2016

The Next Billion: Lessons in off-grid electricity development from the global south

Peter McDonough
University of Montana

THE NEXT BILLION: LESSONS IN OFF-GRID ELECTRICITY DEVELOPMENT FROM THE GLOBAL SOUTH

By

PETER JAMES MCDONOUGH

MS, Stanford University, Stanford, CA, 2013
BS, University of Puget Sound, Tacoma, WA, 2008

Professional Paper

presented in partial fulfillment of the requirements
for the degree of

Master of Science
in Environmental Studies

The University of Montana
Missoula, MT

May 2016

Approved by:

Scott Whittenburg, Dean of The Graduate School
Graduate School

Dr. Len Broberg, Chair
Environmental Studies

Joshua Slotnick
Environmental Studies

Dr. Steve Seibert
Forestry and Resource Conservation

McDonough, Peter, M.S., May 2016 Environmental Studies

The Next Billion: Lessons in Off-Grid Electricity Development from the Global South

Chairperson: Dr. Len Broberg

Today about a third of the world's population has no access to electricity, and another third has only limited access. Driven by the push for development on one hand and the reality of climate change on the other, a combination of for-profit companies, NGOs, missions, and aid organizations is looking for the silver bullet to sustainable electricity development. In order to understand the challenges facing off-grid electricity projects I used recent literature in the form of peer-reviewed journals, agency reports, news articles, and technical documents; stakeholder interviews; and on-site observations in selected case studies in Nepal, India, and Tanzania. In each case I explored and classified methods of electrification; challenges facing each method; and the larger political, cultural, and economic contexts of the projects in question. The full range of considerations precludes drawing broad generalizations regarding effective and sustainable approaches to rural electrification. I address questions raised by these case studies regarding the role of off-grid electricity globally. The sought-after silver bullet does not exist; instead, sustainable electrification requires unique, bottom-up approaches specific to each local community and environment. Ultimately, the diversity of methods is an advantage in a rapidly changing energy climate.

Table of Contents

Glossary of Terms and Acronyms

- AEPC — Alternative Energy Promotion Center (Nepal)
- CO2e — Carbon Dioxide Equivalent
- CSR — Corporate Social Responsibility
- DG — Distributed Generation
- DSM — Demand-Side management
- GHG — Greenhouse Gas
- GP — Gham Power (Nepal)
- INR — Indian Rupees
- kWh — Kilowatt-Hour
- MDoD — Maximum Depth of Discharge (Batteries)
- MGP — Mera Gao Power (India)
- NEA — National Electric Authority (Nepal)
- NGO — Non-Governmental Organization
- RET — Renewable Energy Technology
- ROI — Return on Investment
- Rs — Nepali Rupees
- SHS — Solar Home System
- Tsh — Tanzanian Shillings
- UNFCCC — United Nations Framework Convention on Climate Change
- USD — United States Dollars
- VAT — Value Added Tax
- W/kW/MW — Watt/Kilowatt/Megawatt

Introduction

It was a dark and stormy night. Pithy classic references aside, it really was as I bounced, jolted and slid into a small village in the southern highlands of Tanzania, my home for the next three years. A newly minted Peace Corps volunteer, I was crammed in the cab of a pickup between two local headmasters, my worldly belongings quickly becoming saturated with rainwater in the truck bed. The front seat of the truck was reserved for a representative from a solar NGO – an engineer or technician, perhaps – and I was informed via several translations into and out of Swahili that he was here to check on the viability of installing solar on the new secondary school. Though neither of us could have guessed it, this man, and the industry he represented, would become the topic of introduction for a paper written by the soggy, helpless American quietly coveting his spacious front seat.

Within a month, two technicians arrived at the secondary school with a truck full of supplies – three large panels, spools of wire, aluminum frames, and several large boxes I didn't completely understand. Unwitting students were swept up in the daylong labor of installing the system on the roof and running wires to bulbs and switches in each classroom, mud brick flakes and curly steel roofing scraps announcing their progress. That evening, with NGO staff and half the village gathered around, the speeches were given, local *Wahehe* songs of thanks were sung, and the switch was thrown. CFLs slowly glowed to life to the hum of the inverter fan and, for the first time in its history, electric light, these recycled rays from the sun, poured through the windows of Luhunga village. Within a year the system was all but dead.

Development?

The story of solar at Luhunga Secondary School is not an exceptional one, nor is it a cautionary tale of tragic misjudgment or uncommon failure in international development (the solar NGO is based in the UK); if anything it is common. Similar stories could be found across the country and world (see Adams 2001, McMichael 2000, and Easterly 2006 for an extensive collection of case studies and examples). Even many of the details are the same – the system specs, the brief educational component accompanying the almost free system, the payback scheme… even the speeches and songs of thanks are practically expected when completing development "aid" projects such as these. But the failure of this particular project to help a poor, rural community electrify raises a host of questions not only about the project's design and organization, but of the very question of "development" itself.

The more practical questions that this electrification project might elicit from the casual observer include:

- Why did the system fail in such a short time?
- Who was in charge of regulating the system's use to ensure its longevity, and why did they fail to fulfill that role?
- Are these problems systemic, or unique to this particular school and community?

- Did the NGO know these issues going in, or did they make assumptions that didn't pan out?
- If this is such a common problem, is it even possible to sustainably develop and electrify poor, rural communities?

Of more immediate concern, however, is the question: who are you and what do you want? Are you a student at the school who received free electricity out of thin air only to watch it degrade, or are you a teacher who has been left in charge of the system without any understanding of how it works and why it is failing? Do you represent the implementing NGO that put time and effort into bringing a sustainable technology to a community in need only to see your efforts go to waste, or are you a regular donor contributing a percentage of your income every year to further sustainable development only to hear that the NGO you support has failed to make much of a difference? The success of a project is highly dependent on who is given the authority to define that success. Each person has a different perspective and a different goal for the project: who are you and what do you want?

Take an example from Afghanistan, a development project funneling foreign aid money to build a road to encourage trade. Aware of the need for local sustainability, the project designers hired local artisans to lay cobblestones to pave the road. At the ribbon cutting to celebrate the one-sixth mile completion – a partial milestone – foreign dignitaries and host country nationals rode in land cruisers along the beautiful new road. Camels, the backbone of the targeted trade, walked on the sand alongside the road (Chandrasekaran 2009). As it turns out, camels cannot walk on cobblestones.

It is easy to point a finger and find fault with the research and planning, but a more fundamental concern lies with the very concept and language of "development." This paper deals with energy, just one of the many infrastructure areas considered a requirement for development, but rarely do we ask what that word even *means*. Before sallying forth into the world of energy development, we need to recognize and clarify our own assumptions and biases as practitioners, academics, or laymen alike.

The Meaning of Development

In the broadest sense we tend to equate "development" with "growth" and "progress," words that are equally over-used to the point of becoming meaningless. "Growth" might be more accurately linked (in international development terms, anyway) to a country's gross domestic product (GDP), while "Progress" could mean any number of things including gender equality, access to education, mortality rate, and more. However, as Adams notes in Green Development, our literature and language tend to "portray the world in particular ways, often in crisis of some kind, and almost always as requiring management and intervention by the development planner" [broadly, 'the West'] (Adams 2001, 1). Therefore the *intention* of the act of development, beyond the metrics and ubiquitous use, remains open to scrutiny.

Taking its colloquial use as an indicator of intention, the act of "development" is largely synonymous with a gradual, linear movement towards the western ideal of a high standard of living (Adams 2001, 6) or, at least, it is "identified with a Western lifestyle" (McMichael 2000, 4). On the surface the "western ideal" seems fairly straightforward: urbanization of rural populations, mechanization of industry and agriculture, universal electrification, modernization of transportation infrastructure, and so on. Communities that have not achieved these standards are often termed "undeveloped," "underdeveloped," "bush," or "backward." These terms are so pervasive that individuals I worked with personally in Tanzania and Nepal referred to themselves, their own families, and neighbors as backward.

A deeper historical look at these two countries reveals decades-long struggles between the dueling ideals of rural-centric socialism and urban-centric capitalism. The failure of the former to take hold opened the door for the latter and the associated social divisions, which were further compounded by development efforts (McMichael 2000, 80). In Nepal the long-established caste system, in which farmers occupy the lowest rung, was challenged by the Maoist rebellion from 1996 to 2006. Its failure to overturn both the urban aristocracy (then monarchy) and social hierarchy seemed to validate the inherent superiority of urban pursuits over rural and agrarian lifestyles. Tanzania explored a longer experiment with socialism under its first president, Julius Nyerere ("*Mwalimu"*). His policy of *ujamaa*, which mixed the country's ethnic groups and forced disparate communities into agricultural villages succeeded in promoting inter-tribal peace, but left the rural populations poor and under-served by a gradually growing urban elite. As a survival measure, the rural and urban poor took advantage of parallel markets – more than 90% of household income at times - that undermined the government's ability to regulate or drive economic activity in compliance with the West's terms of aid and assistance (McMichael 2000, 144). The shift to capitalism and relaxation of *ujamaa* seemed, again, to leave a certain association of "badness" with rural life.

The association extends beyond physical amenities and roots itself in people's opinions of their own capacity – I heard the same refrain countless times in Tanzania especially: "we Africans are not just poor in money, we are poor in our ability to plan ahead or make good decisions." Not only is this statement (and its myriad variations) damaging and false, it is an entirely impossible opinion to have unless it has been forced on you, or the concept exposed to you in terms of "better" (me) and "worse" (you). Gone is the overtly racist and patronizing language of the colonial era, but its essence lingers and continues to influence the views of developer and developed alike. "'Uncivilized' became 'underdeveloped.' 'Savage people' became the 'third world'" (Easterly 2006, 24). In census and development reports from the Indian government, an entire subset of the population is formally described as a "backward class," often used in reference to tribes, lower castes, and the economically deprived (RGGVY 2014). The word choice may be entirely objective, but the word itself implies something lacking on the part of people who live in contrast to the western ideal described above. In a development report on Tanzania, the urbanization rate was described as "lacking," implying an inherent "goodness" to urban living and "badness" to rural living, again, a western ideal adopted by the people to whom it was first applied (Smith 2014). Even the term "third world" has lost its original meaning – the alternative to the first (capitalist West) and second (communist East) worlds – and has come to be used by the first world to mean “those less fortunate,” a paternalistic usage that somehow ignores the means by which the West became so “fortunate.”

In an effort to achieve the high standard of living equated with development and defined for them by the first world, the undeveloped have pursued an agenda of meeting that ideal. The end result is that the world now assumes those development goals – mentioned above and in every UN report – are universally needed, desired, and good.

This paper does not attempt to support or refute the western model of development, neither by arguing for universal modernization by western standards nor by romanticizing low-impact rural life and the so-called global south. Ultimately the choice of *how* to develop, in the truest sense of simply pursuing a self-defined ideal, is up to the community itself. When engaging in the global development project, which this paper’s audience inherently does, there must always be a consideration for *whose* ideal is being pursued.

To briefly break from abstraction, as a rule it is never the job of anyone besides the community itself to decide that electric power is needed, why electric power is needed, how much electric power is needed, or for what the electric power will be used. Thus, the challenge of project implementation is to provide a service that meets the expressed needs of the community in a manner that is self-sustaining – to be a “servant of local passion” (Sirolli 2012). It seems simple, even romantic, to consider the many ways in which a successful project might manifest itself but, as this paper will discuss, the challenges are great and numerous. Indeed a single, unifying, successful model has not yet arisen in energy development, but scattered entities from large government utilities to small private businesses are learning to work through the complexities and frustrations and find locally appropriate solutions.

Weather of the Day; Climate of the Era

When we talk about energy, we are talking about climate. There are several common arguments to leave climate out of the conversation about energy. For one, the participants may not believe climate change is real, or that it is real but human activity is not the cause. Second, though the participants may completely understand the causes and effects of climate change, they may not feel a sense of urgency or responsibility, freeing their collective conscience to maintain the status quo and make decisions based entirely on economic considerations.

Last, and of more relevance to this paper, is the assertion that basing energy project decisions on climate change automatically biases final project designs towards low-carbon technologies in cases where fossil fuels may actually be the locally appropriate option. This (entirely valid) position is argued in depth by, among others, Hisham Zerriffi in his book "Rural Electrification: Strategies for Distributed Generation" (2010). As he explains, rural communities in developing countries have contributed negligible amounts of GHGs and so should not be saddled with the same demands for carbon-free technologies as communities and countries that have contributed greatly and benefited from the associated wealth. In addition, the minimal energy requirements of these communities would mean that, even if they did adopt carbon-intense energy technologies, the overall contribution to the atmospheric carbon stock would, again, be negligible. The second assertion is factually true (the contribution would be less than a percent of global carbon emissions) in the short term, and the first assertion is a valid argument that has been a primary focus of the annual climate talks by the UNFCCC (United Nations Framework Convention on Climate Change). The challenge of climate change, however, requires us to think globally and long-term, in which case neither of these arguments can be taken as deal-breakers for including climate considerations in energy development.

First, the use of fossil fuels (which we can approximate as diesel for small electric generators) to meet the basic needs of poor, rural communities contributes little to global carbon emissions (Sanchez 2010). However, this is only true as long as those communities continue to consume minimal energy indefinitely. In reality these communities are likely to expand their energy consumption just as the electrified world has done. Numerous studies have shown that exposure to electrification leads fairly rapidly to increased interest in acquiring more electrical appliances as well as a greater willingness to pay (a term that will be discussed in more depth in Chapter 3) for those services (Zerriffi 2010). Any consideration of electricity use in poor, rural communities must assume a steady increase in consumption, at least to a point on par with the idealized standard of living. A community's contribution, though negligible at first, might eventually be equivalent to a community of similar size anywhere in the world, and therefore non-negligible.

Second is the argument that it is inherently unfair of those who drive climate change to ask those who do not, and who are likely to suffer most from it, to bear the burden for mitigation. This argument gains weight when we consider that the West expects these communities to "catch up" despite the fact that they are the communities whose resources were exploited in order to develop the West, (McMichael 2000, 13) and they are expected to catch up without the benefit of colonizing and exploiting anyone else, limiting their options. There are situations in which fossil-fuel-based energy generation is the most accessible option; it is the community's right to choose that technology over another despite its climate implications. But these situations are less common when other factors, often externalized, are considered. These include other environmental costs (local water and air pollution), health effects (indoor air quality), fuel price fluctuations, international trade and politics, fuel transportation, equipment maintenance, and others.

As Andrew Scott (2010) explains, "energy security has become a more significant factor in domestic and international policy because of fluctuating oil prices, climate change, and concerns about security and terrorism more generally. Developing countries are particularly affected by variability in oil prices and the new scramble for energy resources by energy importing countries" (Foreword from Sanchez 2010, xi). All told, the long-term costs of depending on diesel (for example), especially if it is imported, can come to dwarf the costs of renewable energy technologies (RETs). In addition, in no case is diesel fuel the only option for electricity generation; every community has access to some form of renewable energy, whether it is moving water, sunlight, wind, surface-subsurface thermal gradients, or energy-rich organic matter. In cases where fossil fuels are still the most accessible option, the responsibility to minimize carbon emissions may instead be reflected in national or state policies that favor RETs.

The global community recognizes that it is now at a point where it must reduce carbon emissions and avoid technologies that increase them (UNFCCC 2015). With current emission trends, by the end of this century we will have raised global temperatures by over 4C, raised sea levels by over a meter, and reduced the ocean pH below 7.8 (IPCC 2014). And these are not eventual setline points; these numbers represent single data points on trends that are not only increasing in 2100, but still accelerating.

Collectively, developing countries, even excluding China and India, will account for the vast majority of projected emissions by the middle of this century, and their energy development choices will define the response to climate change (IPCC 2015). Off-grid, or Distributed Generation (DG), is emerging as a viable but challenging approach to both climate mitigation and electricity access. This paper will discuss methods and challenges of DG in developing countries, outline viability and sustainability considerations, and present case studies from Nepal, India, and Tanzania in order to better understand the complexity of and potential for off-grid electricity development. A more complete understanding will help practitioners pursue DG, not as energy development for development's sake, but in order to recognize when RETs are the most appropriate option and then make them accessible and successful when needed.

Chapter 1: Business as Usual

The image of "electricity service" that comes to mind for many in the West is of sprawling grids linking a few large, centralized power plants to consumers via interstate transmission lines and tree-like distribution networks. Much of the West, especially the US, has achieved near-100% electricity access primarily through this centralized system. The large power plants powering the grid have traditionally taken advantage of the most cost-effective and accessible energy resource, whether through the construction of large hydroelectric dams or the burning of coal mined locally or as far away as the other side of the globe. The result is a centralized grid spanning entire countries or even continents heavily dependent on coal (~39%), nuclear (~13%), hydropower (~17%) and, more recently, natural gas (~21%) (EIA 2015). Non-hydro renewable energy for electricity generation was negligible until the early 2000s, but has since seen rapid expansion to account for roughly 9% of world net electricity generation. These approximate proportions have been the trend for the western grid's nearly century history, making it unlikely that RETs will take over quickly without concerted efforts on national scales. This does not account for everyone, however; nor do past trends accurately predict the future of electricity generation, for several key reasons.

First, the magnitude of electricity generation is not static. Total world generation is expected to increase about 70% between 2015 and 2040 (EIA 2015), and most of that is expected within developing countries as opposed to the west where electricity production has recently begun to decrease. Among the "developing countries" are the so-called BRICS countries – Brazil, Russia, India, China, and South

Africa – also called “rapidly developing” or “emerging” economies. Within these countries, where electricity consumption and generation are expected to grow considerably, fossil fuels like coal and natural gas will play a large role, especially considering that all of these countries sit on top of plentiful reserves (2015). The BRICS countries are also developing their extensive renewable energy resources. Fossil fuels are typically less accessible in other developing countries – much of Central and South America, Sub-Saharan Africa, South and Central Asia, Southeast Asia, and the South Pacific – necessitating the development of RETs. In addition developed countries have dramatically increased their development of RETs, driving cost reduction worldwide. All told, RETs are expected to account for over a quarter of total energy generation by 2020. That portion is expected to level out around that time, but consistent policies supporting continued growth could drive RET development further over the hump to replacing Business as Usual.

Second, there is uncertainty as to the direction developing countries will take energy generation. Considering that about 1.6 billion people are currently without any access to electricity, and roughly another third of the population has only limited access, the expectation for growth rivals all current generation combined. In terms of global emissions, a concerted effort to meet that growing demand with RETs would provide a stark contrast to Business as Usual.

Third, and most pertinent to this paper’s discussion, central grid extension is not the only, or even the best, method for meeting electricity demand in every case. The grid’s design presents some challenges to using RETs as it was designed to work with one-way transmission of power from large coal and hydro plants to nearby population centers. This structure does not cater well to the needs of much of the developing world, leaving local entities to either brute-force a utility grid or explore alternatives. These alternatives, which are comprised more and more of local renewable energy resources, may not only set the norm for sustainable energy development in developing areas. Through rapid iteration these alternatives may collectively build a market for, and industry around, distributed renewable energy that may even find its place in the energy future of the West.

1.1: The Current Trajectory

The direction of global energy demand is only up. Generation has begun to decrease in North America and Europe, but much of that can be attributed to exporting industry to developing countries discussed in this paper, low or negative population growth, and increased efficiency. But consumption continues to grow worldwide, and generation must grow accordingly. We might consider generation to be at a fork in the road: developed countries are dealing with aging national grids and a dependence on fossil fuel-based power, while developing countries are just now at the point where they can take major strides to increase electricity access. The question is: where do we take our energy infrastructure? Let us focus for now on the preferred, tried-and-true methods of establishing electricity access.

Electricity service was first developed in the eastern U.S. with its large urban centers and relatively tame geography, lending itself to centralized generation, long-distance transmission, and tree-like distribution networks. Most subsequent electricity service has followed suit and, from an efficiency standpoint, such systems are ideal in comparable areas. The scale of necessary infrastructure often requires government-scale investment, and large-scale generation using cheap fossil fuels is more cost-effective (when externalizing social costs) for electrifying large population centers than distributed, intermittent generation. With a few exceptions for countries rich in hydro or geothermal resources (e.g. Iceland), RETs continue to make only a small contribution to total generation. Rarely does a renewable energy power plant actually replace a traditional power plant; that honor goes to natural gas.

Natural gas has become so affordable and versatile that it discourages adoption of other, cleaner technologies. From a climate perspective, the decline of the coal industry ideally is met, kWh per kWh, by the rise RETs. But natural gas has effectively inserted itself as a so-called "bridge fuel" that reduces carbon emissions at a much lower cost than with renewable energy. Natural gas is also comparatively versatile and can be used as a direct fuel for heating and cooking, as well as for electricity generation. That it can be compressed (CNG) or liquefied (LNG) for easy transportation means that it is marketable to a wide range of countries. Add to this the support from public health specialists that prefer natural gas to biomass for cooking and heating, and you have a fuel that is not easily displaced from the world energy market. Considering only non-externalized monetary costs, natural gas is the fuel of choice and is likely here to stay (its reserves remain plentiful).

This raises some concerns, however. First, the carbon intensity of burning natural gas is, indeed, preferable to that of burning coal, but it is nowhere near negligible. Second, like all fossil fuels, natural gas is not evenly distributed across the globe, leaving the same geopolitical tensions that currently exist due to oil distribution. If there is any doubt as to the economic power in energy resources, one need look no further than Russia's influence over European and Central Asian politics as the overwhelmingly dominant source of natural gas despite its current (2016) economic crisis. In response, energy independence has become a buzzword and developing countries especially have begun exploring alternatives to their grids. Falling prices and increased efficiency have begun to turn the tables, bringing RETs and DG into the realm of affordability. What would this shift look like, and what would it take to make it happen?

1.2: A Conscious Effort

What if the world opted out of the current trends and focused on sustainable development – what would that involve? Though it may be attractive to make a massive transition to grid-scale RETs, geographical and economic limitations make this nearly impossible. The challenge is two-fold: current electrification needs to transition to RETs, and the global un- and under-electrified majority demands access. Not only would a grid-scale transition to RETs be unrealistic for most countries, but simultaneous and rapid grid extension would make such a transition impossible. It turns out that the solution to the grid extension issue may also provide the most practical alternative to fossil fuel expansion.

Distributed Generation (DG) simply means the generation of electricity separate from, or in addition to, a regionally centralized grid (author's definition). Everything from rooftop solar panels on a forest cabin to village-scale micro-grids counts as DG, and there is no limit to the variations possible. Perhaps the most popular version currently is the solar home system (SHS) – prefabricated generation, storage, and end-use units that have sprung up all over the developing world. With the help of start-up funds from donors and scattered subsidies from governments, SHS companies have long been established and self-sustaining, providing electricity service quickly and (relatively) cheaply to areas that are not likely to see more advanced alternatives any time soon. The challenge is to move beyond just the basic service provided by something like a SHS and toward a more scalable, high quality method of DG.

Chapters 2 and 3 will directly address the major logistical and social considerations for DG in general, setting up the case studies in Chapter 4 and discussion in Chapter 5.

Chapter 2: Technology Selection and Demand-Side Management

The aim of this analysis is to explore the factors of, and challenges facing, renewable micro-grid technology in rural villages. Beyond generation technologies, which will be discussed, one of the larger challenges facing project developers is the management of electrical loads from customers on micro-grids. This practice, commonly called Demand-Side Management, or DSM, includes methods ranging from flat load limiting to complex tiered pricing structures and auxiliary circuits, all of which will be explored in this chapter. In Chapter 4, DSM options will be applied to projects in Nepal, India, and Tanzania, taking into consideration relevant technology, policy, and socioeconomics of the communities involved.

2.1: Generation Type by Limiting Factor

DSM as a practice does not originate from rural electrification; utilities of any kind implement DSM strategies as a matter of course world wide, from leveling electrical loads to incentivizing water conservation. By definition DSM simply means the influence of consumer electricity use through incentives, which can be in the form of price structuring, supply restrictions, conditional financial benefits, metering, education, and more (Harper 2013; Powers 2014). The question, though, is: why would we want to control customer electricity usage? The answer depends as much on the customers themselves as it does on the type of generation being used, both of which will be addressed in this chapter, changing from site to site and even customer to customer.

Not all power generation is created equal: the average generation of a solar PV array, small wind turbine, or micro-hydro system might be comparable over a year's time, but the minute-to-minute generation behavior is not. Taking solar PV and hydro as examples, we can characterize generation in two ways: power-limited or energy-limited (Harper 2013).

In hydro generation, the supply of energy is relatively constant, meaning that power (the rate of energy conversion) does not fluctuate up or down very far or frequently. In many ways this is preferred because it is largely immune to the intermittency issues plaguing other renewable energy sources, and so hydro is often considered a must-use if it is available. However, because power is limited to what the river can provide, consumers at any given time might draw more power than is being generated, over-taxing the generator and causing a brownout (Harper 2013). This is surprisingly common, even where DSM measures are used, as it is difficult to regulate customers' appliance choices, system bypasses, or other decisions not made in the interest of the greater good of the grid. For the sake of accountability of over-consumers and justice for under-consumers who unfairly experience frequent brownouts, hydro grid operators can employ DSM to encourage consistent use of low-power appliances as opposed to intermittent use of high-power appliances.

In solar PV generation, the opposite problem exists. Solar generates intermittently: it is predictable on a diurnal cycle but is highly susceptible to any kind of shading, especially cloud cover. As such, solar PV is almost always installed in conjunction with some type of storage, typically lead-acid batteries (which are in abundance in developing areas as car and motorcycle batteries) or Lithium-ion batteries (Kazempour 2009). Solar generation can therefore be considered "energy-limited:" the sun only provides a certain amount of energy each day, which is stored in the batteries (Harper 2013). A consumer can draw as much power as they want from the batteries, but they will only be able to draw a limited amount of energy. Someone could use a high-power appliance, like a water boiler, for a short time, or they could use a low-power LED light for a longer time, drawing the same amount of energy in either case. This provides some options, particularly in places where certain industrial activities are expected, such as grinding flour. The downside, however, is that the batteries can easily be drawn down by over-zealous customers to the point that a brownout occurs – this time there isn't an option of simply restarting the generator, as with hydro – and damages the batteries such that the overall capacity of the batteries is permanently reduced. Again, DSM can be employed in this case to encourage overall efficiency and conservation. The limitations for DSM with solar PV are fewer than with hydro, but the potential consequences of poor DSM are greater (Harper 2013).

In summary, the greater goal of DSM is to reduce the likelihood of brownouts and the need for power rationing while still providing equitable and affordable service. While the utility itself can control supply, as with power rationing, customers might end up paying for service that they do not receive, and the unreliability of power could be a hurdle to economic development, the presumed goal of electrification. In other ways, however, DSM is critical to the viability and long-term success of any grid, micro or otherwise. Excess electricity is financially wasteful while insufficient electricity makes for poor service, unhappy customers, inequitable distribution of benefits and burdens, brownouts and, ultimately, damage to the system itself (Deshmukh 2013).

There are countless methods of encouraging particular electricity use patterns among customers, and every power provider encounters different challenges. Most strategies, however, fall into the following categories: (1) efficient appliances, (2) commercial load scheduling, (3) restricted residential use, (4) price incentives, (5) community enforcement, and (6) consumer education (Harper, 2013). These are each described briefly below.

2.2.1: Efficient Appliances

A straightforward solution to energy load matching issues of any kind is the use of low-power appliances. Not to be confused with conservation, which is encouraged through other means, efficiency reduces the overall consumption of all customers without sacrificing services, allowing for greater range of service (more customers) or more appliances per customer given a fixed generation capacity. Efficient appliances tend to come at a higher upfront cost than common appliances, but the energy savings over time can make up for this. In developed countries with expansive utilities and strict policies addressing energy efficiency, such appliances tend to be subsidized either by the government or by the utilities themselves, with extra cost reductions for low-income households (UNDP 2011). In rural developing countries, however, upfront cost is the single greatest barrier to the adoption of most technology (Deshmukh 2013).

This raises the question of whether project developers in these areas should also incorporate the sale or distribution of efficient appliances into their business models, a la *d.light*, which produces solar lamps that commonly accompany the installation of rural solar systems by NGOs in sub-Saharan Africa (d.light 2014). On the other hand, personal experience shows that, given the right conditions, efficient appliances may be the only appliances available to some communities given the adaptable infrastructure and rural grid limitations. For example, again from personal experience, the only electric lighting available to 89% of Tanzanians as of 2008 was in the form of small, battery-powered LED lamps (UNDP 2009). Incandescent, fluorescent, and halogen bulbs are entirely unavailable except in historically urban areas where decades-old development has left its mark in the form of fixtures that require these inefficient light bulbs.

Overall, the provision of or access to efficient appliances is a commonly recommended form of DSM. It reduces the chance of a brownout during peak hours and/or extends the potential reach of the grid to more customers or more appliances, depending on the size of the community and existing industrial electricity uses (Harper 2013). Efficiency is recommended regardless of the type of generation, whether power-limited or energy-limited.

2.2.2: Commercial Load Scheduling

As rural electrification expands beyond the classic SHS model of small DC appliances attached to a few panels and batteries, electrical appliances tend to grow in size as more commercial or industrial scale activities come into play. Beyond the home, where most electricity use is from lighting, radio, or phone charging, larger consumers may need to run grain mills, large water pumps, computers, and more. In a worst case, these loads will draw power at the same time, potentially creating large changes in voltages in the grid (the high current needed to run industrial machinery will cause the grid to drop the voltage to compensate and maintain constant power) and, at worst, a brownout of the entire grid. Rural customers paying a substantial percentage of their income for electricity are decidedly underserved if voltage drops or brownouts are frequent due to commercial or industrial use.

Load scheduling can solve this issue by requiring commercial or industrial customers to operate during hours of low demand or high generation, assuming that large-scale storage has not been pursued as an option (especially unlikely in a rural village setting). By scheduling customers of a solar PV micro-grid, for example, the operator can clump the larger consumers into the hours of peak generation, around noon, and require that they reduce or eliminate their load in the mornings and evenings. In addition, because load scheduling may become an inconvenience for commercial customers, it will ultimately encourage investment into energy storage, particularly with intermittent energy sources or low-power hydro.

In the case of the Nepal pilot projects discussed in Chapter 4.2, battery storage is installed with the panels, allowing operators to monitor the energy usage centrally. The mini-grid currently only serves small businesses and households, but the arrival of a larger commercial customer may require (besides an upgrade to the system generation capacity) the use of load scheduling and the consideration of additional storage.

In essence, commercial load scheduling can serve a range of purposes and may be suitable under both generation types (power- and energy-limited). In the case of consistent, low-power generation such as hydro it helps to smooth the load; in the case of highly intermittent but anticipated generation, such as solar or wind, it helps to reduce wasted energy during peak generation and decrease peak demand (Harper 2013). In all cases load scheduling encourages investment in storage technologies that will allow businesses to operate independent of the grid's generation tendencies.

2.2.3: Restricted Residential Use

One of the more problematic practices in DSM is the restriction of allowable appliances or customer electricity use. Ideally, an energy project developer will supply the exact number and types of appliances that will work in conjunction on the home system or grid, and customers will stick to those restrictions. In reality, however, it can be in a customer's short-term interest to have an additional appliance, or to bypass the system altogether and install a full outlet in their home. DC systems don't usually have outlets, but instead supply power directly to lights, chargers, etc., making them more difficult to take advantage of and reducing the need for restriction. AC systems, however, can support outlets, and frequently do despite design intentions. The result, naturally, is frequent voltage drops and brownouts (Harper 2013).

The most direct solution is to ban or restrict certain appliances or usage; but without a method of enforcement this quickly falls by the wayside as customers find bigger and better appliances or bypass individual metering to overdraw the system. Culture and community involvement play a major role in the type of restriction that works: according to a 2013 study by Berkeley Labs, communities served by mini-grids with restrictions based on verbal agreements routinely broke the agreements and caused regular brownouts. The noted exception was in a village identified by the authors (though no indicators or methods were given) as "predisposed" to rule by consensus (Harper 2013). The global development community has largely misunderstood the question of "predisposition" or informal social arrangements, discussed in more depth later (Easterly 2006, 87). Development's "planners" (Easterly 2006; Sirolli 2012) have long pursued the top-down application of the West's market structures and social laws, including DSM, to little success in developing areas, ignoring and even undermining local structures (Easterly 2006, 101). Harper's admission of the failure of energy developers to utilize or even understand local methods of accountability/consensus indicates that the energy development community is as inexperienced as the rest of the development community, if not more so.

2.2.4: Price Incentives

A common DSM measure in many areas is the use of adaptive pricing to encourage conservation and efficiency, as well as load leveling. These pricing schemes come in many forms, the most common of which are capacity-based (power-based) and consumption-based (energy-based), appropriately called for their applications to the power-limited and energy-limited generation types (see Section 2.1). In addition, pricing schemes are necessarily often paired with metering devices to monitor usage and inform both customer and provider (Deshmukh 2013).

Capacity-based pricing is the simpler of the two: customers are charged by the maximum power they are allowed to use at any given time (e.g. they can use up to 30W for $5 a month, or 60W for $8 a month, etc.). Typically, multiple power tiers will exist for customers to choose from (analogous to a monthly mobile phone plan), but overall the billing is easier to monitor and enforce through written agreements/contracts or, more directly, with current limiters that gauge the power into a home and limit the current (voltage is already set by the generator), thereby limiting power (INENSUS 2014). Current limiters are fairly standard devices used to prevent fault currents and surges, among other tasks, and are increasingly used as a standard DSM measure for micro-grids (Gham Power 2014). Though capacity-based pricing is simple to apply to power-limited generation systems, the downside is that customers will not always use the power they are paying for (again, like a cell phone plan), a major problem in a community that already has trouble affording electricity or predicting electricity needs. Also, anyone wanting to use a single high-power device like a water heater, even infrequently, is forced to pay a higher flat rate.

Consumption-based pricing is able to get around many of the challenges facing capacity-based pricing systems by removing restrictions on the types of appliances or consistency with which they are used (Harper 2013). Instead, this pricing scheme looks only at the actual energy consumed and bills customers on a per-kWh basis. Most people in developed areas will recognize this as the basic billing mechanism used by utilities, where monthly bills inform customers of their kWh consumed and charge a (usually) consistent rate. This requires the use of metering, which adds disproportionate upfront cost to the system.

One of the greatest benefits of consumption-based over capacity-based pricing is the encouragement of conservation. A customer paying for maximum power all the time will be incentivized to be more thoughtful about when they use appliances, but will actually fare better by using as much energy as possible to make the most of their allotment. With consumption-based pricing, customers always fare better by using less. The downsides, however, include the need for reliable and accurate metering, and the possibility that peak power demand will exceed supply at any given time, resulting in a brownout.

One way to mitigate this uncertainty is through price incentives, such as time-of-use pricing, tiered pricing, and real-time pricing (Harper 2013). Time-of-use pricing identifies peak and off-peak demand periods and then assigns higher prices during peak and lower prices during off-peak to incentivize load leveling, which is an enormous benefit to utilities and therefore customers (PG&E-2 2014). This, however, requires a thorough analysis of grid load dynamics on a yearly scale or longer. In addition consumption trends become more difficult to predict with smaller grids, as the variation in individual customer usage becomes a larger proportion of total demand (someone turning on a light bulb in Kathmandu would not be noticed by the utility, while the same light bulb in a small village would cause a noticeable spike). Nonetheless, time-of-use pricing can play a role in DSM of rural grids, especially where storage is limited or industrial uses coincide. This scheme is fairly common in large utilities in developed countries, but is still largely experimental in other areas (2014).

Tiered pricing targets conservation and efficiency rather than load leveling (though the two are related). The energy provider sets block prices on ranges of energy consumption per billing period, with the lowest range of consumption costing the least per kWh and the highest costing the most (PG&E-1 2014). This particular form of tiered pricing is called "inverted block rate" pricing, and it has several effects. The first is to "nudge" heavy consumers towards conserving their energy use and/or investing in more efficient appliances. These consumers pay the lowest price until their consumption crosses into the next tier, at which point they start paying a higher price per additional kWh, and so on into the subsequent tiers, resulting in an overall higher average price per kWh at the end of the billing period (AEP 2014). The potential to avoid the upper tiers incentivizes conservation habits and smarter appliance purchases.

A more straightforward approach to encouraging conservation is to simply raise the price of electricity, but this disproportionately affects low-income households, particularly those with poorly insulated homes or cheap appliances. The inverted block rate bypasses this potential pitfall by maintaining or even lowering the cost of energy for customers who consume the least, who are typically low-income. The downside, however, is its accessibility. Inverted block rates tend to be confusing to customers, and can penalize certain customers that share grid connection with heavy consumers, as may be the case with renters and sub-letters, or in rural micro-grid systems depending on the distribution network (Harper 2013).

Real-time pricing works similarly to tiered pricing in that higher rates are charged during peak demand. The difference is that real-time pricing adjusts the price in response to demand, rather than in anticipation. This is a newer strategy in developed countries that can afford the necessary smart metering and notification mechanisms (Harper 2013). To work effectively customers require real-time monitoring and notification so that they can adjust their usage accordingly. Wirelessly controlled smart power strips and smart-phone apps have made real-time pricing more viable and adaptable to fluctuations in demand, allowing the few utilities that have implemented this option to smooth the load.

2.2.5: Community Enforcement and Involvement

While the methods discussed to this point have been direct and measurable in their implementation and evaluation strategies, other DSM methods can be more nuanced and unpredictable. On a city or county scale, blanket policies and financial incentives are the only practical, tried-and-true ways to address collective electricity usage; a population of such size and diversity would not be able to agree on social methods of self-regulation. On a village scale, however, collective self-regulation may find success. Smaller, rural communities regularly set their own policies around the use of "commons," resources that are used by all but potentially at risk of abuse by a few. In rural Tanzania, for example, each village adopts its own policy for addressing deforestation, voluntarily restricting the harvesting of certain trees for firewood or agricultural burning practices. In rural Nepal, villages manage water resources collectively to ensure upkeep of dykes and canals, and to regulate irrigation.

Community agreements are often used for electricity usage as well; representatives from the community form a committee that then works with the project designer to determine appropriate appliances to allow or restrict, informal load scheduling, or any other measure deemed appropriate in the context of that particular generation scheme in that particular community (Deshmukh 2013). The difficulty, however, is that the "commons" in this case is not *observed* in common: the electricity itself is commonly available, however the actual usage is hidden from public eye and therefore easily abused. The result, as mentioned earlier, is sufficiently widespread dismissal of the community agreements resulting in frequent brownouts and gradual degradation of the generation and/or storage systems (Harper 2013).

For community agreements to succeed, they would need to be structured in a way that builds on that particular community's cultural norms and values. Harper (2013) refers in the Berkeley Labs study to several cases in which adjustment to the community electrical usage agreement resulted in dramatically reduced brownouts, but implies that these are rare. Whether in addition or response to this, the relevant literature (as cited in this paper) tends to treat these social DSM methods with skepticism, acknowledging them as options but not ones that are well understood or predictable. While the actual decision of what behavior/appliances should or should not be allowed on a village micro-grid is fairly straightforward – it is determined by the system's capacity and availability – the chosen method of enforcement is not. It is possible that enforcement is not considered adequately in the design phase of some electrification projects, allowing for unchecked customer abuse of the system and, in extreme cases, corruption of the supposed enforcement entity. Methods of community information gathering and project design are discussed in Chapter 5.

The extent of corruption around these grids, while recognized, would be difficult to identify; therefore an analogous example (again from personal experience in Tanzania) may illustrate the type of corruption that can exist. A cluster of three villages in Tanzania's southern highlands collectively installed a large well and distribution system that was meant to serve as the primary freshwater source for each of the three villages, where drought had become more frequent with deforestation and climate change. The village governments appointed one resident to operate the water distribution network as a part-time job, responding to the need of each village by rationing water equally between them. Instead the operator cut one entire village off from the supply and demanded bribes before he would continue the service. Once he had been paid and resumed service to the village, the other villages (who had been receiving more water recently) offered bribes to repeat the shut-off, and the cycle continued.

While this is an extreme example, the remoteness of many communities in developing countries makes law enforcement difficult. Oftentimes business owners in smaller, remote communities represent the local political and economic power. If energy generation and distribution is controlled by businesses, project developers and stakeholders will have to consider enforcement and accountability where community agreements are pursued as a method of DSM. In other cases a mafia, illegal but legitimate as far as the community is concerned, enforces and directs local laws (Easterly 2006, 89).

2.2.6: Education and Outreach

A common response to the unpredictability of user behavior in any electrical grid is customer outreach and education (UNDP 2011; Goulden 2014). This can manifest itself in any number of ways, but generally the goal of an electrical grid project developer is to provide education or training in the following areas: technical limitations of the grid, consequences of overload, methods of distributing electricity, power ratings of appliances, home energy efficiency and phantom loads, load management devices, tariff structures and collection/billing, enforcement methods and penalties, and incentives for smart consumption (Harper 2013). These can be pursued via community meetings, small group workshops, or even in-home visits depending on the community's needs and availability. However, education should not be assumed as a catchall for addressing "tragedy of the commons" issues – indeed it has proven less effective than many had hoped in the case of climate change – but may instead be viewed as a necessary aspect of any project introducing a new service with new challenges to a community. Indeed, reviews of case studies of mini-grid projects concluded that outreach and education should be presumed aspects of any project implementation (Harper 2013; Sarangi 2014) and should be pursued on the community's own terms.

In addition, developers should not view community outreach and education as a legitimate excuse to apply Western structures to a given project. A community's education about a project does not imply acceptance or even interest. Such education, if done poorly, can even undermine a community's ability to invent and develop homegrown solutions that the developer never considered. As Ernesto

Sirolli quotes, "'There is a problem with public meetings: entrepreneurs never come'" (2012). Instead of a one-way communication to bestow the developer's values on the community, education is first used to help a community make an informed decision about potential project mechanisms and DSM to adopt or invent, and finally to ensure that everyone is aware of what the grid provides them and the impact of their own consumption decisions on the grid.

2.3: Case Example

Examples of tiered pricing and time-of-use pricing were discussed earlier in the context of large utilities such as Pacific Gas and Electric (PG&E). These methods are largely practicable in developed countries but less so in small mini-grids where the technology required is too expensive or the grid infrastructure is not designed to support it. The following brief example and case studies in Chapter 4 illustrate attempts at some of the other methods of DSM discussed so far, particularly incentives for using efficient appliances, community education, and community agreements and enforcement.

Northwestern Energy (NWE), which serves most of western and central Montana and parts of South Dakota, spends a certain percentage of its annual budget on promoting energy efficiency among its customers. This can take the form of anything from city retrofit programs to outreach campaigns targeting large energy consumers. Perhaps their most popular program is the Energy-Plus (E+) program that provides, among other services, free home energy audits and minor retrofits to any customer that requests assistance (NWE 2014). The assumption is that greater efficiency among consumers will result in reduced loads, especially at peak hours, reducing NWE's need to purchase peaking power (much more expensive per kWh than base load power, such as from coal or hydro) and thereby recouping the utility's E+ expenses. The externalized savings, and the impetus for the efficiency program mandate, are those of emissions from power plants that are no longer being run.

2.4: DSM Technology

Throughout the previous section several forms of technology were referenced in the context of their associated DSM methods. This section will go into greater detail about the two major types of technology – meters and limiters - available for DSM as highlighted by practitioners and researchers of rural electrification and mini-grids.

2.4.1: Meters

A common form of DSM on any grid is not necessarily the command-and-control style of DSM that is most often associated with the term, but is instead more closely associated with methods of billing. Meters provide the basis for DSM by monitoring some aspect of electricity use and informing the customer and/or the provider in order to accurately bill for the service provided and help both parties make decisions about good usage or service practices.

The vast majority of customers in developed countries use conventional meters, namely those meters that simply measure and report the total kWh used in a given time period (typically a month) allowing the provider to charge the customer accordingly. In the context of small, renewable energy mini-grids, these meters can be most effective in energy-limited systems (wind, solar) as the power provider is more concerned with customers using too much energy than too much power (see previous section). One advantage of conventional metering is its potential to be coupled with smart billing (per kWh) to encourage conservation (Harper 2013). While the meter alone can help to decrease consumption, further combining it with a current limiter (discussed in greater detail below) could further encourage the use of efficient appliances and reduce the risk of brownouts. The downside of conventional meters is that they, themselves, draw energy. In addition to the upfront cost (around 20 USD), customers would have to factor in the cost of electricity for their own meters, potentially a significant portion of their total usage if they only want electricity for occasional, basic services.

An alternative to the conventional meter is the prepaid meter (Harper 2013). The operation of a prepaid meter is analogous to buying phone vouchers. In many developing countries (most of sub-Saharan Africa, for instance), cell phones are operated not on monthly plans but on a system of buying vouchers and texting a code to the phone company to increase the balance. The prepaid meter works the same way; customers can purchase vouchers from a vendor in the village and text the code to a server that automatically increases that customer's electricity allotment (in kWh) (GP 2014). On the surface the prepaid meter resolves many of the issues presented by the conventional meter. Payments and service are more reliable due to the automatic nature of the billing, customers can make smaller payments on their own schedule and without the need for meter readers, and the system of vouchers is already a comfortable one for many rural communities.

The challenges arise in the logistics. Each meter runs from 35 to 50 USD on the low end (Harper 2013); while this cost can be paid off through the greater efficiency and lower billing costs, the upfront cost may be too steep for individual customers to afford. Also the prepaid meter system does not provide a method of restricting peak power use, so it may be necessary to pair the meters with current limiters, an additional cost. One method proposed to address the issue of peak usage is to separate customers into primary and auxiliary circuits (Sarangi 2014; Harper 2013); primary circuit customers are the last to be shut off in the case of an impending brownout (such as clinics that need to keep vaccines and blood cold) while auxiliary customers are the first to be shut off. The determination of who counts as primary or auxiliary would depend on the community's values and consensus. This can be (and often is) a method of "load shedding," in certain contexts also referred to as a "rolling blackout." More intense versions of this method keep a rotation of customers that are blacked out for the purpose of reducing load.

One of the primary concerns for project developers is the assurance that vendors will appear in order to sell vouchers or codes for use with the prepaid meters (Harper 2013). The lack of vendor could present a challenge both to the developer and the customers. There is also great potential for a business opportunity, however, and this has been the conclusion of case studies in Tanzania and Haiti. In these cases customers were charged a small connection fee and then purchased scratch cards (vouchers) from local vendors. Personal experience in Tanzania provides similar evidence: the rise of cell phone usage in the region resulted in business opportunities for tens of thousands who took up the job of selling phone vouchers on buses, on street corners, in traveling markets, and so on down to individual students selling vouchers during tea break at school. The same village that saw the solar installation on the school was connected, three years later, to a nearby hydroelectric dam. Customers were, again, charged a small connection fee and then purchased electricity by the kWh using codes from local vendors. Personal reports from the village consistently indicate that the business is expanding: one resident remarked recently *ni kama mjini kabisa* – "it's just like in town."

On the more expensive end of the meter spectrum are smart meters, or advanced metering. These are fairly expensive and not widely tested in poor, rural areas (and so won't be explored in this paper) because they require the combination of real-time metering and control systems that manage generation and storage in addition to distribution and billing.

2.4.2: Current Limiters

Beyond metering, current limiting is the most common method of DSM (Harper 2013). The goal is straightforward: limiters keep customers from drawing too much power at any given time while simplifying billing at low cost. The technology available for current limiting is varied, ranging from basic fuses (cheap but inaccurate) to electronic circuit breakers (expensive but accurate) (ESMAP 2000). In each case the mode of action is simple: limiters open the circuit if current rises above a given limit, a standard safety requirement in almost all appliances and households. As noted earlier, current limiting also offers power distributers a way to avoid brownouts from peak loads.

Two current limiters are designed primarily for mini-grids: load checker thermistors and electronic circuit breakers (Harper 2013). The thermistor restricts current within a certain range but is easy to tamper with or bypass. It is relatively cheap, around 5 USD, but is inaccurate and difficult to maintain without disconnecting all loads. The electronic circuit breaker represents the opposite end of the spectrum: it is more expensive (15 USD unless produced locally) but much more accurate (ESMAP 2000). Other than price the downside is that breakers are easy to bypass with limiters that have higher current ratings (essentially ignoring the breaker's effects by providing a path of less resistance, to borrow a colloquialism) (Harper 2013).

In general these simple current limiters can provide a fundamental service for grid stability as long as they can be secured from tampering and the degrading effects of weather. However they do restrict consumers in several ways. As noted earlier, a set current (and therefore power) limit means that customers using capacity-base billing and who aren't using their allotment are paying for a service they are not receiving. In addition customers who want to occasionally use high-power appliances are forced to pay a higher flat rate. The combination of factors could incentivize people to use as much power as possible under their limit, and potentially bypass the current limiters in order to use larger appliances without paying an unfairly (from their perspective) high rate.

Smart current limiters address this issue by monitoring supply and adjusting the current limit accordingly. During peak supply customers are alerted and allowed to use high-power appliances; they are similarly alerted when supply goes down and the use of certain appliances will cause them to be cut off (Harper 2013). This technology is still in development, but pilot projects so far have shown significant drops in brownout rates while reducing wasted energy and increasing welfare services associated with electricity usage (2013).

A similar technology is a distributed intelligent load controller. As with the smart current limiter it is likely expensive and still in development, but it operates by selecting and disconnecting dispensable consumers at peak (on a meter-by-meter or even appliance-by-appliance level) and allowing them during off-peak. Neither the load controller nor the smart limiter are likely to be widely used by poorer communities, but the expansion of distributed generation in developed countries (as evidenced by the 2014 announcement by the largest European utility that it will begin focusing on distributed generation) may provide a strong market for these that will eventually make the market more accessible to developing countries.

Further details about specific technology and devices used for DSM can be found in Appendix A, Tables 1 and 2.

Chapter 3: Viability and Sustainability Considerations

If any statement can sum up the lessons learned from rural energy development, it is this: there is no silver bullet. In fact, the search for such a single plan is a disservice to those in need: while the West searches for a catch-all to drive economic development, it overlooks the successes of smaller, homemade solutions discovered in the name of business or chance. "... asking the aid agencies and development workers to attain utopian ideals makes them much worse at achieving the doable things… It also makes them much less accountable for making specific things work, as focus on the Big Goals of the Big Plan distracts everyone's attention from… more modest, doable steps to make poor people's lives better" (Easterly 2006, 29).

Literature on the topic has been able to communicate this reality, at times using case studies like the ones presented in this paper to illustrate the range of challenges facing everyone from un-electrified residents to national policy-makers. But where most literature informs policy, financing, or engineering, this paper seeks to inform project development as a whole within a range of political and economic environments. Project designers exploring rural electrification may not have influence over policy and economic development in their respective regions, but they can recognize the aspects of their given environments that make one technology choice or finance scheme more viable than another. Similarly, a savvy policy-maker can recognize and address gaps in national or local policy that inhibit sustainable energy development or discourage investment. In either case, there are key indicators and factors that can inform decisions to accommodate a unique social environment, or alter the greater environment to encourage the desired development.

Before beginning any quantitative aspect of project design, developers must consider the following to gauge viability:

- What energy resource is being replaced or challenged?
- What has been the customers' exposure to electricity services, and what is their expectation or demand?
- Will electricity need to be scaled up gradually, immediately, or not at all?
- What is the customers' willingness to pay?
- Is grid extension expected in the area and, if so, will customers demand compatibility?
- What policies exist to promote or discourage the proposed project, and are those policies expected to persist?

3.1.1: Viability: Competing Resources

The immediate success of introducing a new energy resource depends on the resource that is being replaced. Diesel and hydro in Khotang replaced biomass and kerosene and have been, in turn, partially replaced by SHSs. Those SHSs are now facing competition from solar micro-grids. In Luhunga, solar directly replaced kerosene, and was replaced by hydro and a different model of solar. Some relative advantage, whether higher quality service or lower costs, drove each transition. But while a project developer must accurately gauge the competition before making initial design decisions, simple logistical considerations do not account for every factor. Cultural momentum is a powerful driver of change, and resistance to change, anywhere in the world. The most directly analogous examples of this inertia are the pushes for efficient cook stoves and water pumps, particularly in sub-Saharan Africa.

As discussed in the Luhunga case study (Chapter 4.4.1), residents have relied on biomass for cooking for their entire history; a pot sits on three large stones and firewood (*kuni*) is placed between the stones (a method called *mawe matatu*, or "three stones"). The one common variant is a charcoal stove, similar to charcoal burners in the west. The social effects of firewood dependence are far reaching: lung disease, disproportionate burdens on women and girls, absences from school, increased risk of kidnap or rape, deforestation, and the resulting damage to water systems and local ecosystems are all quantifiable effects on the HDI tracked by the UN (UNSTATS 2010; WHO 2016). In response, hundreds of organizations have poured resources into designing, purchasing, and/or proliferating efficient cook stoves among rural populations. Results have been meager at best with only a few taking hold, and many of those have been of local design. The failure of these initiatives to take hold, beyond the usual problems of non-sustainability or cultural impropriety, can often be attributed to cultural inertia: people are accustomed to what they've always used, and the negative effects are too gradual to cause alarm. My own attempt at building efficient cook stoves in Luhunga met strong curiosity and interest at the beginning, followed by disinterest and abandonment in favor of customary methods.

The massive aid effort to drill wells and install pumps in drought-affected areas has illustrated similar inertia. One classic story comes from Tanzania, where aid organizations have drilled and installed thousands of well-pump systems, and thousands of these now sit abandoned. In one village westerners installed a pedal-powered well and the residents used it for a short time before abandoning it for the original method – walking several kilometers to the river to fetch water and wash clothes. As the developers discovered too late, it was considered inappropriate for women, the primary users, to lift their legs in public. And since the pump was in the middle of town, the women missed the social freedom and connection they felt at the river.

Electricity development faces its own challenges. Some societies, for example, place spiritual importance on, and are therefore protective of, traditional energy resources like wind, water, sun, or anything removed from below the earth's surface. Developers will not encounter the same limits or freedoms in any two sites and must be open to exploring alternatives that complicate preconceived notions of optimization. Readers should also note that this section is not a discussion of some "other" culture: local idiosyncrasies are universal and stem from a wide range of religious views, poor understanding (as in the 2015 case of a North Carolina town refusing solar because it might deplete the sun), or simple inertia (Osborne 2015).

3.1.2: Viability: Customer Expectations

One catch-22 of the product development world is that customers sometimes (often?) do not know what they "want" or "need" until they are presented with an option. Electricity development faces the same issue. One might expect that a previously un-electrified village will settle for minimal service – some lights and phone charging capacity. And at times this may be the case: William Kamkwamba's village in Malawi, featured in the book *The Boy Who Harnessed the Wind* (2009), had never had electricity before William built a home-made wind turbine. Without the resources to pursue more sophisticated systems, and emboldened by the use of local resources and local ingenuity, the village continued to expand and improve its own turbines, content with and proud of the limited service they were able to provide.

Other communities have different expectations. Either their proximity to electrified areas or history with development projects may have instilled higher expectations for what an electricity system should provide. A project developer is therefore best served, along with the community itself, by thorough research. Higher levels of expectation require higher quality service and associated increase in cost. Once grid-quality service is required – involving transformers, inverters, and code-compliant components – cost increases disproportionately to the service quality as perceived by the customer (individuals do not necessarily observe the difference between aluminum and copper wires, or between DC and AC power). As such, customer expectations are a primary indicator of willingness to pay, to be discussed in the next section.

3.1.3: Viability: Willingness to Pay

Embedded within the question of expectations is the surety of payment. Put simply, willingness to pay, as a describable quantity, depends on too many variables to be accurately predicted by indirect means. After gauging the scope and quality of service that a community might expect, a project developer can design several options to present for feedback. Each will have a cost associated with it and an expected upfront and continuing input from the community. Based on these options a willingness to pay, in terms of monetary payment rate (per kWh or per month, depending on the payment method), can be determined as a threshold. The developers can make any changes to the system that would keep payment within that range.

Despite its unpredictability, willingness to pay can be estimated for at least a cursory understanding. A community's level of poverty can tell a developer the rough range that might be expected, but not to great detail. A solar engineer visiting a village in Nepal's Terai region (southern lowlands) found the community's poverty to be so visible that he declined to even ask what residents might be willing to pay for electricity. But an Indian solar technician visiting a similar village in the same region referred to the community as "wealthy" because of its close proximity to the grid and corresponding high expectations for electricity service despite its poverty (MGP 2015).

Willingness to pay also draws from local economic factors, such as the relative prices of other goods and services, or general awareness of local limitations to cheap electricity. The U.S. state of Hawaii, for example, pays electricity rates almost triple those of Montana, while the cost of living and income ratios between the two states are much less (EIA 2016; MERIC 2015). Lacking direct access to traditional forms of energy generation, Hawaiians are aware of (or at least accustomed to) the higher cost of importing fuel oils and natural gas, and therefore "willing" to pay more for electricity. In areas where transportation and trade infrastructure is still a limiting factor of village-to-village commerce, price localization can still play a deciding role in making one energy technology more affordable than another.

3.1.4: Viability: Grid Arrival

The arrival of the national grid can either encourage or discourage scalability and, though it may not be possible to accurately predict, developers must consider and discuss the eventuality with the community. If customers expect the grid to arrive, they may be willing to accept minimal service in the hope that it will become obsolete when grid power becomes available. Otherwise, any electrification project will need to consider the possibility of establishing grid-quality service from the beginning, or scaling up with demand over time.

3.1.5: Viability: Policy

The broadest of the *viability* considerations, government policy can make or break an electricity development project at any point in its lifetime. Subsidies that existed one year may be gone the next; trade tariffs may change to favor one import over another. The case studies in Chapter 4 illustrate that even mild subsidies can be powerful in driving one technology over another, unpublicized subsidies are easily abused, and supportive policy can cause as much harm as good when it is inconsistent. A classic example comes, again, from the U.S., where production and investment tax credits were renewed on an annual basis until 2016. Each year, the priorities of the Congress could cause final decisions to be put off until the end of the year, leaving investors and energy companies in limbo and therefore uncertain about pursuing projects until the next year (Nussbaum 2015). This slowed development considerably and kept technology from advancing and prices from dropping as quickly as they would with a longer renewal period.

Many developing countries experience even greater legislative tumult that leaves energy developers without a clear sense of which policies are dependable. Especially with micro-grids or other community-scale projects, research alone can take over a year, and the first year or two of operation is subject to rapid iteration as the implementing entity "patches" its product and adjusts to early changes in demand. But project developers can also have a positive influence on policy by proposing pilot projects that require policy changes. Industry proposals can serve to meet a demand that the government has so far struggled to meet due to scarce resources, limited expertise, or high turnover, and can therefore encourage new policy. Conversely, where government seeks to develop, it can open the door via subsidies and other policy mechanisms for industry to drive that development. Generally, however, it is upon the project developer (industry) to identify existing policies, predict which will be in effect throughout the project's development, and design accordingly.

3.2: Sustainability

While viability considerations can help get a project off the ground, there remains the pervasive question of sustainability. Naturally we must be wary of using the term "sustainability" too lightly, given its over-use in the development world. "The literature is strewn with the terms 'sustainability' and 'sustainable development'… but too seldom are [they] given a clear and consistent meaning"

(Adams 2001, 5). For the purpose of this paper, and to avoid making "high-sounding statements with very little meaning at all" (2001), sustainability requires the thorough consideration and adequate resolution of the following questions. Can the project survive and remain relevant through changes in demand, new technology, competition, and more? Once the original developer completes installation, can the developer and its creation survive apart? Should they? The following considerations form the framework through which designers can gauge and plan the longevity of their electrification projects.

- Independence from outside funding, even if only after start-up funds have been secured
- Developer buy-in for a significant portion of the project's lifetime
- Customer ownership, either immediate or gradual
- Flexibility in response to changing demand, climate, or competition
- Reasonable upfront cost to customers
- Demand-side management that minimizes misuse and system degradation while respecting customers' independence

3.2.1: Sustainability: Donor Dependence

The already impressive flow of donor funding into the global development project is likely only to grow as donor countries fulfill their commitments to the COP21 Paris climate agreement, or equivalent. But the equally impressive rate of electricity development cannot be matched, dollar of donation for dollar of expense, by donor funding alone (IEA 2011). Dependence on outside funding for the bulk of the system, or for its continued operation, can deprive the recipient community of ownership and lower the incentive of both the developer and the community to thoughtfully design the system for optimal performance, relying instead on initial excitement and good publicity to ensure continued funding (Moss *et al.* 2006). Donor funding can be a powerful tool, probably even a necessary one, but only in certain contexts.

All but one of the subjects in the case studies in Chapter 4 relied on large donors at one time, but the duration and/or repetition of that dependence is one indicator of success. When a developer's business model depends on donor funds to sustain it from project to project, it aligns its priorities accordingly. A typical, for-profit business may receive start-up, or seed, funding to begin a new type of project or explore new territory, but ultimately its goal is self-reliance. If its income from one project cannot sustain it through to the next project, it will fail as a business. Therefore longevity and the associated guaranteed profits of each project becomes the top priority, leading to consideration of its own buy-in, customer ownership, project flexibility, cost, and demand-side management – namely the following sections of this chapter. In short, playing within a market, rather than in spite of it, demands constant feedback and accountability, or exactly what the "big development plan" community lacks (Easterly 2006, 27).

When outside funding drives development, however, the priority for the developers themselves is to guarantee more funding and thus continue working. But outside donors (historically speaking) tend to respond more to a project's or developer's positive publicity than to decade-long performance reports when deciding what to fund (Kopinak 2013). Examples abound of catchy internet videos advocating causes of all kinds, from freeing child soldiers in East Africa to lighting up slums in India. Regardless of the urgency or effectiveness of the cause, clever marketing attracts donors. Therefore a developer (NGO, mission, non-profit, etc.) has to dedicate funds and effort towards fundraising and outreach to its donor base, often necessitating a home office elsewhere, additional staff, and attention to early project success and excitement among clients.

At this point the longevity of a single project does not necessarily affect donor satisfaction compared to that initial publicity. It is more the expression of need (Porter *et al*. 2002), ability to have positive impact, and the positive response from the community (a la the songs of thanks recalled in this paper's opening paragraphs) that encourages funding. Individual projects could completely fail several years later with little or no impact on the greater effort. The following considerations are, therefore, paramount to any developer's attempt to create effective, lasting electrification opportunities for invested communities.

3.2.2: Sustainability: Developer Buy-In

Under the old model of distributed energy, companies sell and install systems to customers, who are responsible for paying the upfront cost. Financed and leased systems followed, particularly with the rise of SolarCity, which was the first to perfect the model of financing the systems they sold (Martin 2014; Malik 2015). Customers can pay over time at a low interest rate until the total cost plus interest is paid off and they acquire total ownership. In many ways this method mimics the auto industry, with loans or leases managed by the company itself rather than a third party. The most recent step in this evolution is the separation of sourcing/installation from financing, and is most common with solar. Firms entirely dedicated to financing are able to process requests from customers all over the country or world and contract local companies to source and install components, and often provide technical support for a specified period of time. But while these methods have largely evolved in developed areas, they have only recently expanded into rural or developing areas.

Without financing mechanisms in place, energy developers are limited, by logical extension, to three options: they can (1) pay out of pocket and essentially "gift" the system to the community (total developer buy-in), (2) demand that the community pay for the system up front (zero developer buy-in), or (3) gift the system and demand some level of partial repayment (see Chapter 4.4.1). If communities are too poor, upfront payment (2) or partial repayment (3) are not likely options, leaving a developer in a poor area few options. But if the system is gifted (1), the developer cannot guarantee community buy-in and thus longevity, and must depend on donor funds. In either extreme – total developer buy-in through gifting (1) or zero developer buy-in through complete community payment (2), there is little incentive for both parties to work towards a sustainable system. The alternative to these three scenarios is for the developer itself to buy into the system in some way, similar to the model employed by SolarCity and others.

With developer buy-in, the installing firm or even a third party pays for the upfront cost of the components and installation, and then determines a payback time and percentage, as with any loan, that will give the company a suitable ROI.

This period is usually around ten years - well within the project lifetime of 25-30 years but long enough to keep payback rates palatable. Over that time, customers pay their power bills directly to the developer at a rate that will guarantee the ROI and also be acceptable to the customers. At the end, the developer hands over full ownership to the community to act as its own utility, set its own rates, and determine its own expansion. Aside from a smoother financial ride for all involved, this model also guarantees that the developer will continue to provide technical support and advise local stakeholders in best management practices, all beneficial for its profit and for the community's capacity upon ownership transfer.

A slight modification of this model involves a SPV, or Special Purpose Vehicle (Wilmington Trust 2016; GP 2015), which involves joint ownership between the developer and the collective customer (and, in some cases, a donor). Rather than the developer retaining full ownership until transferring it to a local entity, the two (or more) retain ownership together for a certain period - again, usually ten years. The same advantages apply, namely developer investment in technical support, customer satisfaction, and efficiency; but the community itself has more active control over and investment in system performance. If the developer alone is responsible for collecting payments to bolster its ROI, the community is not terribly affected by under-payment or misuse. But with community ownership from the beginning, a local representative entity is necessarily concerned with its own members' activities. This gives the developer, who is usually not local, a break from dealing with customer accountability, and gives the community experience with management from day one.

In truth, any combination or iteration of the above models may be applicable depending on circumstances. Community interest, the presence of local businesses or other economic activities, poverty level, and other factors will inform the most suitable method of financing. It also may be most efficient to separate the financing from the installation, with one firm providing a payback scheme and outsourcing acquisition and labor to a local company, thereby supporting local business and reducing the literal and figurative distance between technician and customer (SunLender 2016). Some consider such specialization to be the future of off-grid energy development (GP 2015). Whatever the chosen model, however, developers should avoid either extreme – total developer buy-in or zero developer buy-in – and focus instead on creating long-term interest and accountability to create a sustainable project.

3.2.3: Sustainability: Ownership

Ownership can be synonymous with Buy-In in many cases, so this section defers financial ownership considerations to the previous section, and focuses instead on the intangible concept of ownership. A related discussion can be found in Chapter 5.5.

Generally speaking, ownership includes power in decision-making, self-reliance in terms of maintenance and operation, control over planning and expansion, and the sense of responsibility and accountability for all aspects of the system's success. As a developer in any sector, it is important not to confuse *sense* of ownership for *real* ownership. A researcher working in Tanzania noted that outside organizations working with local communities frequently described their work as an "equal partnership," indicating a high level of local ownership. But further investigation showed that local partners did not feel the same way, describing the arrangement as decidedly unequal (Bickel 2009). Many others, both in academia and on the ground, have observed this misrepresentation, making truly equal arrangements all the more notable.

Energy project developers automatically enter into a rural electrification arrangement in a position of power. Experience and expertise give them an advantage over local entities and place them in a position to override decisions with relative credibility. In most situations this is appropriate, but it is also the developer's responsibility to acknowledge its advantage and recognize when it does not or should not sway local decisions. The developer knows its craft better than the community, but the community knows its capacity better than the developer. Capacity can include resource options, ability to pay, ability to collectively manage resources, etc. The solution is not for one entity or the other to dominate, but for both to communicate freely and listen readily through all steps of the process. A developer's pre-determined plan is the "kiss of death of entrepreneurship," undermining local ingenuity and problem solving (Sirolli 2012). Despite the abstraction, the mutual trust this creates leads to real ownership on the part of the customer or community.

3.2.4: Sustainability: Scalability

With regards to two previous sections regarding viability – *Customer Expectations* and *Willingness to Pay*, the other side of the coin is that each of these factors changes over time. A community that will only pay for limited service now will almost certainly demand expanded services in the future, potentially the near future. Neighbors will expose a community to other services; or its own economic growth, spurred by the introduction of electricity or other factors, will drive demand up. Regardless of the cause, project developers should assume scalability as a requirement from the beginning. Whether it takes the form of generation modularity, oversized distribution capacity, or some other technical preemption, scalability should factor into the system design when presenting the community with design options and gauging willingness to pay.

Scalability will also affect the method and duration of developer buy-in. If customers expect a gradual expansion of service, the developer may benefit from extending the payback time to assist with a planned up-scaling. If, on the other hand, customers expect a sudden expansion due to the arrival of industry or the national grid, the developer may prefer an earlier transfer of ownership in order to receive its ROI before investing in a second, major phase of the project.

3.2.5: Sustainability: Cost of Participation

Section 3.1.3 discussed the effect of customers' willingness to pay on viability, but this term is rather broad when considering the design details of each project. Connection fees, monetary or in-kind contributions for installation, home appliance installation, ongoing electricity rates, and maintenance costs all factor in. All of the upfront costs – connection fee, pre-connection home installation, and contributions to the installation cost (see Section 3.2.2) – might be considered the "cost of participation" and affect the rate at which the service might be expanded or even adopted elsewhere. This section will focus on the upfront costs.

There are several reasons that customers might encounter participation costs depending on the project design. In the case of an SPV or partial payback mechanism, particularly with a micro-grid, the community shareholders may be expected to share part of the up-front cost with the developer and any donors (GP 2015). It may be a small fraction of the total cost, but it requires each customer-to-be to contribute money or in-kind labor. For systems that offer grid-quality power, each household or business will need to install wires, switches, sockets, etc., that are up to code before the connection can be made. Finally, in the case of community micro-grids, each customer typically pays a connection fee, equivalent to a month or two of electricity bills, for installers to run the distribution network to that customer. Together these fees can create a barrier to participation if they account for a disproportionate fraction of a customer's income.

Due to economies of scale, any given electrification project requires a critical mass of participants before being considered viable (GP 2015), and each component of a community's willingness to pay can be discussed and set accordingly. But the long-term sustainability of the project depends on growth and therefore assurance that, once exposed, other residents will opt into the system. Whereas the initial participants had a say in the ratio of upfront to ongoing costs via information gathering sessions, the outcome will more likely favor their perspective. With the system and payment rules already in place, newer customers will instead be confronted with the take-it-or-leave-it upfront cost of participation. It is therefore in a developer's (and community's, in the case of joint ownership) best interest to keep the cost of participation as low as possible. Affordable entrance can be achieved any number of ways, but most commonly through slightly inflated ongoing costs (higher electricity rates) or a longer payback period.

Analogous schemes abound in which companies offer reduced entrance fees knowing that, once someone is participating as a consumer, they are likely to continue and thereby guarantee a profit/ROI for the business. Mobile network companies, auto dealers, banks, and just about any type of business short of public utilities will advertise the low cost of entry. In cases where an electrification project is meant to expand and evolve, the lower cost of participation can drive faster expansion and therefore more rapid iteration and flexibility. In short, treating such projects as a business, even when they are not, can create greater sustainability.

3.2.6: Sustainability: Demand-Side Management

Chapter 2 outlined the specific DSM technologies available or in common use, as well as their respective ideal contexts. In terms of pure design, DSM choices should be straightforward: the common appliances, usage patterns, and generation types should dictate clearly which combination of technologies or rules will result in optimal system performance. The challenge, rather, is to balance ideal technology with appropriate technology. In many cases the ideal technology choice is not affordable or easily maintained, and therefore not appropriate. Project developers must therefore find a way around barriers to engineering decisions and consider the less tangible aspects of design. How can local resource management practices play a role? To what extent can community ownership alleviate the burden of DSM on the developer? Can technicians and engineers design a similar device locally, thereby bringing down cost and creating local business (see Chapter 4.2.1.3)?

The viability of DSM technology is also subject to change as new devices and programs make their way onto the market. Long a niche industry, individualized electricity management devices are quickly becoming popular in the developed world, driving innovation and reducing costs for all markets. Even a decade ago, mobile phones were not common enough to make prepaid metering possible, and charge controllers could not typically respond to batteries' maximum depth of discharge. But even over the course of the two-month research period in Nepal, GP and MGP engineers noted cheaper prepaid meters appeared on the Chinese market, likely contributing to DSM decisions for the next several years (Chapter 4.2 and 4.3). In this context it behooves the project designer to keep a close eye on available DSM technologies rather than continue to only use familiar devices from familiar suppliers.

3.3: In Context

This discussion in this chapter has been largely abstract. Chapter 4 illustrates the challenges developers have faced, or are facing, in a range of contexts, and provides an opportunity to put these considerations to the test. No one approach is ideal – indeed there may be no such thing – but each has its strengths and weaknesses that can inform our understanding of local complexities and opportunities.

Chapter 4: Case Studies

Case studies are not an exact science; they are by nature anecdotal, they tend to represent a statistically insignificant sample size for the purpose of drawing general conclusions, and their value is limited to the comparisons that can be drawn between them. One would not, for instance, take a lesson learned from one case study and apply it wholesale to a new challenge. It is more constructive to take the lesson from one case study and consider if or why it applies to a new challenge. When reading the following anecdotes and analyses, consider the greater context of the communities, regions, and countries in which they occur. There are historical, political, cultural, economic, and technological forces in play, all of which form the context for, and directly affect, a developer's approach to electricity development.

Each case study evolved from direct interviews with developers, customer interviews, field observations, literature review, or a combination. The analysis in each study is based on experience and quantities (cost, capacity, etc.) were acquired from literature, interviews, or directly from vendors. While not quantified or coded as qualitative research, these case studies illustrate by example the deep complexities of DG development and the (perhaps) surprising variety of approaches to apparently similar challenges.

4.1 Site Selection and Research Methods

Given the comparative value of case studies, I found it necessary from the start to explore DG development in two or more countries that exhibited apparent similarities from a traditional "development" perspective (see Introduction) as well as local differences that would profoundly alter an observant developer's approach to DG projects. My personal experience and ongoing communication with local residents, government officials, NGO staff, and ex-pats made Tanzania an ideal launching point for this paper's research. Seemingly ideal as a comparison was Nepal with its similar economic history, brush with socialism, and overwhelmingly rural, un-electrified population. These similarities hid the vast cultural and geographical differences that would come to dominate the notable variation in DG approaches. But the bipolar comparison, even with its local variations, was still too simplistic.

While in Nepal I corresponded with an Indian company as they explored and partially abandoned plans to extend their service across the border. Intrigued by the more immediate illustration of local variation, I added India to the analysis. Thus this paper explores DG approaches across an ocean through the countries and individual communities of Tanzania and Nepal, and across a single border through Nepal and India.

Within each country, individual communities became the subjects of this paper purely by chance. In Tanzania, I drew on the one community from which I could gain the most direct and up-to-date information and personal correspondence – my own community of Luhunga. In Nepal, I worked with and shadowed the only company pursuing rural solar micro-grids and so had no choice but to study their three pilot villages of Harkapur, Kaduwa, and Chyasmitar. And in India, though there are countless rural electrification projects happening across the country, the largest and most accessible operation was just south of the Nepali border in Uttar Pradesh which, though not an individual community, represented a collection of communities whose average need was being met by a single company.

Time and resources allowed me to study just one country directly – Nepal – and it was through the fortune of personal experience and chance encounters that I was able to add Tanzania and India to the mix with a comparable depth of analysis. Therefore each case study, though heavily grounded in statistics and literature, is observed through the lens of individual experience.

This chapter makes liberal use of statistics to paint broad pictures of national or regional demographics in order to give a rough sense of scale and context. Considering national census data, the village of Luhunga, for example, is clearly not an exception in Tanzania; by contrast, Uttar Pradesh is an exception in India, if only slightly. In addition, I include recent literature in order to provide a base of accepted practice and current wisdom in the energy development world. This is to avoid reinventing the wheel with regards to common technology, modern information gathering practices, financial structures, and so on.

I based the bulk of this analysis on personal interviews and observations, though the numbers and positions of people interviewed are not uniform across all case studies. In each case I interviewed anyone willing to give me the time, with results ranging from three in India (the co-founders and lead technician of the solar company) to several dozen in Nepal and hundreds in Tanzania.

In Tanzania I spoke with people at all levels of society, including secondary school students, shopkeepers, farmers, local government officials, national government officials, short- and long-term ex-pat NGO staff, transient workers, and village elders. In order to gain up-to-date information after leaving there in 2011, I received updates from teachers and former students still living in the village. Conversations always varied, but they tended to center around the history of electricity in the country and village, their hopes for newfound business opportunities and youth retention, and fears about what would happen to village culture due to such sudden change. I recorded many of these conversations in journals, but ultimately relied on three years of daily life and encounters to inform my understanding of electricity in rural Tanzania.

In Nepal I took a more direct approach to gathering opinions and information about electricity development, recording all conversations and formal interviews with company staff, local and national government officials, rural and urban business owners and vendors, and community members at various stages of electrification. Though I administered and/or analyzed several rounds of surveys, mistranslations and other shortcomings prevented me from including their results in this analysis. While working with the company I interviewed all administration and management employees as well as several technicians and engineers to learn project details, planning methods, competition, challenges of working with various entities, and so on. These interviews and those conducted along similar lines with rural participants informed the majority of the Nepal case study.

In summary these research methods, though non-uniform, allowed me to explore a range of challenges and methods in rural DG at a level consistent with what a project developer might encounter before choosing to begin a project or not. In addition, the "shut up and listen" approach (Sirolli 2012) led me down paths of inquiry I would not have thought to pursue and that informed areas of research for subsequent visits. More formal, coded information gathering would provide a level of detail necessary for technical project design that, though informative, is beyond the scope of this paper.

4.2: Nepal

We had found the little homemade hydroelectric generator in several pieces, its hand-welded Pelton wheel discarded not far from the tractor motor, awaiting repairs. The plastic penstock emerged unannounced from the shaded brush above us, its mountain spring water gurgling onto the stones of the generator hut before disappearing again down the gulch. We had heard that the man who made it lived in the nearby village, home to about forty people, and we were making our way there across the hillsides, pounding footholds into the loose dirt to avoid a hundred foot slide to the valley below. After getting better directions from two kids passing by, my friend turned to me with a note of caution in his voice. "The man who made the hydro generator lives just up there. His name is Rai, a caste known for being quick to violence and very efficient at it. Let me do the talking."

-Author's field journal

Nepal's central government-operated utility cannot readily extend to the country's rural majority, most of whom are several mountain ranges-removed from the central grid (AEPC 2013; REDP 2014). Most of the country's energy, whether islanded or provided through the main grid, comes from hydroelectric generation, much of it in the form of micro-hydro facilities (REDP 2014; Sarangi 2014). Nepal is an extreme example – many developing countries are at least considering central grid extension as a viable option for rural energy development (Harper 2013) – but in many ways Nepal is an ideal subject for this paper because DG is perhaps the only feasible option. In addition, the government decided in 2006 that all electricity service development was required to use renewable resources (AEPC 2013). Distributed renewable energy development is likely the country's future.

Nepal is powered by roughly 75% hydro, with the balance coming from solar PV, imported electricity, and diesel generators (AEPC 2013). Hydro generation operates best during spring melt, early summer monsoon, and shortly after; in the long run hydro is the more efficient generation method, with a levelized cost of energy (LCOE, or the average cost of electricity over the predicted lifetime of the project, accounting for interest, inflation, etc.) in Nepal roughly 25% less than that of solar (Sarangi 2014). Otherwise the climate is fairly dry in the higher elevations, leaving any hydro-dependent electricity consumers, literally, high and dry. Given Nepal's renewable energy policy and inability to import expensive power from India and China, both of which have historically vied for influence in Nepal's economy, one alternative is to augment hydroelectric generation with solar PV, which peaks when hydro does not. Realizing this, Nepal has opened the door for solar development to NGOs, aid organizations, and for-profit companies seeking to provide a viable solution to their energy needs (REDP 2014).

Since 1985 The Nepal National Five-Year Plans have encouraged the expansion of RETs in the private sector, gradually expanding that encouragement to include alternative energy policies (1990), subsidies and subsidy delivery mechanisms (1995), and a specific focus on alternative energy as a means towards economic development (2000 and 2005) (AEPC 2013). The Energy Policy of 2006 took a holistic approach to alternative energy by expanding the rationale to include reduced dependence on traditional (synonymous with "imported," in Nepal's case) energy, environmental conservation, increased employment in the RET sector, higher productivity, increased standard of living, and the integration of RETs with social and economic activities (2013). The policies themselves reflect the holistic approach by emphasizing environmentally friendly practices, enhanced local capacity, focus on poverty and women's rights, and involvement of both public and private sectors to achieve these goals. In 2013 Nepal expanded financial incentives to poor communities, women, and marginalized groups in order to reduce the gap between rural and urban electricity supplies and rates. The expanded view of both the importance of distributed generation as well as the wider positive impacts is indicative of a long-term commitment.

The executive director of the Alternative Energy Promotion Center (AEPC) monitored and reported on the policy impacts; they are summarized as follows. The 2013 outcomes from the growth of the renewable energy sector included an additional 14% of the population receiving electricity from RETs, an additional 500 jobs added each year (totaling 30,000 jobs in the RE sector upon publication), more than 40% reduction in fuel wood consumption by more than 700,000 households, and more than 500 small businesses opening in the RET sector (AEPC 2013).

The micro-hydro systems like the one mentioned in this section's introduction have long been the preferred method of electrification in rural Nepal.

Indeed, this would be expected given Nepal's hydrological conditions and consistent spring monsoon. If a single mountain spring that already supplies several villages with irrigation water can also generate 1 kW through a homemade generator, the possibilities for other un-electrified communities are encouraging. But electrification of many rural areas, however attractive and accessible micro-hydro seems, is far from secure.

The village of Kaduwa, down the hill from Rai's village, is a good example. Perched in the saddle of a mountain road leading to the famous Hindu and Buddhist cave temple of Halesi Mahadev, Kaduwa is home to a secondary school, a diesel-powered grain mill, and a few dozen families of subsistence farmers. Diesel generators, ubiquitous across the country, were chosen over hydro and serve a few main businesses. More recently, the individual households have opted for the subsidized solar home systems (SHS), stand-alone DC solar systems that cost relatively little and can power a few lights and a cell phone charger. Now just about every house and business in the village has a SHS.

The SHSs, an attractive option since the price of solar started dropping, became affordable to even poorer communities when the AEPC began subsidizing the systems by a quarter or third of their value. Since then the systems have spread across the country, providing low-voltage DC generation and appliances faster than any previous effort could have hoped to achieve. The challenge is that, while these systems provide basic electricity services to those that might have otherwise waited decades for electrification, they cannot provide much beyond basic lighting and charging. Those wishing to use computers, TVs, rice cookers, or other appliances, many of which require AC power instead of DC, cannot do so.

Kaduwa, for example, has a growing demand for AC or high-power appliances, including a dairy chiller. Situated between two major dairy markets with a limited local supply – Halesi Mahadev several hours up the mountain, and the busy town on the Dhudh Kosi River at the base of the mountain – Kaduwa could potentially increase its economic activity through its robust local dairy production if it had the means to store milk and gee for transport. A chiller, however, requires more power than a 1 kW DC hydro system or a few SHSs can provide.

An additional consideration, especially for those located along major roads, is the possible extension of the national grid. Upon arrival, the grid would provide AC power at a quality and voltage not compatible with smaller DC systems currently in place. For consumers, this would require choosing between their limited home systems, a complete conversion of their systems to accommodate grid power, or the use of two different electrical systems in the same building, at which point the investment in local energy generation would be rendered useless. The original decision to invest in local energy or to wait for the grid therefore carries some risk for those without sufficient means. This is the case in much of rural Nepal – communities must weigh the immediate investment in local energy generation against the probability that the grid will arrive. The grid itself, however, is not quite the *deus ex machina* it might seem to those awaiting its prophetic arrival, as evidenced by Nepal's urban centers.

The greater Kathmandu area (including Baktapur, Lalitpur, and surrounding areas) is entirely encompassed within the NEA grid and has challenges of its own, the most notable of which is load shedding. Accepted as “business as usual” throughout the developing world, load shedding involves shutting down sections of the grid when generation cannot meet demand. Kathmandu, Nepal’s center of commerce, industry, and government, experiences between 5 hours (monsoon season) and 14 hours (dry season) of load shedding per day. To avoid the monetary losses that frequent power loss can incur, homes and businesses often employ diesel generators, rooftop solar, battery storage, or some combination thereof.

Using stand-alone battery storage, while relatively affordable and reliable, is merely an individual solution that causes a greater social disruption. If a home opts to charge a battery bank while the power is on in conjunction with all of its appliances, it simply increases the load on the grid, requiring longer or more frequent load-shedding periods for everyone. Diesel generators, as in rural areas, are also reliable and relatively affordable for an office or apartment building, but are subject to highly volatile fuel prices (Nepal does not have much in the way of proved fossil fuel reserves) and are dangerous for indoor air quality in a city already known for its high levels of air pollution. Here, as in Kaduwa, solar has found a niche to fill, proliferating quickly as large arrays on hospitals that need to run freezers 24/7, or as small SHSs on homes and offices looking to maintain minimal electricity service for day-to-day life.

Over the past several years, especially the past three or four, a method of using solar or hybrid micro-grids (the prefix, sometimes used interchangeably with *mini*-, *nano*- and *pico*-, does not have a universal definition; I will use "*micro*-grids" as a general term to refer to systems of any size not connected to the central grid) has emerged in response to both rural and urban electrification challenges. Micro-grids, though somewhat unproven in Nepal, are being considered as one solution with potential financial, logistical, and social advantages over their individualized counterparts. The following case studies from Nepal illustrate the challenges of adopting various electrification techniques, methods of overcoming these challenges, and initiatives that are being taken on the village, city, and national levels to drive electricity development.

4.2.1: Rural Nepal – Harkapur, Kaduwa, and Chyasmitar

The villages of Harkapur, Kaduwa, and Chyasmitar, located along the border between the Okhaldhunga and Khotang districts in Eastern Nepal, all have something in common: they are the first in their country to adopt solar micro-grids. Far from having the resources to fund and engineer such an initiative themselves, they have collectively entered into a business partnership (called an SPV, discussed in Chapter 3.2.2) with the Kathmandu-based solar company Gham Power (GP) and the Asian Development Bank (ADB). Of the over 150 solar companies in Nepal, just the few largest are considering breaking into micro-grids and the largest, GP, began its three village pilot projects in 2013.

When GP put out a notice announcing their search for pilot candidates, the regional development office of Khotang recommended several villages. GP narrowed it to three (Harkapur, Kaduwa, and Chyasmitar, hereafter referred to collectively as "Khotang") based on each community's level of interest, previous experience working with business or industry partners, and willingness to pay. One of the primary questions GP is trying to answer during the development of these projects is of how to gather and interpret the right information to gauge the viability of a micro-grid in a given village. After years of development and gradual, stuttered progress, much of the information gathered in the early stages became irrelevant, insufficient, or contested. GP's primary project developer travelled seven times to each village over the course of a year to hold community meetings, created and analyzed several rounds of surveys, and maintained consistent phone contact with village representatives to stay abreast of developments on both sides. Yet still, after two years, miscommunication or missing information led to occasional doubt as to whether the projects would be successful.

First among GP's concerns and criteria for project success is a community's willingness to pay. More than just a means to an end (i.e. a for-profit company's bottom line), willingness to pay represents a community's literal and figurative buy-in to the project's success. Development projects run by non-profits or donor-funded NGOs typically have less concern for community buy-in, aiming more for rapid deployment to meet basic needs (see Chapter 3). But a for-profit company like GP and many others in the energy development world has a fundamental interest in predictable and measurable investment by the customer. Though ADB is funding GP's Khotang pilot projects, it is continuously calculating the long-term viability of the micro-grid model sans outside funding, analyzing whether GP could continue to develop such projects on its own.

Willingness to pay is a metric considered not just in itself (a sum or rate of money that a household will commit for the service provided), but also in comparison to other electricity options. In Khotang, the other main generation options are diesel generators with moderate capital cost but high fuel and maintenance costs, or SHSs with intermittent generation but moderate capital cost and near-zero upkeep. A 10W SHS costs Rs 8000 (USD ~80; conversion as of 2015 was roughly 100 Rs per 1 USD) in early 2015, including the panel, battery (12V and 10Ah, providing 120 Wh of storage, ignoring inefficiencies and MDoD), three bulbs, wires, charge controller (1A), and charger unit. The AEPC subsidizes these systems, reducing the upfront cost by 2500 Rs (25 USD) and therefore bringing it into the range of affordability for many rural residents. Solar companies will sometimes take advantage of the reduced awareness of the government subsidy among rural households, secretly charging the full Rs 8000, reporting only Rs 5500 of income, and pocketing the extra “subsidized” Rs 2500 (GP 2015). But for the purposes of this comparison, and in fairness to the vast majority of companies that conduct fair business, we can assume a Rs 5500 cost for a 10W SHS. The AEPC offers subsidies on a sliding scale as well, reducing a 20W system by Rs 6800, and a 50+W system by Rs 7800 (AEPC 2015). The combination of subsidies and falling solar costs has brought the price for a 10W SHS down from Rs 15,000 in 2011, a dramatic increase in accessibility over a short time (Kathmandu Post 2016).

In Kaduwa, the typical income pulled in by a farming household is between Rs 10,000 and 15,000 a month (Kaduwa, 2015). In a good month for a family raising buffalo and farming, income could be as high as Rs 20,000, and for those that own businesses or perform other jobs on the side, it can get as high as Rs 40,000 or 50,000 (the wealthier few of the village). Even with other expenses such as food, school fees, travel, etc., a typical household could afford a SHS with a few months of moderate savings. Thoughtful use and further saving would also allow the household to afford a second system or replacement battery without undue hardship.

Given the average household costs of each major electricity option in Nepal, including the NEA grid ($0.10/kWh), hydro ($0.08/kWh), diesel ($0.40/kWh), and SHS ($0.20/kWh - $0.30/kWh), a solar micro-grid would need to get its cost down to roughly $0.20/kWh in order to compete on a purely financial basis (GP 2015). It is worth noting, though this price is an educated estimate more than a hard figure, that each of these options is competitive for different reasons in different contexts. Though more expensive overall, diesel would be the most attractive for a milling business that doesn't have access to hydro resources and needs higher voltage and more reliable power than a SHS can provide. For a household on top of a mountain ridge that just needs basic lighting and charging, a SHS is the best option. The reasons that a micro-grid does not need to beat NEA or hydro prices (or even diesel and SHS prices, in some cases) are many, but the basic reason is one of quality.

As mentioned earlier in this chapter, SHSs, micro-hydro (for the same reasons as SHSs), and some diesel are all sub-optimal for electricity development, despite their accessibility. First, in their basic function, none produces the AC current required by many desired appliances (many diesel generators do, but not all). Second, with the arrival of the national grid, those systems would not be able to work in conjunction with grid power, rendering them useless or, at best, secondary, to be used only as backup or in the case of load shedding. Even if a household wanted to retrofit their home systems to work with the grid, the upfront cost of inverters (to switch DC to AC at grid frequency) and transformers (to step up the voltages to grid requirements, such as from 12V to 220V in the case of a SHS battery) could be crippling. For example, a central inverter (as opposed to micro-inverters installed on individual panels) can run around 10% of total system cost, and can run as cheap as about USD 50 per kW up to around USD 1000 per kW, depending on the size, efficiency, company, etc. (ENF 2016). Also the power conversions through the aggregated system would drop overall efficiency enough to be pointless (inverters and transformers both have low efficiencies – closer to 85% or 90% - relative to other system components).

The Khotang micro-grid, one of the more sophisticated iterations of its kind, overcomes many of these problems through economy of scale and long-term planning. Rather than inverting and stepping up power from every individual system, the micro-grid centralizes its generation in a single array, inverts and stores on-site, and delivers ready-to-use, high-voltage, AC power through a local distribution network rated for the grid. Once community interest is gauged, GP designs the system specs accordingly for a 20-40% growth margin, expecting later buy-in from late adopters. In addition, the system allows for simple scaling by adding more modules and batteries as needed without much other additional infrastructure. Each customer is required to install wires, outlets, and fixtures in advance at her or his own expense at a cost comparable to installing a SHS, or around Rs 6000 (GP 2015). After installation, the entire operation consists of monitoring, payment, and maintenance.

4.2.1.1: Cost, Willingness to Pay, and Business Structure

As noted previously, a solar micro-grid does not necessarily, on a case-by-case basis, need to compete with other methods in terms of cost. It may be the case that the relatively affordable SHS, with moderate upfront cost and near-zero upkeep, is the best option for one family, whereas another family may prefer the higher cost associated with power to run TVs, rice cookers, or computers, and would therefore be willing to pay more per kWh. When gauging interest, a primary consideration should be not only how many people are interested, but what electricity needs they expect in the near future and how much they are willing to pay to meet those needs. This information is not meant to allow the project designer to maximize their profits, but to know whether payment can be expected and the business is sustainable.

The Khotang pilot villages all saw high levels of commitment for the proposed micro-grids. In Kaduwa, 100% of nearby residents and businesses agreed to buy into the system, accounting for 60% of the total village population. The remaining 40%, who live in a separate area too far away to be serviced by the micro-grid (the grid transmission maxes out at 3 km), announced their intention early in the process to purchase a micro-grid once the three pilot systems had been completed. Harkapur and Chyasmitar both saw well over 50% buy-in, particularly among businesses, with more residents committing once installation began (and more expected as the systems have recently come online). As of March, 2016, the participants numbered 540 people in 83 households, as well as 25 businesses (Prasain 2016).

Despite the fact that pilot projects, experimental and iterative by definition, are always more expensive than the successive generations, the micro-grid projects in Khotang are no small investment. A total of USD 237,000 is being invested by multiple parties to install a total of about 35 kW to serve all 83 houses and 25 businesses (Prasain 2016) – 4.8 kW in Chyasmitar, 21 kW in Kaduwa, and 9 kW in Harkapur – to meet customers' stated need for lighting and charging for everyone; radios for many; and TVs, laptops, and rice cookers for a few (Khotang survey results 2015). And while GP's investment will (should) be recouped via customer payments, much of the seed funding is from outside sources. The ADB has contributed USD 100,000, and the Dutch DOEN Foundation has contributed USD 70,000. GP's upfront investment was USD 32,000, and the villages collectively have paid USD 35,000, partly as in-kind contributions through physical labor and materials for system infrastructure (GP 2015).

By simple comparison, purchasing 35 kW of SHSs (assuming the subsidized prices mentioned previously, also made possible partly through outside donor funding) would cost just under USD 200,000 and would not provide the same quality power as GP's micro-grids given their low voltage a DC limitation. Considering the significant amount of money GP has spent on travel and information gathering, as well as the skilled technical labor required for installation, the cost of the Khotang micro-grids is roughly comparable to that of SHSs of equal generation capacity. Yet the viability of micro-grids as a profitable business model – perhaps the single most important driver for widespread adoption – is far from certain.

In order for GP to continue installing solar micro-grids of this type, the company would need a profit return high enough to seed subsequent projects without direct outside, conditional funding like the ADB and DOEN funds for the pilot projects. Such donor funding is project-specific and must be requested each time, leaving a for-profit business without predictable, reliable funding and therefore without the ability to move quickly and decisively on business opportunities. In short, depending on donor funding can work for short-term, focused projects; but if the funding cannot be easily sustained, the market-based approach to development cannot operate. There are several ways to overcome this, however, without waiting for prices to conveniently fall.

4.2.1.2: Enter the Government

Nepal's energy subsidies through the AEPC, such as for SHSs and larger rooftop systems, are largely funded through donor, or aid, money. These subsidies, most of which simply reduce the price of a system on a sliding per-kW scale, are reliable enough that local businesses have sprung up around the country to distribute solar systems, free to plan business investments several years into the future. To date, no such subsidy or other continuous funding exists specifically for micro-grids. The ADB's investment in GP (and others) is its own pilot project to test the success of these systems and pave the way for a possible long-term investment. Should the Khotang projects prove successful (financially sustainable and relatively disruption-free), continuous funding may well be ensured for the near future. Thus GP's success determines not only its own future in micro-grids, but possibly Nepal's.

The AEPC, a proxy for the Nepali government for the purpose of this paper, has ultimate say in the direction energy development can take in the region. Responsible for testing and approving technologies (importing unapproved tech incurs a VAT, making tech approval a high priority for frontline industries and a bargaining chip for the AEPC), it can prioritize technology choices and trade relationships. It also designs and proposes the subsidies adopted for the industry. In essence, the AEPC can decide if micro-grids have a future in Nepal and, if so, which kind(s) of micro-grid will be pursued. While GP is pursuing high-quality AC micro-grids, the AEPC (partnered with GP) is pursuing cheaper, DC micro-grids in another region, in which it has placed greater hope of success (AEPC 2015). The timing, reception, and publicity of each of these approaches, many of which are being pursued by other companies, could determine how and where a future investment/subsidy might apply.

The other piece of the Khotang project financial viability is on the demand side. Whereas the AEPC and outside donors influence the long-term viability of maintaining a national business, essentially raising the "floor" of any ROI, the willingness of individual communities to pay for the systems determines local viability. This paper has already shown that, collectively, the upfront cost of a micro-grid can be comparable to the aggregated cost of individual SHSs, but there are additional costs to individual customers buying into a micro-grid that have not yet been counted. Aside from the USD 35,000 committed by the three villages, which was collected as a combination of direct payments and in-kind manual labor and materials, individual customers are responsible for wiring their homes and businesses in advance of the system's installation. This amounts to about Rs 6,000 per household, or about a half of average family monthly income. This is a one-time investment that should be up to code upon the potential arrival of the national grid.

The long-term expense, of course, is the electricity bill, charged to individual accounts and paid in person (see Chapter 2) to collectors in each village. GP and the Khotang representatives agreed on a Rs 90 per kWh price for the pay-as-you-go customers, substantially higher than any other option, at least by direct price comparison (above). Customers can also opt for a flat rate depending on what maximum power they expect to use. Households pay Rs 500 or 1000 a month for 100 and 200 W respectively (rates can go as low as Rs 250 a month for 20 W), and businesses pay Rs 2000 and 5000 a month for 1000 and 2000 W respectively (Kathmandu Post 2016). This price choice arose through surveys and village meetings with GP project designers who calculated actual usage and monthly costs. While the per-kWh price is high, actual usage is low given the small number and high efficiency of appliances used by households and businesses. Even at Rs 90 per kWh, a typical household is not likely to spend more than Rs 100 – 300 in a month. Compared to Kathmandu customers, who pay much less per kWh (Rs 10 per kWh) but tend to use more by leaving appliances on more often, rural customers on the GP micro-grid may not be paying substantially more for comparable electricity service.

To summarize, the success of GP's solar AC micro-grid and therefore its long-term viability as a profitable business depends on financial variables from both the supply and demand sides. Government policy on how and what to subsidize could sway the energy market towards or away from high-quality, community micro-grids. The degree to which communities place importance on high-quality, scalable power systems to meet growing demand, or more accessible and individual systems to meet just basic needs, holds similar sway.

At this point we will assume that micro-grids have a part to play in rural electricity development, and that for-profit businesses can serve as vehicles for implementation and innovation. The next question is: can collective community resource management of electricity, as with other resources like water, forests, and pasture, survive local challenges of theft, tampering, or corruption?

4.2.1.3: Payment and Demand-Side Management

As discussed in Chapter 2, a micro-grid falls victim to problems that national grids and home-based systems do not. Large grids, though subject to line "tapping," have the advantage of dedicated technical crews to address problems, substantial financial resources, and centralized equipment. On the other end of the spectrum, SHSs are individual in both supply and demand, leaving no reason for misuse or theft (the exception, of course, is outright theft of the system by a neighbor, as I experienced when someone removed my solar panel from my window in Luhunga, perplexingly leaving behind the lamp it was charging). A community-run micro-grid has none of these advantages, and designers run the risk of leaving the system open to easy tampering, low ratepayer accountability, and overuse/misuse.

In order to address the challenges in Chapter 2, GP has opted for a relatively expensive but sophisticated method of DSM and payment in Khotang. The payment system, especially, is simple both for customers and for GP. Customers opting out of the flat rate payment option can pay in advance per kWh via a system similar to how prepaid phones work, or how phone vouchers work in many developing countries. Cash payment goes directly to a local vendor, who then updates the given customer's account according to how many kWh the customer has purchased. The customer may then use power until that account has run out, at which point either they can purchase more or their power will be temporarily shut off. In many cases worldwide, this business is conducted via mobile phone (most mobile networks have access to digital payment systems, such as the famous M-PESA in East Africa); however, mobile network is not yet ubiquitous in Nepal and GP has opted for in-person payment in the meantime.

Each system in Khotang contains a wireless internet hub – a small but necessary parasitic load on the system – that GP uses to communicate remotely with the system for purposes of monitoring and receiving payment. Local system operators/vendors collect payments from customers, then update each customer's account to GP's database. The case-by-case monitoring of payment and usage allows for quick response to inconsistencies, whether by mistake or intentional misuse.

The per-kWh payment system allows customers to adjust their usage according to their needs without paying for more than what they use or free-loading off of others' overpayments, as would be the case with flat monthly rates. If this was the only form of demand-side management, however, there would still be the danger of over-draw and brownouts. In such a scenario, a single customer could plug in high-power appliances and draw down the system's storage too quickly to be recharged, browning out the system for everyone. Even if that customer paid for the total amount of energy (kWh) she used, her abuse of the system by drawing too much power (kW) at a given time has the potential to disadvantage fellow customers and damage the system. High draw can damage wires through overheating, and overdraw can both permanently reduce a battery's storage capacity and cause system-wide voltage drops that can degrade individual appliances. If GP designs a system based on information that most customers are using LED bulbs and phone chargers (low power demand, on the order of 10s of Watts), and then someone plugs in a hair drier (high power demand, more than a kW) unannounced, the entire grid could suffer.

To combat this, as well as to accurately track usage for payment records, GP employs three-phase AC (meaning grid-compatible) power meters equipped with current limiters (see Chapter 2). The meters can communicate wirelessly with any hub within range (hence the internet hub, and node points in case meters are spread out) and can give real-time information on power usage. Some meters, though not those used by GP, can also accommodate scratch card vouchers and mobile purchasing. The current limiter on each meter is preset by the system operator based on the customer's preference and expected usage, and can be adjusted in person by the operator at any time. Each meter is locked in a secure box accessible only by the operator, and in the event that the wireless internet goes down and the meter can no longer communicate with the hub, the meter stops counting and the customer gets "free" power. The financial burden of maintenance and reliability is therefore on the operator and GP, and affects all stakeholders.

Smart meters like these, however, are not cheap. Along with inverters and batteries, meters make up a significant portion of the cost of each micro-grid. A meter for an individual customer can be anywhere from USD 30 to 200, including license agreements required by U.S. or European companies (Chinese companies do not require a licensing fee, and Chinese meters have been found as cheap as USD 6). While GP is using a suitable U.S.-made meter, the company also employs an electrical engineer whose full-time job is inventing a similar meter using locally sourced components. Other companies forego smart meters completely in favor of over-design and local accountability, to varying degrees of success, simply due to cost.

Battery storage design and information also contributes to the longevity of the micro-grid. In the interest of affordability and performance at high elevation, GP uses lead-acid battery banks, over-designed to account for the worst-case scenario of over-draw during low generation. Even in that instance, the system would have at least an hour before batteries drop below 50%, their recommended maximum depth of discharge (MDoD). At that point the system would notify the operator of imminent over-draw, then the operator could access individual meters and shut them down (load shedding) until the system recovers. The use of primary, secondary, and tertiary grids have been proposed in other areas in order to allow prioritization of load shedding (primary grids would include customers that cannot be safely shut down, such as hospitals or dairies; tertiary customers would be those with more luxury-based demand), though GP has so far not considered such an arrangement to be necessary.

4.2.1.4: Long Term Plan

Despite GP's deep and long-term investment in the Khotang micro-grids, its goal is not ownership. Indeed, from a business perspective GP's only goal is to collect its predetermined profit and remove itself from the equation to pursue other investments unencumbered, leaving behind a self-sustaining, community-driven electricity service. To this end, GP has entered into a SPV arrangement with the ADB and representatives from each village. An SPV essentially functions as a business partnership in order to ensure mutual interest and oversee the transition of ownership. The SPV, called Halesi Solar Minigrid, maintains a five-person council – one representative from GP, one from each of the three villages, and one additional representative from the SPV's headquarters in Kaduwa. It technically owns the systems in all three villages and is responsible for the performance of each. Each representative has a "share" in the business; degradation or loss of profit from any one system harms the ROI for the entire SPV, encouraging collaboration.

GP will remain a part of the SPV for the first ten years of the system's operation, guaranteeing technical support, training local operators and technicians, and providing expert advice for its own interest. During this time any extension or changes to the micro-grid, as determined by the SPV, would be implemented by GP. Each year GP receives 12% of profits from electricity sales, the portion expected to allow GP to at least recoup its costs. At the end of ten years, GP will give up its share in the SPV and transfer complete ownership to the three villages, which will then be responsible for any changes or maintenance. Local operators will be in control of all DSM, monitoring, and payment, and they may contract GP or another company for further grid expansion or repair. The SPV business model predicts that, by this point, the system will have paid for itself and any additional income will be profit, allowing for the replacement or addition of components from then on.

4.2.1.5: Stuck in the Middle: Challenges of Implementation

There is no shortage of unenviable challenges facing anyone working in rural development, or anyone questing for the silver bullet to sustainable energy development; combining the two paints a complicated picture indeed. It is a football (read: soccer) game in which each player is confident in her contribution to moving the ball forward, and simultaneously confounded by the perception that her teammates all seem to be playing defense. Frustrations abound, even in the most successful projects, punctuated by lapses in communication and confidence. Administrative blindness, malfunctioning tools, improbable weather, mistranslation, planning mistakes, funding delays, cultural friction, and others are challenges that every project of this kind faces, no matter how well conceived. Conflicting perspectives are most noticeable by, and stressful for, the one in the middle.

In the last days of 2014, GP sent a team of technicians and engineers to Khotang for an estimated ten days. Their job, given the truck of supplies that would follow them by a few hours, was to install the framing for all three solar arrays that would serve the eventual micro-grids. The villages had been notified and were allegedly busy clearing land and finishing the structures that would house the construction materials and, later, the inverters and battery banks. Aluminum framing pieces, angle-iron fence posts, rivets and rivet guns, a miter saw, a generator, vice-grips, and rolls of barbed wire arrived at the home of Harkapur’s

SPV representative. His home/guest house was conveniently close to the array site (a veritable rock field on a 40-degree incline above a cliff) and would also serve as home to Harkapur's backup diesel generator, a practical requirement for the industry-heavy river town.

The micro-grid projects had been in development for over a year by this point; the project manager had visited this area seven times to hold community meetings, sometimes waiting days in a single village before the community actually met. Since then, nothing had happened as far as the villages could tell, and the framing installation was a sort of carrot to prove GP's commitment and keep some momentum among the villages' increasingly disgruntled customers. The GP team received a friendly reception, but the Harkapur rep's first order of business was to relay complaints from some of the larger would-be customers, particularly two hotels in the area that had promised electricity to their guests.

In GP's reality the framing installation was a risk. The bulk of the funding, and with it the call for bids for solar panels, inverters, and batteries, was entirely the ADB's responsibility. The ADB had not announced the call for bids, after which procurement would take an additional two months, leaving GP in the awkward position of having to commit its own resources to placate the SPV without the assurance that funding and materials would be forthcoming. It would not be professional for GP to explain the ADB's delay; as far as the villages were concerned GP was the project developer and therefore responsible. The team in Khotang had been told that the ADB would call for bids in the next several weeks, meaning that final installation would happen by April; they passed this information on to the village representatives, who seemed annoyed by the delay but content to at least have a schedule. The ADB did not put out the call for bids in the following weeks, or even the following months: as of August 2015 there was still no word as to when bidding would open.

4.2.1.6: Field Observations, Harkapur

Harkapur, the first in line for installation, is an obvious choice for a solar micro-grid. Situated on an ancient floodplain of the Sun Kosi River, one of the major rivers from the Himalayas that flow through Nepal into India, it is home to several thousand and a local hub of industry, agriculture, and transportation. A community fishery hugs the East bank of the river where the region's major road crosses a bridge into the village, carrying dozens of buses and jeeps every day. A Secondary school on the mountainside looks out over several hectares of homes, shops, hotels, partitioned rice fields and grazing plots and, in the distance, a quarry. Every roof has a small 10 or 20 W panel on a bamboo pole pointed roughly south. Though the village already has a stable industry and a growing business scene, the construction of a new road (courtesy of Japan) to its doorstep is expected to transform, albeit slowly, a moderately poor village into a local economic center. The road will bring more tourists, pilgrims (on the way to Halesi), industries, and businesses; and with each of these will come the expectation of amenities such as light, TV, charging, and more.

The village has clearly been careful in planning: zoning separates agriculture areas, grazing, and buildings, which all sit together on the western end. An aqueduct snakes from the hills to the north through long-established earthen dykes, some sporting careful repairs, into the village and past rows of homes and businesses. This water, continuous year-round, can be tapped for irrigation or used to carry away waste. It is not privately owned but, like the fishery and the grazing plots, is managed collectively.

All of these factors – collective resource management, expected growth in business and industry, increased demand for AC power, proximity to a major transportation route along which the national grid will likely extend, a history of large-scale civil engineering projects (new bridge and road) – indicated to GP a high likelihood of success for the micro-grid. The high and expected increase in demand meant high willingness to pay; likely grid access meant a demand for grid compatibility; and a history of communal resource management and prior project experience promised a customer base accustomed to collaborative projects. In essence, the conditions for viability discussed in Chapter 3 seemed to be in place.

4.2.1.7: Field Observations, Kaduwa and Chyasmitar

With the nearest water source one km down the mountain, it was immediately clear why Chyasmitar had bypassed hydro in favor of solar and, as in Harkapur, small rooftop SHS panels were evident on just about every house and business. The only business that was clearly in need of much power was the stationery shop that, at the time, used a diesel generator to power a computer, printer, copier, scanner, photo booth, and more. In contrast with Harkapur, Chyasmitar's decision to install a micro-grid instead of more SHSs was less obvious and may explain the lower participation rate and smaller array of only 4.8 kW.

Local artisans – carpenters and builders – had finished the requisite inverter and battery house mere hours before the GP team arrived. GP had left Kaduwa and Chyasmitar to their own devices to site and build (or retrofit) the buildings, a simple enough requirement for in-kind services that ended up having unexpected positive outcomes.

This area of Khotang has, as do many other rural areas, what can only be described as a mafia. Self-appointed and largely unchecked by law enforcement, the mafia functions as a mix between labor union and brute squad, demanding employment for its members and threatening or attacking non-members that are employed instead. The type of labor is generally manual – moving rocks, digging trenches, building shoring around the mountain roads – and the type of employer is irrelevant to the mafia's conditions. Protected laborers pay dues to the don (local title) and he, in turn, ensures that any relevant work goes to them. If a local resident hires laborers to carry stones for a new shop, mafia members get the work; if the government office of civil engineering builds a new road, mafia members get the (unskilled) work.

The nature of GP's installation was such that the mafia was unconcerned and, except for a near constant presence and stern looks, the mafia largely left the GP team alone. The civil engineer stationed in Kaduwa for the government road project was not so lucky; he was expected to entertain the local don, buy him and his posse drinks, and bend to their demands regarding personnel. The building and retrofit work done in preparation for the micro-grids was also subject to the mafia's influence. Had GP been directly involved rather than letting the village perform its own construction, the use of outside technicians would likely have met resistance and, in the worst case, doomed the project and endangered both GP employees and local workers.

Company communication was mutually nuanced; the technicians reported progress that was far from certain, and the GP home office told the team of imminent ADB and GP visits to the work site that never took place. The same subtleties existed between the village and the GP team: structures reported finished were merely in the works; payment and services reported rendered were simply expected, and so on. While in the West this sort of exchange would be worthy of reprimand or even cancellation of the project itself, here it was considered business as usual. The slight dishonesty was more a declaration of intent than an outright lie. GP was not actually planning to bring ADB officials to the site, but the team got the message that they were expected to work quickly and with an eye towards publicity-worthy quality. Kaduwa had not finished retrofitting the school office for the solar components, but the team understood that the village was committing and the work would be done soon. GP staff, all Nepali, speak this language and have no trouble navigating local business practices. The communication does cause delays – exaggerated progress is a two-way street and each party assumes a grain-of-salt buffer to optimize their own use of time – but the delays are predictable and even normal, after a fashion.

The challenge for GP is to speak both languages – that of their clients in rural Nepal, and that of the ADB and the international, westernized world of business. As Americans and American companies have grown to dominate international business and even the global development project, so the world has learned to adopt American business practices and ethics. Punctuality, regular reporting, extreme specialization, and regimented time management are expectations of anyone working within this realm. Businesses or organizations that operate differently, perhaps with more locally appropriate expectations, may be decried as lazy or dishonest by partner Western organizations. Local institutions, in turn, accuse Western organizations of being pushy, impersonal, or any other term associated with a neo-colonialist attitude.

When operating as GP does in between these two cultures, there is a lot of room for mutual growth, but also mutual disappointment. GP's donors and occasional foreign consultants can put unexpected and perhaps misunderstood pressure on staff to operate in a more American style, while the villages can put equal pressure on the company to relax that style and conform to local expectations. When the company assumes the American business model, the villages may feel disrespected; when the company assumes its local (and natural) disposition, donors and international business partners may feel that it has become unreliable. Staff are therefore driven, both individually and as a company, to walk a fine line, one that can be seen especially when all levels of business are in play.

While the technicians were in the field and company administrators were waiting on ADB funding, there was a continuous line of communication, translated and retranslated between each level, keeping the ADB informed of progress on the ground and the customers informed of progress at the top. It was precarious, and the juggling act clearly fatigued everyone but, in the end, it worked.

One of the more effective and widely applicable strategies that GP employed was another carrot: in the months after the framing installation, and without any date by which to expect the ADB to purchase the other materials, GP installed small solar arrays of their own in each village. Each consisted of only a few panels and batteries, a fraction of the full system, at the company's own expense. The idea was two-fold: the systems would raise the confidence of customers that GP was serious about finishing the project, even going so far as to donate the materials itself; and each array would provide a specific service in each community.

Power in Harkapur was designated for the hotels that had been impatient earlier and had been contributing most to the community's grief with GP. Kaduwa's system powered a small movie theater that charged a tiny fee for frequent movie screenings in the old school. Chyasmitar's system was being designated for a stationery shop. The temporary systems had the intended effect: customer complaints decreased and the full systems were purchased and installed in the fall of 2015, about two years after the projects were first proposed.

4.2.2: Urban Nepal: Kathmandu

One evening, while out with a foreign business partner at one of Kathmandu's Newari establishments, our plate of potato curry and beaten rice was suddenly and unceremoniously plunged into quiet darkness. Our now invisible waiter carried on listing the drink options, apparently unconcerned that eternal darkness had descended upon us. Of course nothing at all was the matter; the restaurant, like practically every building in Kathmandu, was simply taking its turn in the never-ending cycle of load shedding. And, like many, their backup power system was taking its time deciding *whether to turn on, or to let us dwell in darkness a while longer, pondering the futility of the national power grid. After the lights did finally blink back into existence to the hum of an outdoor generator, they blinked out again. Someone had forgotten to turn off the sound system, which had been gracing us with Billy Joel's "Uptown Girl," and the generator couldn't quite handle the demand.*

-Nepal Energy Development Council, by author, Jan 2015

Kathmandu, Nepal's commercial hub, is subject to between 5 and 14 hours of load shedding a day, with the annual average shifting towards the upper end of that range as demand continues to increase without much new generation. Though there remain some untapped hydroelectric resources, particularly in the western region left undeveloped during the Maoist rebellion, Nepal lacks the financial capital to harness it without outside investment. India, desperate for affordable energy resources and increasingly under global scrutiny for climate mitigation, has long eyed Nepal's rivers. In recent years agreements have been all but signed to allow Indian companies to fund and build the dams, then receive the vast majority of the power generation at a price lower even than what Nepali pay on their electricity bills. Opponents consider the deal to be legal theft of Nepal's energy future and a desperate sale that benefits India far more than Nepal, while proponents note that the resources would be underutilized otherwise. And so the NEA grid inches along, a MW at a time, unable to keep up with demand.

Residents' responses to the resulting load shedding, as discussed previously, range from unenthusiastic acceptance to proactive gap filling. SHSs have become popular despite the smog and heavy particulate concentration, as have battery systems and various combinations of the two. Before the recent drop in the cost of solar that made it competitive, many preferred diesel generators on everything from a household scale to a commercial park scale. Large compounds like the US Embassy and UN offices employ large backup diesel generators specifically for load shedding hours (a blackout would mean a loss of security and communication), as do large or international businesses that cannot afford to lose power even briefly.

As of 2014 Nepal had about 600 MW of diesel capacity, almost entirely in the form of non-utility-scale generators, with about 240 MW of this designated for load shedding response specifically (UNDP 2015). The remainder is mostly rural, off-grid generation. Assuming optimal generator operation and an average of 10 hours per day of load shedding, this 240 MW capacity translates to just under 600,000 mt of CO2e per year, or more than all of the cars in Nepal combined. The cost also adds up: at an average of 30 Rs/kWh diesel, though reliable and consistent, is one of the more expensive generation options. A large commercial enterprise filling 10 hours of load shedding a day (timing is everything, and load shedding schedules change from place to place) could meet upwards of 200 kWh of daily internal demand with diesel. Over 25 years, or the average lifetime of a solar panel, this would cost the business just under USD 550,000. While this may be a reasonable price for a large business to pay for reliable electricity over 25 years, it looks far less attractive when compared to zero load shedding or even solar.

Electricity on the NEA grid costs 10 Rs/kWh; consistent power without load shedding would cut the diesel cost above by two thirds, saving the hypothetical business enough money for half a dozen enviable salaries. Assuming that Nepal gets an average of 5 sun-hours per day (IEA 2014), small DC solar systems (SHS) are comparable at less than 12 Rs/kWh, as are prefabricated AC systems using 12 V batteries, made cheaper by scale (Author's notes 2015). For a home or business that is just looking to run basic appliances, solar is clearly the better option in the face of load shedding. (It should be noted that this analysis ignores inflation, though its inclusion would make solar even more attractive due to diesel's ongoing fuel costs.)

An Indian solar company, Mera Gao Power (MGP, discussed in Section 4.3), installed a solar micro-grid in downtown Kathmandu to test the feasibility of meeting load shedding with low-cost, densely distributed solar. The system uses cheaper distribution wires (aluminum instead of copper) to reach a large number of customers within a small radius – several apartment buildings wide. Panels on the roof provide DC power to individual households, which pay a flat rate for basic service. Individual customers would not have had access to prime solar panel real estate, nor the funds to purchase a large system themselves; with MGP's DC micro-grid they can pool their resources and pay off the system over time, avoiding the cost of diesel and logistical problems of a SHS on the ground level of a downtown apartment complex.

When considering the need for grid-quality power, however, small diesel generators and low-voltage solar systems are insufficient (Nepal's grid delivers at 220 V), and larger consumers must turn to the high-voltage alternatives. These include the aforementioned large diesel generators and, more recently, solar micro-grids.

4.2.3: Urban Micro-Grids Example: UNICEF

The UNICEF (United Nations International Children's Emergency Fund) office in Kathmandu became Gham Power's first Business Micro-Grid project, or BMG. Designed for the expressed purpose of combatting the effects of load shedding and reducing dependence on diesel, the BMG does what its smaller counterparts cannot: it delivers grid-quality power from a solar array with several days (depending on the customer's requirements) of battery backup.

GP's original intent with UNICEF's 42 kW system was to reduce the office's diesel consumption by at least 50%, a direct replacement for running the 250 kVA diesel generator. At the time of installation, UNICEF was using the generator to run, on average, 30 kW of equipment during the winter, peaking a little higher in summer to run air conditioning units. Even in summer the generator was heavily over-designed, generating dramatically less than its optimal output. Under-generation, as with over-generation, can be damaging over time. Like with car engines, running the generator at lower RPMs than it was designed for strains the efficiency and uses more fuel than a smaller generator with the same output. GP's design called for a complete overhaul. All systems would be connected to the solar array, which would cover everything during load shedding, and a small diesel generator would serve as backup for times of peak demand. The result would have been a 90% reduction in diesel use and a 20% overall reduction in energy costs, even with solar payments.

What should have been a win-win for UNICEF fell short when the office decided to only connect the main appliances, such as refrigerators and computers, to the solar, which account for just 20 kW. The remaining 22 kW of solar were left unused, and the over-sized diesel generator continued to run at sub-optimal output during load shedding, further shortening its life and negating the energy savings that would have paid off the solar micro-grid. Fortunately, the office is able to switch its other systems onto the BMG with relative ease should it decide to do so.

In UNICEF's case, the as-designed 90% fuel reduction and 20% overall cost reduction was a product of load shedding scheduling and the office's time-of-use patterns. Other offices with other outage schedules would fair differently, but GP reported that it could reliably provide a 50% fuel reduction for any BMG, which would still be enough to pay off the (proprietary) cost of the system. As of February 2015, GP was pursuing several similar contracts with little competition. The most common complication involved customers' misunderstanding of GP's financial models, leading to debates about the appropriate estimates of inflation and interest rate during payback. The concept of the BMG and its benefits, however, was generally accepted.

The comparison between diesel and solar micro-grid backup is not always simple to communicate to customers because they operate under different sets of rules. Diesel is reliable and well understood, but has a high upfront cost and requires ongoing fuel costs that are subject to price fluctuations on the international market. Solar is intermittent and therefore requires a higher upfront cost to cover the necessary redundancy. However, with no fuel costs and minimal maintenance costs (most of which are covered by warranty), solar lends itself to financing mechanisms that make use of savings to pay itself off. With the right tools, a solar customer could see zero additional cost and, upon repayment, net savings. Agreeing on payback schemes and helping customers understand the financial mechanisms are the current challenges for solar companies now that the technology is approaching grid parity with other generation types. Tipping the solar market beyond this confidence barrier, combined with the growing utility of SHSs, may see the end to diesel.

4.3: Rural India: Uttar Pradesh

The two-kilometre drive on a kuchcha road lined with sugarcane crops to Hasnapur in Uttar Pradesh at night leaves you with an eerie feeling. The road is dark, but as the village approaches, you can spot tiny dots of light emanating from thatch-roofed huts. The government has not brought electricity to the village in Sitapur district — but there is light.

-The Telegraph, India, 2014

Just across Nepal's southern border is Uttar Pradesh, one of India's more impoverished states. The population of Uttar Pradesh, 80% of which is rural and 38% of which lives in poverty (compared to India's ~30%), is partially organized into over 200 hamlets (UPID 2011). The hamlets themselves are densely concentrated around commercial centers, many of which are un-electrified. Though electricity generation on the national utility is increasing, Uttar Pradesh's annual electrification rate is actually decreasing (-2.5%) as population growth (20% decennial) outstrips generation growth (UNESCO). In 2014, Uttar Pradesh's off-grid residents account for 2% of the global population.

The national grid in Uttar Pradesh pulls from a mix of generation types – primarily coal, followed by wind and gas, then solar and biomass. In addition, a combination of small solar systems, biomass gasifiers, small hydro, and various other methods serves to electrify some rural homes and businesses, though many go without. The dense hamlets lend themselves to a solar micro-grid, though one that is different from that employed by Gham Power to the north. Where real estate is valuable, finances are limited, needs are minimal, and distribution is concentrated, a cheap DC micro-grid can serve the majority of demand at an acceptable cost.

In 2011 a company called Mera Gao Power (MGP), meaning "My Village Power," adapted an electrification model from West Africa to the hamlets in Uttar Pradesh. For USD 900 MGP technicians can install, in about a day, a system for an entire hamlet. Each customer buying into the micro-grid pays a INR 200 (USD 3) installation charge, then INR 100 per week for continuous power. For every three micro-grids, each of which usually has a maximum radius of 90m, MGP builds and staffs a "brick and mortar" office to provide technical support and collect payment.

At first glance, MGP and GP appear to have similar situations: they are both trying to provide affordable and appropriate power via solar micro-grids where the national grid or other electrification methods are inaccessible. But a closer look reveals divergent philosophies suited to contrasting environments, both financially and culturally. Payment mechanisms, demand-side management, and technology all differ, providing a contrast that illustrates the importance of site-specific project design.

4.3.1: Uttar Pradesh: Technology Preference

The density and high level of poverty in the Uttar Pradesh hamlets present challenges and opportunities that Khotang does not. First among these is the need and willingness to pay. The hamlets had depended on kerosene lamps for light, and mobile phone charging was typically a local business venture in which one person would own a battery bank, diesel generator, or SHS, and would charge customers accordingly. The majority of customers in each community (~85%) required that a solar micro-grid would provide similar services (MGP 2015), but also expected to pay an equivalent amount or less. MGP had to design a system that provided basic services but also competed with alternative prices. Following GP's example of using only high-end, grid-quality materials was not an option.

The solution presented itself via the hamlets' densities. Centralized generation, as opposed to SHSs or kerosene, relies on minimizing loss along its distribution network in order to affordably meet demand. GP uses high quality copper wires for distribution, limiting line loss (power falls off linearly with the length of the wire) along its wide networks that cover several square kilometers.

MGP, on the other hand, decided from the beginning to ignore grid requirements and focus on the specific materials to meet the specific local need. Instead of copper, they use aluminum, which has a higher resistance that becomes non-negligible only over long distances. By limiting each micro-grid distribution radius to the length of a spool of aluminum wire (90 m), MGP was able to cut 30–40% of the cost of distribution for only a 1–2% line loss. With this method, the challenge of distribution, in hamlets or even urban centers (see 4.2.2), becomes less one of expensive resource conservation (optimizing networks) and more one of sphere packing.

MGP also opted to implement monthly payments in conjunction with appliance management, rather than GP's method of metering and limiting the otherwise free use of appliances. Customers pay a monthly rate comparable to or less than what they would pay for kerosene and other services, and in return they can use their lights and chargers whenever necessary. As a result, no meters (which are expensive) or limiters (which can be tampered with) are required, dramatically reducing the cost of the system. Customers pay directly to a MGP collector, a trained local resident who has the authority to shut off their service upon non-payment. But the simplicity comes with its own challenges.

The benefits of metering are two-fold: the grid operator (micro-utility) can use individual consumption information to optimize service and plan for future growth; it can also track misuse and maintain payment accountability. When grid oversight is done remotely and there is a high likelihood of misuse or non-payment, it can be worth the cost to install meters and limiters. But where operation is done locally and the risk of misuse or non-payment is deemed acceptable, the added cost of meters and limiters may not be worthwhile in the short-term. Until recently, MGP opted for the latter, relying on mutual trust afforded to/by locally employed technicians and collectors. In the past year it was able to develop in house its own low-cost prepaid meter, which it plans to roll out in the coming months (MGP 2016). The addition could have a dramatic impact on its ability to track misuse, and will help if MGP decides to scale up its service and monitor higher and more varied levels of consumption.

4.3.2: Uttar Pradesh: Real Prices

The choice of technology also depends simply on what materials can be imported to the sites reliably and affordably. Much of the western world can rely on established trade agreements and tariffs, consistent and regulated customs laws, and so on. Even Nepal, which trades readily with both China and India and has limited regional import laws, can predict and rely on international prices. For example, a 150 Ah battery produced in China and approved by Nepal's AEPC will cost about Rs 26,000. This price includes a 10% hike above the price in India, plus a 6% import tax.

The same battery in Uttar Pradesh, which should cost only Rs 23,000, could still be even more expensive than the same battery in Nepal. This is due in large part to the somewhat convoluted interstate taxes on goods that have been imported to India, and bribes expected by officials processing large orders across state borders. Indian states that are not home to international trade hubs or major production centers end up paying more, in some cases, for products than other countries do.

Take another example from one of MGP's co-founders: from early in its life, the company has preferred local sourcing, for reasons of both cost and sustainability. They had been purchasing LED bulbs from China at INR 60 per bulb, and then paying an extra INR 40 per bulb in national and state taxes just to get them across national and state borders. The same bulb, produced in India, cost INR 40 per bulb, and MGP had to pay just INR 1 per bulb to transport it, cutting the price by almost 60%. MGP's situation in Uttar Pradesh is not entirely unique – in fact it represents the norm in several key ways.

First, its place as a non-industrial, mostly rural state creates dependence on processed materials and components from elsewhere in the country or world, and it is therefore subject to tariffs, commerce laws, and corruption within the port authority or local equivalent. Those working in international development will recognize this frustration – among ex-pats and international NGOs, the concept of receiving large shipments through Dar es Salaam in Tanzania without delays or bribes has the status of a joke. This unpredictability factor in component sourcing can contribute to the abandonment of development projects such as MGP's and GP's micro-grids. Accountability and consistent, transparent policy in this realm can go a long way to ensuring rapid iteration and development in the energy sector, among others.

Second, for-profit companies like MGP can survive only by adapting quickly and frequently to changing economic and technological environments. Since beginning this research in 2014, the price of solar has dropped significantly worldwide (EIA 2015), including the cost of batteries, panels, inverters, etc. (Gifford 2015). In addition, the relative shares of the solar markets held by various countries change – companies in China, the U.S., and Germany are just a few of the major players and, from year to year, one or another might present the greatest bargain to customers like GP or MGP. In places like Khotang and the hamlets of Uttar Pradesh, the low ability to pay and tough competition with other electrification methods requires that companies in any specialty walk a fine line and maintain only a minimal profit margin. Failure to maintain that balance by adopting appropriate technology, financing, or scale can result in long-term loss of profit and an end to investment.

4.3.3: Uttar Pradesh: Fighting for Viability

For the first years of operation, MGP's model was heralded as a success of appropriate clean energy development, and the company grew dramatically as demand increased across Uttar Pradesh. More recently, frequent issues with local collectors, the falling price of meters, changing demand, and external pressures are forcing MGP to rethink its model. As with all of the systems discussed in these case studies, the pervasive question remains: is this model the answer to energy development, or is it merely the first of many steps in a rapid progression?

MGP is no stranger to iteration: they experimented quantitatively with different types of distribution systems and considered the relative benefits of AC versus DC, limiting current versus limiting appliances, and so on. But one aspect of their projects has remained constant: customers pay a flat rate that is collected in person by a local staff member. While this was done to reduce costs and avoid the perception of MGP's "otherness," the result has been mixed. Employing local collectors has the advantage of using established, trusting relationships to maintain the financial viability of a common resource. The downside is that those relationships can lead to lower accountability among customers, whether in the innocent form of leniency on the part of a sympathetic collector, or the more egregious form of nepotism on the part of a corrupt collector.

The company started to see losses that, though minor, belied the likelihood of increased losses as the scale of MGP's operation increased. Though the majority of customers pay on time and without complication, enough losses from non-payment reduce the company's flexibility, making it harder for them to scale up, adopt newer technologies, implement pilot projects, or otherwise improve their operation. As of 2015, MGP was exploring meter options, trying to find a device that would accurately track individual usage that MGP could use to predict profits, track misuse, or identify truant customers. Most of the meters they had found would have increased the cost of each system beyond their means, though a few meters out of China seemed, at first glance, to be promising.

Demand was also in flux, as it tends to be in newly electrified areas. Roughly 15% of MGP's customer base wanted higher quality power to run bigger appliances such as TVs, computers, and refrigerators. Not only do these appliances require significantly greater generation in most cases, but some require AC rather than DC power. Unfortunately, the price increase for customers would not be linear with the cost increase of these additions; it instead increases stepwise. The cost of MGP's DC system was kept just within the margin of viability, but the addition of even an inverter, or higher gauge wires, would increase the cost well beyond feasibility even with the increased payment from the higher-paying 15%. Therefore MGP has not been able to get any other system design to pencil out, and has instead continued to provide the minimal service demanded by the majority of its customers at the rate they are willing to pay.

Several factors are changing this equation, however. The cost and power consumption of many appliances, especially TVs, has come down in recent years, to the point that a 5.5 W TV was on the market in India where, a few years before, a TV below 50 W was almost unheard of. In addition, the several-year presence of basic electricity has led to a gradual but positive change in average income, creating more buying power and increasing demand for electricity that cannot be met with the current micro-grid. The 15% "high demand" minority is therefore expected to grow following a rough *S*-curve – slow initial growth followed by rapid expansion of an electrified local "middle class" and, finally, a declining growth rate as a given hamlet approaches saturation. Many customers, having been exposed almost exclusively to MGP, expect the company to provide that service, thus requiring MGP to either gradually adapt their current grids, or redesign the micro-grids entirely to be scalable. In essence, what the hamlets can currently afford is something akin to MGP's micro-grids, but what they expect in the not-so-distant future is something more akin to GP's Khotang micro-grids.

4.3.4: Uttar Pradesh: Conflicts of Interest

A third factor challenges MGP's established model from the outside: other, not-for-profit organizations also aim to drive electricity development in the area, sometimes to the detriment of local efforts. To understand the principle of the issue, consider the following analogy.

You live in a town that is working to make electric cars affordable for its residents. It is a poor town, and the cars you are collectively able to purchase are functional and meet your needs, but are not the high-end. Still, residents are largely satisfied by the effort, and increasingly more are purchasing one of these cars. One day, a wealthy philanthropist comes to town and donates a single Tesla Model S to one of your neighbors. There are no other donations and, once the wealthy philanthropist leaves, fully believing that she has done a good thing for your town and the world, there is no indication that she will ever return.

Without attributing any particular characteristics to the residents of this imaginary town, it is easy to picture the fallout of the philanthropist's actions. The town's collective efforts would be undermined by newer, unrealistic expectations, and residents could either lose faith in the town's initiative or turn on the project designers altogether. What had been a locally driven and appropriate first step towards greater local sustainability would be entirely wiped out, or at least weakened. The philanthropist's action, which seemed like a net positive for the community, would end up being a net negative.

In Uttar Pradesh, well within MGP's operating "territory" (referring more to an area of influence than an economic monopoly, though MGP is the largest employer in the region), an outside project developer has installed a single, high-quality, donor-funded micro-grid that provides 24/7 AC power. The project required minimal local buy-in yet provides maximum service, much to the chagrin of nearby customers paying for MGP's limited services. The donor funding came from CSR (Corporate Social Responsibility) money, or money that large corporations and businesses are legally mandated to invest in community development. While this funding is sustainable in its own right, its use for rural micro-grids in Uttar Pradesh is uncertain. CSR money often goes towards highly visible flagship projects rather than towards iterating successful projects over a large area. Therefore MGP's customers, though aware of the high quality system nearby, are not likely to receive anything similar.

Instead, customers will look to MGP to match the quality of the island AC micro-grid, and to do it for the same cost to ratepayers, an impossible order. Though MGP got its start with the help of outside investment, its current business model is now sustained by its electricity rates rather than donor funds and, as discussed previously, the cost-benefit analysis of scaling up its systems does not pencil out. The new donor-funded micro-grid has increased local expectations without increasing willingness to pay, leaving MGP with a dissatisfied customer base and the risk of revolt in the form of withheld payments ("My neighbor pays half of what I pay and receives superior service – why should I continue paying you?") or stagnant growth.

Businesses in general are no strangers to these type of challenges – unbalanced competition, changing demand, fluctuations in source material market – and a smart business manager or project developer keeps a close eye on each factor and adapts when necessary. At some point the financial situation will be right for MGP to transition to expanded service to meet higher individual demand; willingness to pay will increase, and component costs will decrease, to the point that inverters, high-gauge wires, and meters are affordable given the expected buy-in.

4.3.5: Rural Nepal and Rural India: The Terai

Directly North of Uttar Pradesh, across the border, is Nepal's Terai region. The southernmost of three geographical regions – the hill and then Himal (mountain) regions follow to the north – the Terai is the most similar to Uttar Pradesh. Its low-lying, humid plains support Nepal's agricultural base, and much of the population is densely concentrated in hamlets and serf-like villages around large agricultural estates. The population here has some of Nepal's greatest income inequality, with estate managers at the top and serf-like laborers at the bottom. The electricity situation is no less segregated; the national grid follows major thoroughfares, reaching estate homes but not the laborers' villages. In one case relayed by one of GP's engineers, the grid serves an estate house, but the estate owner refuses to extend the distribution lines across his property to his employees' village barely a hundred meters away (GP 2015).

In 2014 Nepal's AEPC approached MGP in Uttar Pradesh, as well as GP in Kathmandu, about exploring micro-grid options for these communities. In 2015, a small MGP team visited Nepal to meet with GP and tour the Terai. The initial assumption was that, given the relative poverty and high density of the Terai villages, MGP's micro-grid model was more appropriate than GP's. But when the team returned to Kathmandu from their visit, the consensus was that neither would be optimal. One GP engineer, after visiting a proposed Terai village several weeks earlier (he had intended to visit all five AEPC proposed sites, but a national strike stranded him in one village for a week instead), confessed that he had not even felt comfortable asking villagers about their willingness to pay, so obvious was their poverty.

The villages could not afford GP's grid-quality micro-grid, but they also were not willing to pay for MGP's cheaper yet limited services. Residents had long been exposed to high quality electricity service while in close proximity to the NEA grid and wealthy employers, and they were not keen to settle for basic lighting and phone charging. In addition, the AEPC had already promoted SHSs in the area, and residents could get similar service through those systems without the hassle of collectively managing a community micro-grid.

The Terai represents a situation in which national grid expansion may be the best option for electrifying otherwise rural areas. The geography of the region does not present a physical challenge to expanding transmission and distribution lines, unlike in the hill and Himal regions, and the higher population density ensures the NEA a more robust ROI. There is also an opportunity for mid-scale generation in the region; instead of relying on hydro expansion in the hill region, biomass from agricultural waste could be used in gasifiers or thermal power plants to generate locally. Micro-grids still may have a role to play in the Terai where the NEA grid is still absent and communities could either afford a GP-style system or benefit from a MGP-style system.

4.4: Tanzania

In the last 40 years Tanzania has experienced severe and recurring droughts with devastating effects to agriculture, water and energy sectors. Currently more than 70% of all natural disasters in Tanzania are climate change related and are linked to recurrent droughts and floods. …An initial estimate of immediate and start-up financing needs for enhancing adaptive capacity is about USD 150 million. In addition, about USD 500 million per year is needed to address climate change adaptation and building resilience up to 2020, increasing up to

USD 1 billion per year by 2030. These costs are likely to increase further depending on global mitigation efforts. Estimated costs are up to USD 60 billion by 2030 in mitigation investments in Tanzania.

-Tanzania INDC, submitted to UNFCCC 2015

Tanzania submitted its INDC (Intended Nationally Determined Contribution) in advance of the Paris COP21 climate negotiations, at once predicting the effects of unmitigated climate change, quantifying its own negligible contribution to carbon pollution, and estimating the high cost of adapting to and mitigating the effects.

To give some context, Tanzania's GDP is USD 50 billion which, per capita, falls roughly between Nepal (lower) and India (higher) (IMF 2015). The country could not fund its own mitigation and adaptation efforts without dismantling its economy. The INDC goes on to explain that "every annual event has economic costs in excess of 1% of GDP, and occurs frequently, reducing long-term growth and affecting millions of people and their livelihoods" (2015). In a country where over 75% of the population is engaged in agriculture in some capacity (Feed the Future 2016), and about 37% of installed electricity capacity is hydroelectric, more frequent and intense droughts and floods are more than just a newsworthy nuisance.

But Tanzania's direct climate challenges, along with its neighbors', are just the most recent manifestation of decades of misguided development efforts by the West following centuries of exploitation. Energy developers naturally operate in the context of climate change and economic crisis, and therefore the country's development history.

Though it gained independence as Tanganyika in 1961, Tanzania's period of self-determination was brief and, in many respects, has yet to begin. With a difficult economic starting point and the fallout of Nyerere's socialist policies, Tanzania has been a recipient of foreign aid for decades, a fact that by Western expectations should mean that it is well on its way to self-sufficiency. But with aid comes demands, and the West, particularly the U.S., has required numerous "structural adjustments" from the Tanzanian government, often at the expense of the government's own initiatives. Even aid money itself is not completely in the recipient's hands: the U.S. requires that roughly three quarters of money sent abroad be circulated back into the U.S. economy, more than double the rate of next highest required percentage (Canada's).

A recent iteration of this was the Africa Trade Bill, which passed the U.S. Congress with the aim to "liberalize trade and investment flows between the United States and Africa" (Easterly 2006, 217). Despite its many good intentions and provisions, the bill contained a few *quid pro quo*s, as Easterly goes on to explain:

> ... it comes with the usual conditions: reducing social spending, corporate taxes and agricultural subsidies, opening all sectors to foreign investment, emphasizing export crops over local production of staple foods, and privatization of public assets. Many African countries have chosen not to join the WTO, but this bill requires participating countries to join. It does not incorporate policies requested by the Africans: debt relief, sovereignty in determining economic and social policies, and financial compensation for historic exploitation of Africa (2006).

Tanzania's energy development, as well, is guided by similar stipulations, sometimes in ways that favor Western infrastructure firms and energy markets over local resources. Though this poses a challenge to appropriate energy development, it may also provide an opportunity for small-scale, market-driven projects to fill the mitigation gap that the government may not be able to address itself.

Given its currently negligible contribution to climate change – 0.2 mtCO2e per capita, compared to 17.0 mtCO2e per capita in the U.S. (World Bank 2015) – as well as its low resilience to climate effects, Tanzania's government could be forced to lean more towards funding adaptation measures than mitigation. Relieving drought-stricken areas and shoring up its energy supply with more climate-independent sources will have to take precedence over updating its grid or exploring expensive pilot energy projects. But, as in dozens of countries facing similar prospects, Tanzania's minefield of challenges does conceal a delicate but very real opportunity to pursue sustainable energy development, even in rural areas.

The national grid is not likely to undergo major reform any time soon: just under a fifth of the country – 18.4% overall, closer to 14% in rural areas – was electrified as of 2014, mostly by Tanzania's parastatal utility TANESCO (Tanzanian Electric Supply Company Limited, under the Ministry of Energy and Minerals). The utility's 15% annual growth rate (EIA 2015) has focused more on fossil fuels as hydro resources face increasing difficulty from droughts and floods. Tanzania's INDC promises to decrease overall emissions 10-20% below BAU in the coming years (2015), but BAU is a trend, not a single point in time, and still involves a dramatic increase in natural gas fired power plants (Kichonge 2014). On top of the challenges of load shedding, climate effects on hydro, and expanding a highly inefficient grid (23% line losses on average), TANESCO was also awarded the responsibility of handling rural electrification, which it later delegated to a separate agency due to a lack of government support (Zerriffi 2010; Smith 2008). It is in rural electrification that Tanzania will see, for better or worse, its future emissions and economic growth.

The government's earlier lack of support for, or really attention to, rural electrification efforts contributed to the confusion that the sector faces today. Rather than a concerted, policy-supported drive to thoughtfully electrify Tanzania's rural majority, the recent effort has been a mix of for-profit businesses selling solar appliances, NGOs and non-profits installing islanded systems under a wide range of financial mechanisms (and an equally wide range of success), and individual residents gradually building their own systems as incremental profits have fed incremental additions.

This paper opened with a brief anecdote from the author's experience in the village of Luhunga, in the highland region of Iringa; this will serve as a case example of the various stages of electrification in a rural community far from the national grid.

4.4.1: Rural Tanzania: Luhunga, Iringa

The description of Luhunga as "far" from the grid may be a misleading; the grid dead-ends in several villages within walking distance. Two hours to the North is the village of Mdabulo, as much of a commercial hub as the fringe collection of villages can claim. It is the terminus of a TANESCO transmission spur and, day or night, electric light and loud music spill out into its main road from shops, clubs, and one particularly music-heavy barbershop. Four hours through tea plantations to the West from Luhunga is Sawala, one of several larger villages along the district's Loop Road, which snakes out from the A104, Tanzania's main corridor to the South. Sawala, itself several hours by bus from the paved highway, also bears the telltale signs of recent electrification and the resulting burgeoning population. An impossible web of wires crisscrosses its way from building to building along the village's densest axis; each of the dozens of shops accurately advertises electricity with colorful LEDs, radios, and TVs showing Tanzanian soap operas.

If Sawala and Mdabulo represent where villages are headed, Luhunga represents their origin. With a 14.2% rural electrification rate, and a poverty ratio well over 34% (the national poverty ratio), Tanzania's 70% rural population will be long in awaiting TANESCO grid extension (IMF 2015). Communities are thus left to their own devices, often without assistance or direction from energy organizations. In some ways, the evolution of energy resources in these off-grid areas could be considered analogous to incomplete Western energy development on steroids.

The biomass that fueled the country's needs through most of its history and that led, in conjunction with colonial agriculture, to widespread deforestation, is still in wide use. In Luhunga, people cook exclusively with firewood or charcoal, both sourced in the surrounding, dwindling rainforest. Firewood harvesting is a daily chore for women and girls, as well as for poor or displaced boys, and is locally understood as one of the more dangerous activities because of rape. Firewood has the distinct advantage of being free; charcoal, though also labor-intensive and seasonal, is moderately affordable and far more efficient. A 100-litre *gunia* of charcoal could cost between Tsh 5,000 and 10,000 (USD 2.50 to 4.50), depending on scarcity, and could last a household for a month (exchange based on Feb, 2016 rates).

Lighting is provided by a mix of candles (less popular), kerosene lamps (more popular), pressure lamps (briefly popular and then nearly extinct) and, more recently, battery/solar-powered LEDs. Despite their low quality – *Chinese* has replaced *kishenzi* in the lexicon as a synonym for "cheap" or "low quality" products – the LED lights quickly became popular for their unprecedented efficiency and accessibility everywhere from city shops to rural traveling markets.

The ubiquity of electric appliances in un-electrified villages, even before the emergence of LEDs on the market, can be attributed to mobile phones. Leap-frogging landlines (in much the way RETs are expected to leap-frog fossil fuels in rural electrification), mobile phones rapidly cornered the communication market in Tanzania, creating a sudden demand for charging capability in every corner of the country. Local entrepreneurs responded quickly and creatively, repurposing motorcycle batteries and discarded wires in homemade, decidedly not-to-code, charging stations. Owners would charge phones for a few hundred Tsh and, when the batteries ran out, would give them to the bus conductors on their way to town. The conductors would charge the batteries on the grid in town, return them to the owners in the village, and collect a small fee for their efforts. Business success, in this capacity or any other, often led to purchasing a small solar panel, thereby solidifying an owner's place in the charging market.

These battery stations joined diesel generators as the source of "quality" power in the village. While the generators could power the heavy AC appliances, like the TV in the local guesthouse or the sound system that the school rented for special functions, batteries provided other services. A barber shop offered the requisite haircut to local students, local shops stayed open late without burning through their own stocks of candles and kerosene, and mobile phone charging grew into an established business model complete with competitive pricing and growing demand.

The first major electrification effort came at the end of 2008, and is prefaced in the opening paragraphs of this paper. The UK-based solar NGO, on recommendation from a nearby British NGO and invitation from the school, installed a three-panel array, inverter, and battery bank on the roof of the local secondary school. The roughly 360 W system powered three outlets in the school office, as well as two CFL bulbs in each of five classrooms. The original plan was to provide light to students during evening "prep" time, and power to the office in the eventuality of using a computer.

The solar NGO's model required that the school pay back 10% of the Tsh 10,000,000 installation cost, which amounted to Tsh 1,000,000 or about USD 800 at the time. Project designers argued that the school could tap into the mobile charging market, charging Tsh 300 per phone, over a dozen phones a day, and pay the system off over a year or two. The 10% payment clearly would not sustain the NGO's efforts, especially with a largely European staff requiring Western salaries and lifestyles. The repayment was mainly in the interest of ensuring that the community bought into the system and felt responsibility for its success, as well as providing a source of income for the school. The remaining 90% or more of the funding came from donors.

This model had become dominant in the world of the development project at the time: poor communities that could never afford the upfront cost would still be able to access electricity, they would have some level of much-celebrated local ownership of the project, and they would be free to take advantage of the newfound business opportunities that the project provided. In theory it seemed ideal. The school should have been able to make back the 10% within a year or two with room to spare, and then gone on to make a profit for the remainder of the 25-year lifetime of the system, minus expenditures like battery and bulb replacements. The profit should have gone to expand the system in a feedback loop, thereby growing the service exponentially. Once grown the school should have leased the system additions to neighbors, powered a computer lab, hired new teachers… the sky should have been the limit. Instead, after two years, the NGO was threatening the school with system recall due to non-payment, the batteries were all but depleted, and only a few of the original switches and bulbs remained intact in the classrooms.

As far as anyone communicated at the time, the NGO's model was excellent. After Tanzanian technicians installed the system, they instructed the teachers on the proper discharge depth of the batteries (50%, indicated on the charge controller) before the system should be turned off, and even provided educational materials to use in the classroom. The school designated one teacher to be in charge of monitoring the system, instructed its staff to collect fees for charging phones, and elected a contact person with whom the NGO would stay in touch. In addition the school hired a second night watchman specifically to protect the new system.

Petty theft is common enough in the village and almost never involves direct conflict, while grander theft is rare and is almost always met with strong retribution. Three local men who had stolen from and then burned a fabric shop were caught and punished by having their eyes removed, being burned at the stake, and then being beheaded, their bodies left in the road as a warning to other would-be thieves. Another man had hired primary school students to steal bags of cement from the school construction project, and he fled the village as soon as neighbors got wind that he might be responsible. The shear reputation surrounding theft in the village was likely enough to keep the main components – batteries, inverter, and panels – safe. Smaller components – switches, sockets, and bulbs – were easier to steal and less likely to be missed, and no one ever discovered who stole them. One morning the teachers found a Seussian stack of chairs in one of the classrooms, and several of the CFL bulbs missing.

Teachers at the time speculated that the theft was not done out of a great understanding of likely profit. The benefits didn't outweigh the risks in this case: switch casings, plastic conduit, and CFL bulbs do not fetch a high price on the black market, especially not when simpler alternatives exist. CFLs especially did not compete with the more versatile, efficient LEDs. Instead, the reason seemed to lie in the perception of these devices. In a village that had never seen these components before, their "developed" appearance, especially to younger children who would have needed a stack of chairs to reach the roof beams, might have drawn attention more than knowledge of their actual worth. But theft was the least of the problems; the school could, and did, replace those components with little additional trouble. The system's gradual degradation resulted, rather, from misuse.

4.4.2: Luhunga: System Misuse

Physically, the weak point in the system was the batteries – not because they were low quality, but because batteries are most susceptible to misuse and therefore the canary in the coal mine when operation is sub-par. Lithium Ion (Li-ion) batteries do not technically have a maximum depth of discharge (MDoD), meaning they can be discharged fully and still function properly, as a opposed to lead-acid batteries which may have a 30% or so MDoD. The capacity of the battery (in kWh), however, is reduced over time, and the rate of reduction is accelerated by deeper discharge. A 100 Wh Li-ion battery, for example, could potentially provide the whole 100 Wh if needed. But the chemical strain on the electrolyte and exchange membranes from maximum discharge reduces the battery's overall capacity. The next time the battery charges, it might only acquire 99 Wh, then 98 Wh, and so on.

Anyone selling or installing a battery will recommend a MDoD to the operator in order to optimize the performance and lifetime. A lead-acid battery with a 30% MDoD can provide 30% of its total capacity before recharge is recommended or the battery performance degrades. Li-ion batters typically carry a recommended MDoD of 80%, a significant improvement over lead-acid. The challenge to operators is to know when the battery has reached this point. It is not actually possible to measure the instantaneous kWh charge of a battery, and so the most that solar systems can do is guess, either manually or digitally.

Many charge controllers now take automatic voltage readings on the battery in order to estimate its instantaneous charge. The voltage changes slightly and non-linearly as the battery is discharged; by comparing the instantaneous voltage to the characteristic charge/discharge curve (the two curves are different), the charge controller can get a decent estimate of the current charge (kWh) remaining on the battery (See Figure 4.1 for examples of discharge curves; charging follows a similar pattern with typically a higher intermediate voltage). If a MDoD is programmed into the charge controller, it can automatically shut off the system, or at least provide a warning to the operator, when the battery is getting too low for comfort. This keeps systems safe and makes operators less responsible for effects that they likely do not understand. Luhunga's situation, though, was different.

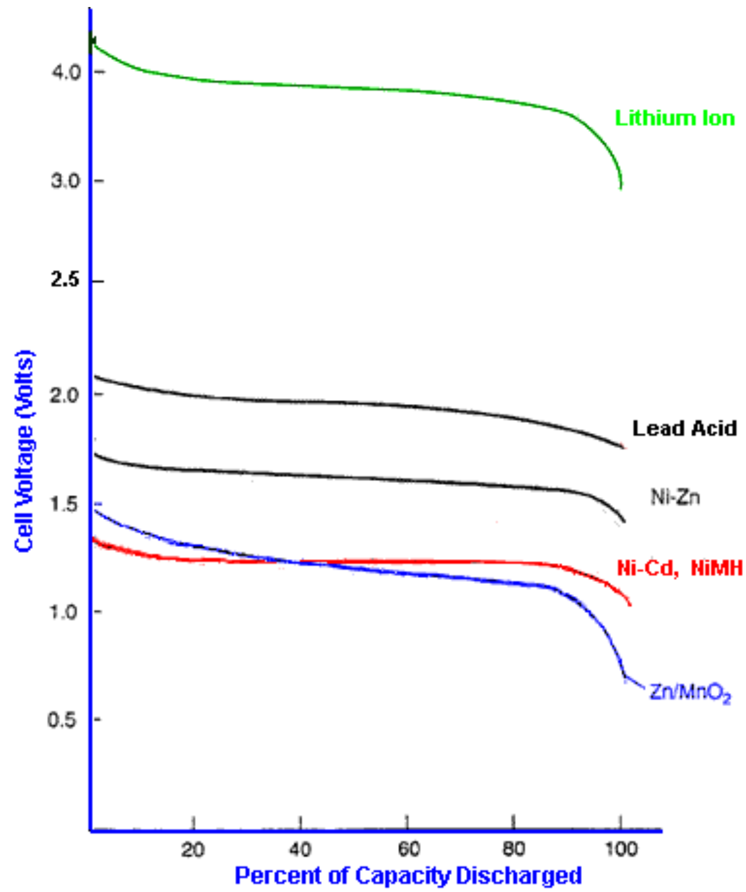

Figure 4.1: Characteristic Discharge Curves, Example (Electropaedia, 2016)

When the Luhunga Secondary School solar system came online, most charge controllers did not automatically shut off the system upon reaching the MDoD, leaving the operator(s) with the burden of monitoring. In Luhunga, this fell to the teachers, who had access to the charge controller and outlets. The office rule (whether official or *de facto*) was that teachers could charge their phones or otherwise make use of the outlets for free. The practice quickly expanded to include charging friends' and families' phones as well, and then the phones of favored students, without demanding the customary Tsh 300 fee. During the days of the dry season, the system was able to handle the load without trouble. But during the rainy season or at night, the heavy use from phone charging often drew the batteries down well below 50%, the MDoD recommended by the NGO.

The effect was gradual but noticeable to those keeping track. Unaware of the causes, students saw their evening prep time reduced, minute by minute, until a rainy season prep period would last one hour of the original three, and a half hour of sun the next morning would completely “charge” the batteries. Profits that the NGO had predicted from phone charging dwindled and ceased entirely. When the school missed its 10% payment deadline, and then missed the extended deadline, the NGO called the western volunteer teacher (not the contact teacher or headmaster) to threaten full system recall if the school didn’t pay immediately. Lacking any savings from phone charging, the school raised the money by leveeing an additional fee on its students, thereby meeting its 10% goal. There was no contingency plan to replace the two batteries, each of which cost between Tsh 600,000 and 1,000,000 – more than the school’s annual budget.

The NGO’s short research period left them with few details to work with. Between the engineer’s initial visit in late November, which was purely for a technical evaluation, and the full installation in late December, there was no other village/school visit or follow-up information gathering session. The NGO had its own set of experiences and assumptions that informed its project design; the peculiarities of the school or village never factored into the equation, and no one on the receiving end of the project thought to question those decisions. The promise of free electricity can be a powerful force against constructive criticism.

4.4.3: Luhunga: Power Structures

In the Nepal and Indian case studies presented in this paper, the customers are whole or large parts of democratically-governed communities. When the system is designed, its financial viability depends on customers' ability and willingness to pay, and the ultimate success of the system depends on a collective interest in its correct operation. A school works very differently: instead of a democratic, collective interest, operational decisions are made or ignored by a single authority. And instead of continuous collective payment, the school administration bears the sole responsibility of complying with payback schemes and finding the income to do it. This situation raises the question of buy-in and "ownership."

A percentage buy-in, such as the 10% expected of Luhunga Secondary School, can serve to create a sense of ownership in a recipient entity as long as that sense is universal. When one person or group (the school administration) feels responsibility, but no one else has a vested interest (teachers, students) beyond the free services provided, it is a simple step to abuse the original intent of the project designer. The school administration is responsible for profiting from the system's excess generation, but it is far simpler to levee a fee on the students. The fee itself does not imbue the students with the blessing of ownership, however, as they still have no control over the system's long-term success; it is more a recipe for resentment.

The teachers are on the other end of the spectrum, bearing no burden of payment nor adverse effects from the degradation of the system. At Luhunga, like many village schools, teacher turnover was close to 100% annually. The government assigned new teachers to the school every year, but most never arrived. Lacking any alternatives, the school often hired recent advanced secondary school graduates (two years older than Luhunga graduates) to teach. After several months most of these volunteer teachers left to pursue university or other jobs. Not only was buy-in minimal from the teaching staff, but so was general understanding of the system, which was not effectively relayed to new faculty every few months.

At the time of Luhunga's solar installation, the NGO was entering a solar market seemingly bursting with potential customers. The Tanzanian Ministry of Education and Vocational Training (MoEVT) was in the middle of a decade-long school building spree, creating village secondary schools all over the country. The schools had (somewhat) reliable funding, ideal locations in commercial village hubs, and a high need for electricity. To a solar project designer, this was as close to a sure-fire success as one could get given the potential for economic generating activities and quick payback. But the government had not preceded the expansion effort with a similar push to train teachers, so most of these new schools were dramatically understaffed and struggling to gain a foothold as competitive educational institutions for an underserved rural population. Though not a universal problem, teacher turnover and dissatisfaction was common enough to warrant careful research and planning for school-based projects of any kind.

From the NGO's perspective, the 10% payback from the school was insignificant to its funding. More important than the money itself was the fact that it was repaid, showing outside donors that the model was successful in sustainably electrifying a village school. Regardless of its individual employees' likely desire to see the project truly be sustainable, the NGO's interests were officially met when the school completed its payment, regardless of what followed. This reflects not on the organization's motives or ethics, but on the donor-centric model of outside-funded development itself. Long-term buy-in and ownership are not enough when isolated on the receiving end; in order to encourage thoughtful planning, the project designer needs a vested interest in the project's success over the lifetime of the project itself, not just the payback period (see Chapter 5).

About four years after the solar installation, a contrasting model of rural electrification began selling power to a string of villages, including Luhunga. Curving East and South from Mdabulo (North of Luhunga), successive mountain ridges are home to a series of previously un-electrified villages considered "bush" even by Tanzanian standards. The villages follow a *U*-shape, curving back West towards Luhunga, and near the trough of this *U* is the outlet from the combined drainages of this section of the highlands. The escarpment provides enough head to draw power from the stream, and in 2009 a British company began building a hydroelectric system and installing power poles along the village road, promising power in the near future. In 2012 power generation began and, by 2013, it had reached Luhunga.

As in Khotang, individual customers were responsible for wiring their houses and paying a connection fee; beyond that they were charged for continuing service, with the British company acting as a local utility. The hydroelectric facility is subject to seasonal flow changes; much of it is spring-fed but then augmented by the 5- or 6-month rainy season. Because the facility was designed based on the generation potential of the watershed, rather than the expected demand, the number of customers and their usage patterns determine the frequency and duration of load shedding. The dry season sees more power shortages signaling, as it does in Nepal, an opportunity for solar to serve a vital role.

4.4.4: Tanzania: Entities Converge

In February of 2014, the government of Tanzania officially declared its push for solar power with its One Million Solar Homes initiative. With a USD 100 million investment, the plan aims to electrify roughly 10% of the country's homes at a price that is competitive with, or even beats, that of kerosene (Off Grid: Electric 2016). Due to the steep decline of solar costs, the World Bank estimates that solar is in grid parity with hydro (meaning their costs are roughly equal per kWh delivered, in this case USD 0.20) and is cheaper than fuel oil (USD 0.25 per kWh) (2015). To meet this goal, the Rural Energy Agency has partnered with a private company, Off Grid: Electric, to provide the full range of services.

Off Grid: Electric (hereafter Off Grid), which counts USAID, the IFC, and solar financing-pioneer SolarCity among its investors, acts as a sort of distributed utility. For a minimum of USD 0.20 a day, customers can gradually pay off the home systems that Off Grid installs for less than they typically pay for kerosene or other lighting or electricity services. Unlike GP, MGP, or the solar NGO in Luhunga, Off Grid does not sell solar systems and appliances. Instead, the company leases systems and appliances desired by the customer, and then charges a daily/monthly fee until everything is paid off. Local suppliers and technicians provide the service directly, and customers have access to a 24/7 tech support hotline (USAID 2014).

At its core, Off Grid is both mimicking and making use of a locally analogous sector, telecommunications. Mobile phones in Tanzania offered individual, affordable, and deployable communication options long before landline infrastructure would have become affordable for rural communities. As mobile phones proliferated, industries and businesses learned to harness their universal access in new ways: health clinics and extension agents could provide advice and information to remote patients, and food distribution centers could streamline their supply chains. Arguably the most singularly influential innovations, however, were pay-as-you-go vouchers and a system of remote payment.

In Nepal, India, and Tanzania, as well as much of the developing world, mobile phone service is paid for incrementally, rather than with the flat rate used in the U.S. and much of the West. You can visit almost any shop, rural or urban, and purchase vouchers for a specified number of minutes or texts. After you pay and receive the voucher, you enter the code into your phone and your account automatically updates with your new balance. When you run out of minutes, you just purchase more vouchers. This system allows network service providers to avoid the challenge of making "plans" appropriate for certain categories of customers, and instead allows customers to use freely and pay accordingly.

It did not take long for users to realize that this system could be used as a method of remote payment. If a farmer in Luhunga ordered seeds from Dar es Salaam, the farmer could purchase an equivalent amount worth of phone voucher, transfer the balance to the supplier via his phone, and thus the supplier was paid. The only step missing was an easy way to cash the voucher in. M-PESA, which started in Kenya and has since spread in form if not name to most of the developing world, formalized this system by providing the full, end-to-end service. Customers can purchase M-PESA voucher and transfer it to another user, who can then cash it in.

Off Grid: Electric has filled an analogous gap in rural electricity service. Customers pay a daily/monthly rate based on the system they receive – the size of the panel or array, appliances, etc. – via a mobile phone voucher system. Vouchers can be purchased in person at local kiosks and entered into the phone, or paid for with the sector-specific variant of M-PESA, M-Power. Whenever a client decides to change her system by adding more capacity or by leasing different appliances, Off Grid's local affiliates perform the upgrade at no cost, and the client's balance increases accordingly. But Tanzania's solar initiative, despite the simplified financing and repayment mechanisms, is not without its challenges or limits.

Among these challenges is the potential for a Luhunga-type recap, where a client does not make timely payments and the system is recalled – a lose-lose situation for everyone. Not only does it cost Off Grid resources to recall a solar system, it damages the image of the non-paying client and the solar initiative itself. Tough action may encourage timely payment and realistic choices when requesting a system, but it may also discourage participation for fear of retribution in an already uncertain financial situation. The scale and timeline of the solar initiative may serve to mitigate the non-payment scenario, however.

Assuming that electricity service is replacing use of other fuels, like kerosene, and that the USD 0.20 per day is already less than what a household would be paying for those fuels, non-payment is not an issue of ability, but rather one of familiarity. Where once a client had purchased kerosene directly from a shop, stored it, and used it, she now would be purchasing a non-tangible good using an abstraction of money. Once you have purchased kerosene enough times, its monetary value is perceptible in its weight, smell, etc. Electricity is difficult to value without being familiar with it, and the money itself moves invisibly. But the scale (10% of households nationwide) encourages participation, particularly among neighbors. Similar initiatives in the past have failed because the project was too small to gain attention and therefore confidence, or the technology was too new to deserve household investment. A national project can overcome challenges of participation by using components that clients have become familiar with and have seen function effectively. The scale of deployment may result in a new normal in some communities; having one's system recalled due to non-payment would therefore go against the new normal and would likely be the exception rather than the rule.

4.4.4: Tanzania: Short-Term Goals, Short-Term Impact

The One Million Solar Homes initiative is fundamentally a scaled-up, lease-based SHS program. Its goal is to provide, or at least help drive, electricity development in areas where the grid could not reach even if generation was increased. Several questions that this raises are: What happens if or when the grid arrives in these communities? What if individual clients want to scale up to grid-quality power, either in preparation for eventual connection or simply in order to operate large appliances? Given the large amount of funding on which this program depends, can a company like Off Grid continue this method sustainably? The answers are necessarily speculative but raise some intriguing points.

First up is cost. Scaling in this case faces the same issue that MGP faces in Uttar Pradesh: unmetered, DC systems are affordable on a large scale, but scaling up to grid-quality power requires a disproportionate price hike. Inverters are well out of the range of affordability for most customers, and individual meters would drive household rates out of parity with kerosene or other options. This leaves Off Grid with the option of flat rates and DC service. However, given the company's leasing model and individual installations (instead of communal micro-grids), there is significantly more individual customer freedom to adjust systems to household needs. If Off Grid offered the service a household could, conceivably, lease an inverter for its own use. But the company will likely not be able to offer grid-quality services widely or cheaply, leaving communities that expect imminent grid service in limbo, not knowing whether it is worth it to invest in solar. But even with grid extension, is it worth it to connect? Or can future needs be met over time with distributed generation alone?

Grid rates from TANESCO are comparable to those in the U.S. – about USD 0.11 per kWh compared to USD 0.12, respectively (EIA 2015). At the low consumption rates of rural households, grid connection could mean substantial savings over even Off Grid's low USD 0.20 per day, and it would power AC and high voltage appliances. But as Tanzania explores more natural gas, which has a tendency to fluctuate on the international market (TZ does not have reserves of its own), and considering the lower ROI for extending to rural areas, the low price of grid power is likely to increase. In addition, locally generated and used power can be attractive for other reasons: avoiding load shedding, having ownership and control of one's own resources, increased awareness of and responsibility for individual consumption, and others are all difficult to quantify but very real where consumers are directly dependent on their own sources. But social benefits cannot necessarily be weighed against low grid prices; rural customers would need some assurance that distributed generation could scale to their future needs and still compete with the grid.

If the leasing model employed by Off Grid continues to provide quality components and appliances with reasonable payback rates, scaling may drive its own market. While some customers will continue to require only basic services, others may advance their income to allow for greater generation or storage capacity, inverters, and higher-end appliances. Renewable energy technologies continue to drop in price and are expected to continue doing so as the market establishes itself and technology advances. Perhaps most importantly at this stage, investors are realizing that renewable energy projects are typically low-risk; therefore banks and lenders can require lower interest rates and drive competition in the market. The RET industry, in short, is steaming towards greater affordability and market penetration for the foreseeable future. While grid prices stagnate or even increase (this is true in the developed world as well), the cost of distributed generation continues to decrease. It may therefore be in a community's long-term interest to invest in its own flexible, homegrown, local generation than in the extension of an aging grid. Historically, and to some extent currently, the national grid has benefited from an economy of scale; but with electricity generation markets in flux it will be more difficult for grids to adapt on the fly with smart metering technology and renewable integration.

Another potential red flag raised by Off Grid's model is its dependence on donors, the largest of which are proudly mentioned in announcement publications (USAID 2014; Guardian 2015). A mix of international aid agencies has pumped hundreds of millions of USD into getting the Million Solar Homes project off the ground. As with GP, which received the same order of magnitude in start-up funds for its micro-grids, Off Grid's donors intend for their investment to kick-start a sustainable business rather than serve as a continuous source of funding. Without (local) proof of the concept that customers will make regular payments and sustain the company's expansion, the donors are taking a risk. The model could founder and deprive future endeavors of similar start-up funds if customers fail to pay. However, several factors indicate advantages that One Million Solar Homes has over projects in other case studies discussed here.

First, given the combined earner-payer nature of each customer, Off Grid can avoid a Luhunga-esque situation of split incentives (whereby the school administration could charge students for the service that primarily benefited faculty). This small difference could encourage repayment among individual household and business customers in a way that Luhunga could not. Second, the remote voucher payment system relies on an established method of personal accountability (a la mobile phones) and avoids MGP's issue of personal relationships between bill customers and bill collectors. Third, the entire initiative, though implemented by a single for-profit company and its affiliates, has the backing of the Tanzanian Rural Electrification Administration. This particular public backing imbues the entire project with flagship status, sending a clear message to investors and customers alike that success, if not guaranteed, is at least a major priority for the country. In summary, Off Grid's model, short any forecasts on payback periods, appears to include best practices learned from several sectors and avoid many of the difficulties encountered in other scenarios discussed in this chapter. It is a step in the direction of learning from bottom-up initiatives and building on local norms and capacity.

4.5: Case Studies Summary

The table below gives a summary of the major factors discussed in this chapter. No two case studies have identical conditions, and the reader should note key differences in the timing and scope of each subject.

Table 4.1: Case study factors comparison

	Cases				
	Khotang	**Luhunga Solar**	**Kathmandu BMG**	**TZ: OMSH**	**Uttar Pradesh**
Voltage	Grid-level	Low	Grid-level	Low/Variable	Low
Type	AC	AC	AC	DC	DC
Implementer	Gham Power	International Solar NGO	Mera Gao Power	Off Grid: Electric	Mera Gao Power
Service Start Year	2015	2008	2014	2015	2011
Status (Q1 2016)	Ongoing	Failed	Ongoing	Planning	Ongoing
Scale	Village	School	Building/ City Block	National	Multiple Hamlet
Customer Up-Front Cost	Moderate	Zero	Zero	Low	Low
Customer Ongoing Cost (relative to replaced alternative)	Moderate (SHS)	Moderate (Kerosene)	Moderate/ Negative (Diesel)	Low (Kerosene)	Low (Kerosene)
Customer Buy-In/Participation	High	Low	High	High	Moderate
Planning	Long	Rapid	Moderate	Rapid	Rapid
Policy Support	Subsidy, Government Initiative	None	Subsidy	Government Initiative	Low
Donor Dependence	Start-Up	Continuing	None	Start-Up	Start-Up
Business Model Status	Pilot, Planned Sustainability	Donor-Funded	Sustainable	Pilot, Planned Sustainability	Sustainable

Despite key differences between major factors – scale and timing being primary – trends appear between projects that have failed to meet long-term goals, those that face significant challenges, and those that have found early success (though uncertain futures). These will be discussed in the following chapter with an eye towards drawing lessons that can be applied to projects anywhere.

Chapter 5: Discussion

In *Rural Electrification: Strategies for Distributed Generation*, Zerriffi (2010) ends his opening chapter with a lesson for those working in electricity development: studies of best practices, challenges, and methods, should be broad. Single anecdotal cases are just that – singular: they offer few specific recommendations that are relevant to other situations. By seeking to understand *all* rural electrification efforts generally, we run the risk of falling into the aforementioned "silver bullet" or "Big Plan" trap (Easterly 2006). Noting, for example, that a 30% investment tax credit in solar projects spurred development and increased access in a region of Nepal may lead us to believe that tax credits would benefit all countries where electricity access is low. This is not to discount tax credits, but it would be imprudent to pressure governments into policy decisions they may not want and that may not actually benefit them. Distributed generation as an industry is in rapid flux and differences from one site to another, even in close proximity, can be significant.

Development efforts have historically operated via top-down plans based on ideology more than experience, and little consideration for site diversity. We can better serve rural electrification efforts by using case studies that analyze the development *practice* itself, questioning viability and sustainability, and then supporting local efforts.

This paper analyzes specific cases based on their apparent similarities to, and underlying differences from, one another. No one case study presented here should be taken as a packaged lesson to adjust and recreate elsewhere but, rather, all of the case studies must be considered in comparison to one another, their commonalities and differences dissected. Once understood, a project developer has the tools to apply not the *facts* of each study but the common *approach* they demand for local propriety.

5.1: From Aid to Enterprise

The world development project, or what McMichael terms "globally organized economic development" (2000), operates within a capitalist global economy. Governments, corporations, or well-funded NGOs may be able to "do" development where and how they choose, but the bulk of DG is driven by for-profit companies like GP, MGP, and Off Grid. Project developers are therefore responsible for considering the role that these companies can play and how each project might become a long-term enterprise for both the developer and the recipient community.

This paper has discussed in detail because it is the single most important indicator of a given DG method's financial future. But this should not be mistaken for advocating utilitarian approaches to addressing a very real need. As ROI determines a project's success from the company's perspective, so the project's success influences the likelihood of other, similar projects elsewhere. In essence, the business-centric view of DG development is not based in any allegiance to capitalism but, instead, in the interest of sustainability.

This paper's case studies represent a range of financial sustainability. On one end is the solar NGO in Luhunga, which depends at least 90% on a continuous source of outside funding. On the other is MGP, which was established with start-up funds from donors and later became locally self-sustaining. In the middle are GP's Khotang projects in Nepal and Off Grid's One Million Solar Homes project in

Tanzania, both of which are still in initial development phases and not independent of donor funds. While the donor-dependence example in Luhunga demonstrates the causes of failure in a system with minimal local buy-in/ownership, the relative "success" of the other, business-based case studies is difficult to determine. Each is continuously encountering challenges that make "success" a subjective term and each differs from Luhunga.

Primary among these differences is the history of stability of previous projects. GP has been designing solar projects for years and quickly became one of Nepal's most successful and reputable solar companies. Its push into the realm of micro-grids demonstrates diversity: if successful, the Khotang project will expand the company's energy initiatives; if not, the company's other projects may make up for its losses. Off Grid also has a history of growth, having used its leasing model for several years, and has attracted the attention of national governments. MGP, even facing scalability challenges, has nonetheless established an economic presence as the single largest employer in its operating area within Uttar Pradesh. Though limited in scope, these case studies indicate the intrinsic resiliency in a business approach, however eventual, to DG as opposed to a donor-dependent approach.

Second is the relative level of research done in advance of these projects. Though the solar NGO in Luhunga has had numerous successful projects (including one at a nearby primary school), its research was minimal and primarily technical rather than social. MGP has iterated its design over the years in several countries; GP spent over a year researching and interacting with the Khotang communities before designs were completed, and Off Grid understood and made use of analogous industries – communication technology and leasing models – and local markets rather than relying on some "universal" model.

Case study funding situations are summarized in Table 5.1 below. While each of the five employs a slightly different method, the trend shows that the four cases that pursue a self-sustaining financial model were the most successful (viable, sustainable) at the time of this writing. The one donor-funded case is the least successful, having failed to establish local ownership or long-term financial sustainability.

Table 5.1: Case study financial models, summary

	Khotang	**Luhunga Solar**	**Kathmandu BMG**	**TZ: OMSH**	**Uttar Pradesh**
Status	Pending	Failed	Successful	Pending	Successful
Ongoing Funding	Income-Based	Donor	Income-Based	Income-Based	Income-Based
Start-Up Funding	Donor (ADB, DOEN); Client; Developer	Donor	Developer	Donor	Donor
Client Role	Business Partner; Owner	Recipient; Minimal Payback	Customer; Rate Payer	Lessee	Customer; Rate Payer
Developer Role	Business Partner; Installer	Donor; Installer	Vendor; Installer; Rate Collector	Lessor	Vendor; Installer; Rate Collector

This is not to say that all business approaches will succeed or that all donor-funded projects will fail – there are appropriate applications of each, and this paper's sample size is far too small to draw general conclusions. There are plenty of exceptions on both sides, though to what extent "success" is measured may vary widely. Instead, this paper posits that a basic business ethic has intrinsic value (as a development approach, not as any specific financial structure), as opposed to a purely aid approach, in the long-term success of a development project. An aid ethic places the perceived need of a community first, but then becomes party to a race for donor funds that must be balanced with a drive toward long-term sustainability. A business ethic, on the other hand, demands attention to details that may pay off later in the project's lifetime. That attention raises issues that short-term courtship of donor funds do not.

The other side of the "enterprise" coin is the client community itself. One common and recommended way of ensuring profit from a community project (and income for that community regardless of ownership) is to focus system design on locally initiated income-generating activities. If customers can make money with their newfound electricity, they are more likely to be willing and able to pay. This serves both the developer and the community, which will eventually acquire ownership and will need the capital to expand and maintain.

MGP and Off Grid serve such a wide base that it would be difficult for either to target specific income generating activities to utilize, though both companies cite longer business hours (MGP 2016) and new business opportunities that benefit their customers generally. More direct examples come from Khotang, where GP designed its micro-grids to accommodate specific business ventures in each village. In Harkapur, the community identified several hotels that would offer electricity to their guests and therefore see a higher influx of customers and capital. Kaduwa's perch on the mountains between two commercial hubs – Halesi and the river town – along with its robust dairy production makes it a good candidate for a dairy chiller. Local producers could then sell their milk, gee, and yoghurt to a larger market and possibly eliminate waste. Chyasmitar is the most remote of the three but is home to a secondary school and a nearby stationery shop. The shop's ability to expand with solar power rather than diesel could allow it to serve the school, government offices, and other villages that need printing, copying, internet, and so on.

The company's response to locally identified income generating opportunities served a dual purpose: it reinforced the community's ability to pay and ensured the presence of local advocates invested in the project's success. Even the Luhunga NGO prescribed income-generating activities that, though not fully realized, were intended to create financial sustainability along the same lines. These examples suggest that locally identified opportunities created by development projects should inform the project design.

The moral of the story is that donor funding is often necessary for new methods of DG to be explored, or even for established models to be kick-started elsewhere. But it should not serve as a permanent income source for the developer. If it does, the model in question is not sustainable and will likely fail when the funding ceases. Developers should instead use donor funding as seed money, and rely on an informed, thoughtful, locally appropriate business model to continue forward.

5.2: Local Stakeholders

Chapters 3 and 4 outlined the case of local buy-in and ownership, as well as the reasons that such claims should be met with skepticism. Early community/customer input informs crucial design decisions; true partnership builds mutual trust and respect and requires communication from the beginning; and joint ownership ensures that each party's best interests are tied to those of the project. But more than that, local stakeholders play a key role by demanding accountability and providing much needed feedback to the developer or joint owner. Developers must take the position that feedback is never “wrong” – honestly held opinions reveal real or perceived failures and successes of the system, and should inform decisions to fix a problem, promote realistic expectations, or adapt projects accordingly.

Luhunga demonstrates a failure to empower local stakeholders. Unaware of the real danger of battery depletion, and in only occasional contact with the NGO’s office in the distant city of Dar es Salaam, the school never communicated the problem to the NGO and never received support. Instead the school administration figured that, if the system fell apart, at least it was free. A better arrangement would have seen the school have a say in the project and give the NGO feedback as it iterated its system design. “What would encourage diligent monitoring of the battery’s MDoD?” might have been a standard question, for example, given that it addresses the major weakness of the design. A bottom-up approach in this case might also have yielded support for more appropriate income generating activities.

The GP and MGP cases contain some positive examples. In Khotang, the ADB-caused installation delay created frustration among local stakeholders and customers. Once they communicated their frustration up the chain, GP decided to install temporary systems to regain the communities’ trust and reaffirm its commitment to complete the project. Without community buy-in, the frustration would not have evolved into direct feedback to the company given that a delay in unrequested (lacking any buy-in) electricity would hardly be considered a “loss.”

Similarly, in Uttar Pradesh, local staff and customers noted the difference in quality between MGP's micro-grids and the nearby donor-funded micro-grid, and complained to MGP. Though there is no easy solution, the company understood the source and extent of local frustration. In addition, the local stakeholders and MGP itself share interest in the expansion of services, and can communicate directly to determine the best way forward.

Community buy-in is more than just a nod of approval for receiving power, or the occasional payment: it serves as the communication link, a basis for mutual trust and understanding between developer and client. Without buy-in, clients may answer a developer's questions with the answers they know she wants to hear ("Will you keep track of the battery MDoD?" "Of course."). But buy-in makes mutual understanding necessary for both parties, and therefore gets the project started with both on equal footing.

As discussed in Chapter 3.2.3, recipient stakeholders in a DG project may feel any level of "equality" or lack thereof with the developer in terms of decision-making power and deference (Bickel, 2009). A true partnership includes many levels of equality, from decision-making to actual ownership, and can take the form of something as common as a vendor-customer relationship or as complex as a SPV. Regardless of the arrangement, however, a developer must understand that lack of partnership, even under the best of intentions, disempowers the local stakeholder and can adversely affect project viability. An act of charity, though perhaps admirable and even necessary in some situations, deprives recipients of ownership in all but the literal sense. Even if a developer cannot expect monetary input from a stakeholder, one can establish ownership in other ways, whether via in-kind contributions (labor, land, construction materials, hosting crews, etc.), a place as a representative in the SPV, or simply as a customer with the freedom to tailor a purchase (GP 2015). Despite the complexity and infinite variability, the empowerment of local stakeholders can be a developer's greatest asset. Disempowerment, on the other hand, can be disastrous. As Rich (1994) states, "Surely, if decades of failed international development efforts have taught us anything, it is the folly of induced, uniform, top-down projects. Such schemes ignore and often destroy the local knowledge and social organization on which sound stewardship of… equitable economic development depend[s]" (quoted in Adams 2001, 334)

5.3: Operating Between Worlds

The above challenges and their many offshoots are so pervasive that it can be easy to overlook the subtler, less quantifiable challenges that can plague a project throughout its development. When operating as a developing entity, one necessarily works between worlds. On one side is the receiving entity – a customer or community – and on the other side is the support entity – a donor or financier. When planning or even imagining the play-by-play of a DG project, it is easy to see all the pieces coming together: if the developer performs each task in a timely fashion and leaves some schedule and budget room for flexibility, the project may proceed smoothly. But, as seen in GP's micro-grid project, every player has her own constraints and places pressure on every other player, whether in the form of delayed financing or materials, fluctuating prices, changes to the labor force, or any other unpredictable setback.

GP received donor funding, the bulk of it from the ADB, for its pilot project in Khotang. The ADB has a continuing interest in exploring DG options and frequently funds "small" pilot projects. To the ADB, a USD 100,000 grant is fairly small, likely making it easier to approve than larger projects, but also less of a priority for its staff. To GP, however, the grant is the largest they've received, and its proper stewardship could determine the future of DG for Nepal and for a large piece of the company's business ventures. If the project hit a roadblock the funding might disappear along with the largest DG pilot initiative in the region.

The delay in funding (or, more accurately, the delay in opening the bidding to source grid components) stirred frustration in the villages that had already waited a year for the project to commence. Essentially, the ADB almost scuttled its own pilot project but the villages, particularly the SPV partners, saw the delay as GP's responsibility.

Frustrations in development projects frequently occur at the community level. As mentioned earlier in this paper, practitioners, governments, and others often adopt the classic stereotypes of rural communities (see Introduction). Faced with the failure of a simple project that, to the developer, should have been an obvious success, it is easy to blame community incompetence, corruption, or other failures to meet western "boot strap" ideals essential to readily adopting innovative methods of self-reliance. In my personal experience with long-time foreign service and NGO workers, the behind-the-scenes criticism can become a contagious way to share frustration at the expense of local communities. “The fallacy” is the popular mindset that “because I have studied and lived in a society that somehow wound up with prosperity and peace, I know enough to plan for other societies to have prosperity and peace” (Easterly 2006, 26). But when the effort fails, the fault must lie with the developed, not the developer.

Working with small communities, especially in another culture, can be frustrating. Contrasting perspectives regarding timeliness and punctuality; communication barriers, both verbal and non-verbal; and differing perceptions of when “business-like” assertiveness becomes pushiness are common challenges (GP 2015). In order to avoid frustration, it is the developer’s responsibility to avoid becoming frustrated with local cultural norms and appreciate that there are profound cultural *differences* between developer and client (Adams 2001; Easterly 2006). Learning to work with a community on its own schedule and by its own customs can mean the difference between a project’s grudging completion and actual success.

In Luhunga the solar NGO might have noticed problems raised by the school administration’s non-verbal communication, indicating that the school really did not have a mechanism to recoup the 10% cost, and had only the barest intention to monitor the batteries’ MDoD. The signs would be obvious or at least perceptible to anyone local, none of whom had the NGO’s interests in mind upon receipt of the system. Cultural understanding also would have benefited the NGO’s attempts to engage the school about its repayment plan. It is considered bad form, for instance, to communicate with a western volunteer teacher rather than the headmaster or appointed contact teacher. The NGO did this in order to make sure that everyone involved could be clearly understood, a need created by the lack of native Swahili speakers on the administrative staff. The NGO's staff composition has changed since 2008 but, at the time, the lack of local stakeholder involvement led to many of the misunderstandings with the secondary school (acknowledging, again, that the NGO has many other, successful projects and continues to flourish in Tanzania)

Off Grid: Electric has partially avoided the situation by serving a non-specific and changing customer base. As purely a business (via a leasing model rather than as a "developer," per se) it does not deal directly with individual customers in their communities, nor does it have to engage in design nor accommodate a range of willingness to pay. It does, however, have to answer to its donors and comply with their standards. In addition, Off Grid hires local contractors for installation and maintenance, which adds another step in the process. This also adds another layer of communication that the company has to maintain – processing lease requests from customers and contracting installation with local companies, thereby multiplying the potential for miscommunication in the event that one partner entity falls behind, goes out of business, or otherwise can't satisfy its contract.

The arrangement may have its advantages, however: with the added contractor level between developer (Off Grid) and customer (individual households), the company can essentially outsource its local communication needs to companies that know the communities and understand the business side of the project. This is an over-simplification; Off Grid still needs to monitor the effectiveness and reliability of its contractors and gauge their performance through customer feedback. But given the national scale of Off Grid's operation, it would be more difficult for the company to become conversant in the languages and norms of all 120-plus tribes in Tanzania (the Wapare, if the stereotypes are to be believed, have a stronger history with business development than the Wahehe) than to rely on local outfits.

Regardless of the development project model, certain best practices have long been discussed and accepted for operating between donor entity and recipient community (Adams 2001; McMichael 2000; Chambers 1997). Many of these extend naturally from the bottom-up, community-centric approach to development discussed in this paper. They include the empowerment of local actors to pursue local passions, fluency in the local language, a "listen first" ethic, and many more discussed in Chapter 3 and illustrated in Chapter 4. However, these practices are only possible if the developer (1) maintains open and frequent communication with all partners, and (2) acknowledges from the beginning its own biases, assumptions, and privilege relative to its partners.

5.5: Information Gathering

Many of the case studies and related discussions reference "research" as the means of gathering necessary information about a community's willingness to pay, income generating potential, electricity needs, and other factors that affect a developer's design decisions. The method by which information is gathered, however, is far from established in practice (for this, as for other practices discussed in this paper, the academic world has what it considers established guidelines; to what extent those are translated into practice is less clear). Some, like the solar NGO in Luhunga, don't engage in much beyond a physical evaluation of the site and a cursory information session with the client (in which information generally goes from developer to client instead of the other way around). Others, like GP, perform multiple surveys, community meetings, individual interviews, and site visits to get as wide and redundant an information base as possible before gauging viability or finalizing designs. But many of the results proved irrelevant, and GP is still experimenting with information gathering techniques in the absence of a formalized method set by the DG development community (a need expressed directly by GP during the research period).

In the area of information gathering (and other practices), the DG development world is behind other sectors of development such as biodiversity conservation (Adams 2001, 341), agroforestry, and others. While other sectors have existed for, in most cases, over a century, electricity development is young and struggling to overcome both its own inexperience and the relatively poor energy literacy among its clients and partners. Few of the actors in the case studies presented in this paper, for example, followed the methods of information gathering that have become common practice in other areas of development. Some, like GP, experimented with outdated theories of surveys while others, like the solar NGO in Luhunga, didn't even go that far.

Take, for example, Khotang. GP performed several iterations of surveys, some designed by foreign consultants, with varying results. One round of surveys, written by a consultant entirely in English, was received by participants as too long, impersonal, and complex, and was considered unreliable for the response it evoked.

A subsequent, streamlined survey included a Nepali translation so that it could be conducted locally, and simplified many questions to multiple choice or rankings to avoid ambiguity. But when the communities conducted the surveys, they found that many questions had been poorly translated and others, which had been written as opinion questions, were simply left unanswered. In Kaduwa, the village official conducting the surveys with the author often filled in his own answers while the "participants" sat quietly, a common challenge when working through translators. These results, too, were largely discarded.

The second round of surveys illustrated a fundamental flaw in the simplistic question-and-answer method of information gathering. By its logic any developer, local or foreign, simply needs to formulate appropriate questions in an accessible format and either interview participants individually or give them the form to return later. The assumed advantages are that, if done individually, some group dynamics are avoided that might otherwise bias the results. In Khotang, for example, the author was concerned that wealthier men would be the most likely to receive the survey, thereby ignoring women's and poorer residents' opinions of GP's service and energy needs in general. The surveys would also be an opportunity to voice concerns that did not come up in the crowded format of GP's earlier community meetings. In fact, while the intent of the questions was valid, the atmosphere and manner in which the surveys were conducted made them less attractive than open, participatory methods.

Surveys are a popular form of information gathering, but they may not be appropriate even when simple questions and answers seem like a harmless approach (discussed later in this section). Other developers in a wide range of sectors use anonymous voting, hand raising, town hall meetings, group visualizations, community mapping exercises, and even spectrum exercises to gauge the full range of community buy-in and need. Any DG developer can prepare for their own research efforts by evaluating their effectiveness. But the manner in which the developer conducts these methods, and the relative roles of the facilitator and participants, can make as much of a difference as the method itself (Chambers 1997).

In his frequently cited book *Whose Reality Counts? Putting the First Last* (1997), Robert Chambers outlines methods and recommendations for participatory information gathering, or what is termed Participatory Rural Assessment (PRA). Though the actual methods could take any form, some lessons should be taken into account during any PRA – some of these are paraphrased and contextualized in Table 5.2 below.

Table 5.2: Considerations in PRA (adapted from Chambers, 1997)

Outsider-Driven vs. Locally-Driven	Literature, experience, and common sense all reveal locals' advantages with regards to gauging local capacity, interest, etc. Local participants are generally more adept at identifying previously unknown factors, revealing high levels of detail, and inventing creative methods of community mapping and information gathering than their outsider counterparts. Openness and flexibility on the part of the developer can lead not only to more freedom of conversation, but also to more innovative and locally appropriate means of catalyzing that conversation. GP used town hall-style meetings to present ideas and get community feedback. Though some diversity of opinion may have suffered for it, the collective brainstorming and community capacity identification was far more informed than individual surveys could have been.
Measuring vs. Comparing	Questions of exact measurement can illicit subjective responses and may, at times, be awkward. Comparisons allow for greater nuance to be communicated and can be expressed more quickly and visually. In general, participants in an electrification project are unfamiliar with industry quantities and units, making it difficult to gather information on consumption, durations, etc. If participants can instead communicate their needs, situation, or concerns via spatial or temporal comparisons, the developer can get a feel for not only need, but also motives and social politics.

Verbal vs. Visual	Whereas surveys and interviews require verbal or written communication, visual activities can be more inclusive by reducing the dominance of one participant, and by being more accessible to illiterate or introverted participants. In addition, visualization does not need to be initiated by the facilitator but can be created entirely in the moment, resulting in more authentic and unbiased information.
Formal vs. Informal Materials	In some instances the use of formal materials may appear "elitist" and end up disempowering certain participants. The use of pen and paper, for example, may be the most obvious choice to developers and even local facilitators, but may also be out of place in rural settings. Facilitators can make use of local materials that equalize all members of the community, reduce the feeling of formality to encourage openness and familiarity, and make the activity easily replicable. In Khotang, the author used paper surveys that, to the local facilitators, were entirely acceptable. But the surveys were clearly out of place while sitting on the floors or low stools of individuals' homes, where chalk or charcoal are used to draw, and the floor or dusty ground functions as the pallet. The distinction may seem minor to the "outsider" developer, but these materials reinforce the top-down nature with which rural development has long been associated.
Formal vs. Informal Atmosphere	For many of the same reasons, the rapport and atmosphere established by the facilitator can bias the results if done poorly. Formality, as discussed, creates tension by pitting the outsider as detective and the participant as a holder of information to be extracted. By relaxing, resisting the urge to rush or otherwise stick to some arbitrary rule, and listening rather than interviewing, a facilitator can learn more than what she originally set out to learn. With the right rapport (established over a little time and understanding of local respect and norms), participants should feel that they are free to delve into whatever they have on their minds and speak freely as their opinions are of honest interest, not just importance to a list of data. In this sense, too, the author failed to conduct the Khotang surveys effectively. Left unattended until the last day in the villages, the surveys had to be conducted quickly and with the help of a translator, the village chairman. Due to the time crunch and the facilitator's aforementioned misuse of the survey questions, the atmosphere was informal but mildly tense. The author's presence as "seeker of information" did little to relax the mood and established the role of expert rather than pupil, detective rather than interested friend.
Individual vs. Group	While individual surveys or interviews may make it easier to address marginalized members of a community, a group activity allows for greater overlap of knowledge. As with peer review, these activities give participants the chance to check, edit, or corroborate their peers' contributions to the conversation. Somewhat counter-intuitively, group activities often lead to more accurate quantitative results and greater ease with sensitive subjects. A question or comment that one participant might keep to herself may be voiced by another, beginning a conversation that might not otherwise have occurred.

In a theme that runs parallel to this paper's thesis, Chambers notes that it is easy to gather information incorrectly, or to adopt too quickly a method that was reported to work elsewhere. Practitioners do well to consider not just the information gathering method itself, but the reason that it did or did not work elsewhere, and whether similar conditions apply. Which parts of society did or did not have a voice in the process? How do participants' perceptions compare from one community to another? Information gathering should focus on the *respondents* more than just the *responses* (Cambers 1997). A developer may prefer to know exactly which topics will be discussed and which data will be collected, but one can learn far more by creating a culturally relevant environment in which participants feel free to express and create, and then listening (Sirolli 2012). There will always be concerns and unpredictable factors – who is empowered or disempowered by the process, how participants feel about the use of information they offer, whether information is being misrepresented for any reason, and so on (Chambers 1997). But the openness encouraged by the PRA method (or equivalent) can be more accurate and accessible in aggregate than the potentially biased or misrepresented information produced through individual methods such as one-on-one interviews or surveys. As Inglis says: "if information is wrong to begin with, no amount of statistical manipulation will enable it to help the project staff make good decisions" (quoted in Chambers 1997, 142).

A final consideration relevant to all information-gathering sessions is that of honesty. Experience has shown that communities or individuals that have been on the receiving end of development projects are more likely to agree with developers or give answers that they think the developers want to hear. Luhunga is a prime example: the school was (and still is) the recipient of many projects carried out by a nearby NGO run by long-time ex-pats, and is in a district, region, and country full to bursting with international aid money and organizations. When a developer asks the headmaster if the faculty will take care of a free electricity system, the correct answer is "yes," when "no" might mean losing out to another school. An efficient cook stove project in another village offered villagers the stoves for free and asked if indoor air quality was improving. The correct answer, again, was "yes" even if the new stoves served as shelves or rat-proof bean receptacles. The moral of the story is not to distrust people, but to be aware of the community's or individual's incentive for answering one way or another and to have basic cultural understanding and communication abilities. The developer and community may have very different ideas of the meaning of "yes" and "no."

Conclusion: Pushing All Fronts

To reiterate the main thesis of this paper, bottom-up rural electricity development encourages viable and sustainable projects that build on local capacity and meet local needs. The variability in electricity consumption across both distance and time is such that top-down planning efforts by outside entities tend to fail. Even two neighboring villages may be best served by different DG methods (or even the grid, as in one Terai case), finance structures, and technology choices. Despite the challenge this presents to developers, investors, and policy makers, pursuing diverse energy development approaches can have advantages. A diversity of approaches can encourage rapid iteration, enhance flexibility, and result in improved performance. Given the urgency of climate change and slow pace of adaptation in established grids, a flexible and locally grounded DG industry can adapt quickly to changing climates, both literal and figurative. One important lesson suggested by these studies is not to rely on any one mechanism for DG but, instead, to push all fronts.

The proverbial "tech fix," which many hope will solve the climate crisis, is inappropriate in rural electrification efforts. The technology to generate electricity with zero or low carbon emissions already exists; the tech fix has already happened. The demand for RETs is growing; but local entrepreneurs need markets, markets need investors, and investors need culturally appropriate and flexible policies to reduce risk. In rural electricity development, everyone has a part to play.

Appendices

Appendix A: DSM Technology Summaries

Common current limiter technology

Attributes	Fuse	Thermal miniature circuit breaker	Magnetic miniature circuit breaker	Thermistor	Electronic circuit breaker
Reset Mechanism	Replace	Manual	Manual	Auto	Auto
Accuracy	Poor	Poor	Medium	Very Poor	Medium-Good
Min. current (A)	0.04 A	0.05 A	0.05 A	0.01 A	0.05 A
Max. current (A)	>50 A	>50 A	>50 A	0.7 A**	5 A
Availability	Good	Good for > 6 A*	Limited	Limited	Very Limited
Price	Low	Low-Medium	Medium	Low	Medium-High

*Thermal MCBs rated to limit currents greater than 6 A are widely available; the availability of smaller MCBs is more limited.

**Thermistors with higher current ratings are available on the market, but have not been documented in use on mini-grids.

Table 1: Characteristics of a variety of current limiters (From Harper 2013; reproduced from ESMAP 2000)

DSM technology examples and brief descriptions

Company and Product	Payment System	DSM Capability	Countries of Activity
Circutor ***Electricity Dispenser***	Monthly subscription to "Energy Daily Allowance"; a local vendor programs the EDA and power limit onto a card that is used to activate the meter	-Power limit -Energy usage limited to pre-set rate -Enables loadshedding -Can use "pricing" signals to encourage DSM	Cape Verde, Morocco, Ecuador, and soon in Chad
INENSUS ***Micro Utility Solution***	Monthly purchase of weekly "electricity blocks"; an INENSUS sales agent adds credits to a card that is used to activate the meter. The number of electricity blocks purchased by each household is negotiated every six months.	-Power limit -Energy usage limited to pre-set quantity -Enables loadshedding -Strong emphasis on education and community involvement	Senegal
CAT Projects ***Bushlight India***	Monthly subscription to a fixed daily energy budget (between 0-10 kWh/day) that is programmed on to the household meter.	-Power limit -Energy usage limited to pre-set quantity -Enables loadshedding -Strong emphasis on education and community involvement	India (based on program from Australia)
Modi Research Group Columbia University ***Shared Solar***	Customers purchase scratch cards from a local vendor for electricity credits and then send an SMS message to the central computer to add credit to account. System uses centrally-located meters.	-Power limit -Maximum daily energy limit -Pre-paid metering -Plan to incorporate additional DSM measures	Mali and Uganda
Powerhive	Customers purchase electricity credit through mobile money systems. System uses centrally-located meters.	-Power limit -Maximum daily energy limit -Pre-paid metering -Plan to incorporate additional DSM measures	Kenya
Gram Power ***Smart Microgrid***	Customers purchase electricity credit from local vendor who programs individual meters.	-Power limit -Pre-paid metering -Plan to incorporate additional DSM measures	India
Lumeter	Customers purchase electricity credits from local vendors who provide a code that can be programmed into the meter. Back-end accounting enables project developers to be reimbursed based on electricity purchases.	-Power limit -Pre-paid metering -Enables loadshedding	Soon to be installed in Peru

Table 2: Examples of DSM devices by company (Reproduced from Harper 2013)

Bibliography

Adams, W. M. 2001. *Green Development: Environment and Sustainability in the Third World.* 2nd ed. Routledge.

American Electric Power (AEP). Inverted block rates. [Cited November 4 2014]. Available from http://www.aep.com/about/IssuesAndPositions/Financial/Regulatory/AlternativeRegulation/InvertedBlockRates.aspx.

Barnes, Douglas F., and Willem M. Floor. 1996. Rural energy in developing countries: A challenge for economic development. *Annual Review of Energy and the Environment* (21): 497-530.

Bickel, Sarah. 2009. Hope for partnerships? Local leadership in an international partnership in rural Tanzania. MA. School for International Training.

Chambers, Robert. 1997. *Whose reality counts? Putting the first last*. London, UK: Intermediate Technology Publications.

Chandrasekaran, Rajiv. 2009. U.S. Pursues a New Way to Rebuild in Afghanistan. *Washington Post*. (June 19, 2009)

Chaurey, Ranganathan, Mohanty. 2004. Electricity access for geographically disadvantaged rural communities. *Energy Policy* (32): 1693-705.

D.light Solar. 2014 [cited June 2015]. Available from http://www.dlightdesign.com/.

Deshmukh, Ranjit, Juan Pablo Carvallo, and Ashwin Gambhir. 2013. *Sustainable development of renewable energy mini-grids for energy access: A framework for policy design.* Berkeley, CA: Lawrence Berkeley National Laboratory.

Easterly, William. 2006. *The White Man's Burden: Why the West's efforts to aid the Rest have done so much ill and so little good.* The Penguin Press.

Electropaedia. Battery and energy technologies. [Cited March 2016]. Available from http://www.mpoweruk.com/performance.htm.

Energy Information Administration (EIA). State electricity profiles. 2016 [cited March 2016]. Available from http://www.eia.gov/electricity/state/.

———. Tanzania: Country profile. 2015]. Available from https://www.eia.gov/beta/international/country.cfm?iso=TZA.

———. 2015. *Annual energy outlook 2015.* Washington, D.C.: EIA.

Energy Sector Management Assistance Program (ESMAP). 2000. *Mini-grid design manual.* Washington, D.C.: World Bank.

ENF Solar. Directory. In ENF Solar [database online]. [Cited March 2016]. Available from http://www.enfsolar.com/pv/inverter?page=1.

Feed the Future. [Cited March 2016]. Available from http://www.feedthefuture.gov/country/tanzania.

Gham Power (GP). 2014, 2015. Personal interviews.

Gifford, Jonathan. 2015. IHS: Inverter price declines to lead BoS cost reductions. *PV Magazine.* March 5, 2015.

GNB Industrial Power. Stationary lead acid batteries. [Cited December 2014]. Available from http://www.exide.com/us/en/product-solutions/network-power.aspx.

Goulden, Murray, Ben Bedwell, Stefan Rennick-Egglestone, Tom Rodden, and Alexa Spence. 2014. Smart grids, smart users? The role of the user in demand side management. *Energy Research and Social Science* (2): 21-9.

Harper, Meg. 2013. *Review of strategies and technologies for DSM on isolated mini-grids.* Berkeley, CA: Lawrence Berkeley National Laboratory Clean Energy Solutions Center.

International Energy Agency (IEA). 2011. *World energy outlook. Energy for all: Financing access for the poor.* Oslo, Norway: IEA.

Integrated Energy Supply Systems (INENSUS). Off-grid energy systems. 2014 [cited November 2014]. Available from http://www.inensus.de/en/off-grid2.htm.

IPCC. 2014. *Climate change 2014: Synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change.* Geneva, Switzerland: IPCC.

Jayan, T. V. 2014. Let there be light. *The Telegraph*, September 29, 2014, 2014, sec Front Page.

Kazempour, Moghaddam, and Yousefi Haghifam. 2009. Electric energy storage systems in a market-based economy: Comparison of emerging and traditional technologies. *Renewable Energy* (34): 2630-9.

Kichonge, Baraka, Iddi S. N. Mkilaha, and Geoffrey R. John. 2014. Prediction of the Contribution of Renewable Energy Sources into Electricity Generation in Tanzania. *International Journal of Renewable Energy Technology Research* 3, no. 4:1-13. http://www.ijretr.org/IJRETR_Vol.%203.%20No.%204,%20April%202014/Prediction.pdf

Kopinak, Janice K. 2013. Humanitarian aid: Are effectiveness and sustainability impossible dreams? *Journal of Humanitarian Assistance* (March 10, 2013).

Malik, Saania. Introducing SolarCity, a powerhouse in solar technology. *Market Realist*, http://marketrealist.com/2015/08/solarcity-industry-leader-solar-technology/.

Martin, Christopher. 2014. SolarCity to finance rooftop panels in shift from leasing. *Bloomberg Business* (October 7), http://www.bloomberg.com/news/articles/2014-10-08/solarcity-to-finance-rooftop-panels-in-shift-from-leasing.

McMichael, Philip. 2000. *Development and Social Change: A Global Perspective.* 2nd ed. Pine Forge Press.

Mera Gao Power (MGP). 20152015, 2016]. Available from http://meragaopower.com.

Missouri Economic Research and Information Center (MERIC). 2015. *Cost of living data series 2015 annual average.* Missouri, USA: MERIC.

Moss, Todd, Gunilla Pettersson, and Nicholas van de Walle. 2006. *An aid institutions paradox? A review essay on aid dependency and state-building in sub-Saharan Africa.* Center for Global Development, Working Paper Number 74.

Northwestern Energy (NWE). Efficiency plus. [Cited December 2014]. Available from http://www.northwesternenergy.com/residential-services/efficiency-plus/montana.

Nussbaum, Eckhouse. 2015. Solar, wind shares jump as U.S. nears deal on tax credits. *Bloomberg Business* (December 15), http://www.bloomberg.com/news/articles/2015-12-15/solar-wind-shares-jump-as-u-s-nears-deal-to-extend-tax-credits.

Osborne, Samuel. 2015. US town rejects solar panels amid fears they 'suck energy from the sun', cause cancer - and will harm house prices. *Independent, UK*, December 13, 2015, 2015, sec World, Americas.

Pacific Gas and Electric (PG&E) 1. Tiered base plan. [Cited December 2014]. Available from http://www.pge.com/en/myhome/saveenergymoney/plans/tiers/index.page.

Pacific Gas and Electric (PG&E) 2. Time-of-use rates. [Cited December 2014]. Available from http://www.pge.com/en/mybusiness/rates/tvp/toupricing.page?WT.mc_id=Vanity_tou.

Porter, Michael E., and Mark R. Kramer. 2002. The competitive advantage of corporate philanthropy. *Harvard Business Review* (December 2002).

Powers, Gareth, Harriet Bulkeley, Sandra Bell, and Ellis Judson. 2014. Peak electricity demand and the flexibility of everyday life. *Geoforum* (55): 43-52.

Prasain, Sangam. 2016. Micro solar grids brighten off-grid rural communities. *Kathmandu Post*, March 16, 2016, 2016, sec Finance and Economy.

Programme Evaluation Organisation Planning Commission. 2014. *Evaluation report on rajiv gandhi grameen vidyutikaran yojana (RGGVY).* New Delhi: Government of India.

Rural Energy Development Programme of Nepal (REDP). [Cited November 2014]. Available from http://www.pciaonline.org/node/214.

Sanchez, Teodoro. 2010. *The hidden energy crisis: How policies are failing the world's poor*. UK: Practical Action.

Sarangi, Gopal K., D. Pugazenthi, Arabinda Mishra, Debajit Palit, V. V. N. Kishore, and Subhes C. Bhattacharyya. 2014. Poverty amidst plenty: Renewable energy-based mini-grid electrification in Nepal. In *Mini-grids for rural electrification of developing countries, green energy and technology series.* Eds. S. C. Bhattacharyya, D. Palit, 343-371. Switzerland: Springer International Publishing.

Sirolli, Ernesto. 2012. *Want to help someone? Shut up and listen!* TEDxEQChCh. http://www.ted.com/talks/ernesto_sirolli_want_to_help_someone_shut_up_and_listen#t-1007790

SunLender. Third-party residential solar financing. In SunLender [database online]. [Cited March 2016]. Available from http://sunlender.com/sunlender/third-party-residential-solar-financing/.

Smith, Michael G., and Johannes Urpelainen. 2014. Early adopters of solar panels in developing countries: Evidence from Tanzania. *Review of Policy Research (RPR)* 31 (1): 17-37.

Umberger, Allyson. 2012. Distributed generation: How localized energy production reduces vulnerability to outages and environmental damage in the wake of climate change. *Golden Gate University Environmental Law Journal* 6 (1): 183.

United Nations Development Programme (UNDP). 2011. *Towards an 'energy plus' approach for the poor: A review of good practices and lessons learned from Asia and the pacific.* UNDP.

United Nations Development Programme (UNDP), World Health Organization (WHO. 2009. *The energy access situation in developing countries: A review focusing on the least developed countries and sub-Saharan Africa.* UNDP.

UNSTATS. 2010. *The world's women 2010: Trends and statistics.* New York, USA: United Nations.

United Nations Framework Convention on Climate Change (UNFCCC). 2015. Historic Paris Agreement on Climate Change: *195 Nations Set Path to Keep Temperature Rise Well Below 2 Degrees Celsius*. Paris. (December 12, 2015). http://newsroom.unfccc.int/unfccc-newsroom/finale-cop21/

Uttar Pradesh Information Department (UPID). 2011. Statistics of Uttar Pradesh. Statistical Department U.P. & Directorate Census, Lucknow, India. http://up.gov.in/upstateglance.aspx

USAID. 2015. Reaching for the roofs: One million solar powered homes in Tanzania by 2017. (August 2014) (August 7, 2015), https://www.usaid.gov/powerafrica/newsletter/aug2015/solar-powered-homes-tanzania.

Wilmington Trust. The uses of special purpose vehicles in asset securitization. [Cited March 2016]. Available from https://www.wilmingtontrust.com/wtcom/index.jsp?fileid=3000139.

World Bank. Country carbon footprints per capita. In World Bank [database online]. 2015 [cited March 2016]. Available from http://data.worldbank.org/indicator/EN.ATM.CO2E.PC.

World Health Organization (WHO). Household air pollution and health fact sheet. In WHO [database online]. 2016 [cited March 9 2016]. Available from http://www.who.int/mediacentre/factsheets/fs292/en/.

Zerriffi, Hisham. Rural electrification: strategies for distributed generation. Springer Science & Business Media, 2010.