.5	11.0	0.9
Kettle	1100	0.2	80.3	6.7

Note: TV usage changed from 2 hrs in GTF to 3 hrs, based on other sources and author experience.

Source: Global Tracking Framework, World Bank, Annex 5. 2014. Except lighting, which had a different categorization (task lighting, general lighting), kettle, and computer.

Benefit Estimation Using Propensity Score Matching (PSM)

This section reports the results of applying PSM to the different outcome variables to discern differences between households with and without electricity access, and between those with grid and non-grid connections. The outcomes evaluated were household income, and women's time spent on watching TV and on income-generating activities (IGA).

Table A4 | **Average Household Size by Expenditure Group (Total sample)**

INR 0-249	INR 250-499	INR 500-999	INR 1000-1999	INR 2000+
10.8	8.5	6.7	5.4	4.8

We use a PSM approach for making this comparison. PSM does not rely on a functional form, and makes use of a "common support" from the covariates, which enables a more balanced evaluation of the "treatment" effect of electricity access in comparison to regions without electricity access ("the control") (see Rao 2013). The common support set of variables includes: assets, education level of the head of household, distance from paved roads, distance from a water source, and the size of household.

The average treatment effect (ATE) is computed by taking the average of the difference between the observed and potential outcomes for each subject. Each household is matched with at least one household from the other treatment level. PSM imputes the missing potential outcome for each observation by using an average of the outcomes of similar subjects that receive the other treatment level. Similarity between observations is based on estimated treatment probabilities, known as propensity scores.

In the table below, a z-score of less than 1.96 indicates that, for a 95 percent confidence threshold, the difference in time spent watching TV between households connected to the grid versus non-grid (microgrid or SHS) customers is not significant, whereas the difference in time spent in IGA is significant.

Table A5 | **Sample Propensity Score Matching Results for Women's Time – Average Treatment Effect**

BENEFIT ESTIMATED	COMPARISON GROUPS	NO. OF OBSERVATIONS	COEFFICIENT	Z-SCORE
Avg. time on TV (hrs)	Grid vs Microgrid/SHS	223	–0.69	–0.37
Avg. time on IGA (hrs)	With/Without Electricity Access	614	0.43	5.21

ENDNOTES

1. We are limited in drawing defensible inferences on causality because we have conducted a cross-sectional study, in which it is not possible to overcome the potential endogeneity of some of the variables, particularly income (that is, electricity access may be driven by household income, or other factors, that actually drive income differences, may proxy for electricity access).
2. This section draws on the definitions discussed in Tenenbaum et al. (2014).
3. http://www.mnre.gov.in/mission-and-vision-2/achievements.
4. Central Electricity Authority, http://www.cea.nic.in/reports/monthly/dpd_div_rep/village_electrification.pdf.
5. Provisos to Section 14, Electricity Act, 2003.
6. Section 8.8, Rural Electrification Policy, 2006.
7. Interview with Dr. Hari Sharan, Desi Power, November 2014.
8. See mnre.gov.in/schemes/offgrid/ for details.
9. Interview with Dr. Hari Sharan, Desi Power, November 2014.
10. Customers have to make a down payment and maintain a margin in the bank. See NABARD Circular No. 102/DoR-GSS-34/2014 dated June 18, 2014 (https://www.nabard.org/uploads/Solar%20-%20Modified%20Scheme.PDF).
11. Rural Electrification Plan, 2012, Government of Bihar (energy.bih.nic.in).
12. S. Bhattacharyya, (2013). Rural Electrification through Decentralised Off-Grid Systems in Developing Countries. Springer, London.
13. http://www.moen.gov.np.
14. The AEPC is an independent agency established by the Government of Nepal with the objective of developing and promoting renewable energy technologies in the country.
15. Interview with an official from the Resource Management and Rural Empowerment Centre (REMREC), June 2014. REMREC is an NGO that works closely with the government to set up decentralized energy systems.
16. Phone and in-person interviews in May 2013, October 2014, and November 2014 with Dr. Hari Sharan provided much of the information presented here.
17. Although the study initially intended to include a separate sample (and location) for SHSs, for various reasons, including problems with the identification of providers' customer base, and quality of data from the chosen survey team, the case was abandoned.
18. Because the survey was conducted just after winter, the results likely reflect more favorable conditions than would be experienced during summer months.
19. For PV/battery stand-alone systems, availability is likely to be more situation-dependent than the service dispatched from a power plant, where supply is, to a large extent, under the control of an institution. With SHSs, availability can be considered 100 percent except when batteries fail, or if resource availability doesn't sufficiently follow load patterns. Both are erratic, and unlikely to follow a systematic pattern across households or time. Furthermore, respondents' recollection of erratic events cannot be trusted, especially when dealing with variations in small numbers.
20. It is possible that this variation reflects "measurement error," in a statistical sense. However, we have no a priori reason to believe that customers of grid or microgrid services would be predisposed to making better (or poorer) estimates of their supply conditions. Thus, we take their estimates to reflect actual differences in their experiences.
21. As opposed to low reliability due to intermittency in resource availability, e.g., with solar or wind.
22. Reported as $1.25/kWh, market exchange rate in Cambodia. See Tenenbaum et al. (2014): 37, 51.
23. Interviews with Desi Power representatives indicate that household power is largely subsidized from other commercial customers. It is outside the scope of this report to verify this claim or to conduct a supply-side "audit" of costs of supply.
24. The combination of a diesel engine and an electric generator is known as a generating set, or genset.
25. See Bihar Electricity Regulatory Commission website (berc co.in), Tariff Order SBPDCL FY 2014–15.
26. We conducted a linear regression to examine whether the survey captured any of the determinants of connection. We found that none of the distance variables (to paved roads, water source) were significant. The only significant driver was whether the household was served by a microgrid or national grid. The results are available upon request.
27. Surveyors were told to solicit this information from other household members, where necessary.
28. In Nepal, the administrative entity for villages—Village Development Committees—can span multiple non-contiguous settlements, which are called wards.

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Our Challenge
Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

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We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach
COUNT IT
We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

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We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT
We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

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IIASA is an international scientific institute that conducts research on global environmental and social challenges, which are too large or complex to be undertaken through a single country or by a single academic discipline.

IIASA's mission is to use applied systems analysis to provide insights and guidance to policymakers worldwide to achieve the global transformations and social change needed to improve human wellbeing and protect the environment.

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