

**FINANCING ENERGY ACCESS THROUGH COMMUNITY
PARTICIPATORY EQUITY: BUILDING AND MODELING A
MULTIDIMENSIONAL ENERGY ACCESS FRAMEWORK FOR RURAL
COMMUNITY-LEVEL PV MICRO-GRIDS TO INFORM MARKET ENTRY
STRATEGY**

by

Benjamin M. Attia

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master in Energy and Environmental Policy

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Benjamin M. Attia

Approved: _____
John Byrne, Ph.D.
Professor in charge of thesis on behalf of the Advisory Committee

Approved: _____
John Byrne, Ph.D.
Director of the Center for Energy and Environmental Policy

Approved: _____
George H. Watson, Ph.D.
Dean of the College of Arts and Sciences

Approved: _____
Ann L. Ardis, Ph.D.
Senior Vice Provost for Graduate and Professional Education

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ABSTRACT

This thesis seeks to further the academic definition and practitioner implementation of energy access solutions by developing and applying a theoretical multidimensional energy access framework that understands the drivers and barriers to successful rural energy implementation through the lens of four dimensions: techno-economic, socio-economic, agro-economic and institutional-economic. The rapid deployment and acceleration of rural energy access interventions is also catalytically dependent on financing, and understanding this multidimensionality may help institutional and private investors and policymakers close the \$1 trillion financing gap for rural micro-grids. Because of their open-access nature, micro-grids can be considered as common property resources capable of community management without a tragedy of the commons under a theoretically Ostromian Community Participatory Equity (CPE) framework. Cost-driven by the remoteness of the project, these community-managed systems have significant socio-economic benefits and can see significant improvements in project economics and financing through cost decreases that are instead taken on by the community rather than the third-party developer or project company, reducing the levelized cost of energy (LCOE) by over 50%. This work concludes that the CPE framework, especially when paired with grant financing for capital costs and early-stage O&M&M fees, can greatly increase the attractiveness of these projects for investors and end users and enable an informed and targeted market entry strategy for the vast untapped off-grid markets.

Chapter 1

INTRODUCTION

The International Energy Agency (IEA) recently estimated that over 1.5 billion people do not have access to affordable electricity, representing one quarter of the world's population (*World Energy Outlook 2014*, 2014). In the absence of aggressive new policies and significant financing, it is estimated that that number will drop to only 1.3 billion by 2030 (*World Energy Outlook 2014*, 2014). The United Nations' (UN) Sustainable Energy for All (SE4ALL) initiative, which is working toward a goal of global universal energy access by 2030, estimates that approximately 600 million of these unelectrified people live in Sub-Saharan Africa ("Energy for all: Financing Access for the poor," 2011). This number is expected to rise to approximately 645 million by 2030 under a business-as-usual scenario due to expected explosive population growth ("Energy for all," 2011; Franz et al., 2014). This widening gap of energy access is a complex and multidimensional problem and represents an important hindrance to economic development and social change in the developing world.

Historically, the access gap since the initial commercialization of electricity has "consistently been between 1 and 2 billion people... as grid expansion has roughly paced global population" growth (Alstone et al., 2015). This suggests that the access gap is a reflection of a persistent lack of equity in distribution. In fact, in 1983, Krugmann and Goldemberg famously estimated that at 1983 global consumption levels, the "energy cost of satisfying the basic human needs" of every person on the

planet was well within the available supply of energy resources (Krugmann & Goldemberg, 1983, p. 60).

Today, the consumption and distribution inequalities are even more pronounced. In 2011, the average American consumed 13,240 kilowatt hours (kWh) per person per year, while the average Ethiopian consumed only 56 kWh (Kenny, 2015). Further, across all of Sub-Saharan Africa, annual per capita kWh use is one-sixth the load requirements of a relatively efficient American refrigerator (*Power Africa Annual Report*, 2014). Globally, the poorest three-quarters of the world's population comprise less than ten percent of total energy consumption (Tomei & Gent, 2015, p. 5).

The inequities that underline energy poverty and energy access are also fundamentally connected to climate change. Looking ahead, the world's demand for electricity is estimated to increase by more than 70% by 2040, and the World Bank and IEA estimate that a doubling in installed energy capacity will be necessary to meet the anticipated growing demands of emerging markets (Akikur et al., 2013, p. 738; *World Energy Outlook 2015 Factsheet*, 2015). Despite the accelerating paradigm shift to low-carbon and renewable energy generation technologies, there is a paradoxical irony to the link between development and climate change which has left the poorest countries with the lowest contributions to greenhouse gas (GHG) emissions as the most vulnerable and most susceptible to the effects of climate change (Byrne, Wang, et al., 1998; Yadoo & Cruickshank, 2012, p. 591). As markets evolve to value avoided GHG emissions (Deichmann et al., 2011, p. 215), reconciling the joint--and possibly conflicting-- goals of development through universal energy access and combating climate change will accelerate, but at present, the inequity in energy access is only

further exacerbated by the parallel inequities with respect to climate change adaptation measures.

Many scholars agree that access to electricity in itself is not fully sufficient to bring about the required economic and social development to break the cycle of poverty (Bhide & Monroy, 2011, p. 1058; Mainali & Silveira, 2011, p. 2194). It has also been widely settled that access to electricity is a key catalyst correlated with economic development and that a lack of electricity access is a key bottleneck to growth (Mans, 2014; see Odarno, 2014 for a comprehensive rebuttal). However, approaches for tackling the problems associated with energy poverty are often difficult to scale up because of the difficulties associated with navigating this uneven technical, sociocultural, agricultural, and institutional landscape, and, as will be demonstrated below, the multidimensionality of energy access inhibits scalability of any one catch-all solution. The IEA estimates that 30% of those without access to electricity would best be served by grid extension, 52.5% would be best served by micro-grids, and 17.5% would best be served by stand-alone energy systems (Franz et al., 2014, p. 14). There is a clear need for investment in rural electrification initiatives at all three levels and a clear gap in understanding routes and sinks for effective impact investing (Franz et al., 2014, p. 14). National grid extension programs and firms selling small energy systems are generally much better funded than the community-scale solution of micro-grids, despite their significant potential market share and niche ability to provide scale benefits, rapid deployment, flexibility of business models, and energy storage, security, and reliability (Franz et al., 2014, p. 15). The micro-grid space is rife with opportunity to build markets, innovate new business models, develop new financing

mechanisms, and provide the sustainable development benefits of renewable electrification and increased economic potential.

In light of the enduring problem of energy poverty, this thesis builds a conceptual framework to analyze the possibility of deploying community-contributed rural energy systems. A case study is offered to illustrate the value of the framework, using solar photovoltaic (PV)-powered micro-grids and their financing as illustration of the value of the framework. In rural, agrarian communities, techno-economic, socio-economic, agro-economic, and institutional-economic factors such as recurring O&M costs, the role of women, seasonal variation in income and future yields, and lack of institutionalized support may prevent simple feasible investment in a PV-powered micro-grid. This is where community-contributed investment can take a different form and possibly lead to an affordable and financeable energy system that can be managed at a community level to provide rural electrification and contribute to a holistic sustainable development process. In addition, a modeling exercise is undertaken in order to illustrate the stages where a community's low-cost participatory equity could fill gaps where traditional financing is difficult to secure.

As one development professional put it, "If rural [people] have power in their lives, they will have more power over their lives" (Mans, 2014). Access to electricity is not the answer to the greater global problems of poverty and inequity, but can be a good place to start.

Chapter 2

ENERGY ACCESS, ELECTRIFICATION, AND DEVELOPMENT

2.1 Defining Energy Poverty and Energy Access in the Literature

Poverty occurs at the intersection of several deficiencies, and is, in most instances, a deeper problem than a simple shortage of economic assets. Recognizing that poverty extends to physical health, community connections, and institutional liberties ought to change the perspective of the Global North on the developing world (see Abraham & Kumar, 2008; Alkire, 2007; Corbett & Fikkert, 2014; Pereira et al., 2010, among others). Pereira, et al. (2010, p. 1234) put it particularly well:

“Poverty should not be seen only in terms of income, considering that poverty has many faces, i.e. it extends to other spheres. Although it is repeatedly dealt with as deriving from lack of income, poverty should in fact be perceived as a multidimensional phenomenon, including, inter alia: physical weakness (sub-nutrition, lack of strength, precarious health, incapacity, high rate of active adults who are dependent on others); isolation (isolated location, ignorance (lack of education), lack of access to information or knowledge); income (lack of income); energy (electricity etc.), (lack of energy); vulnerability (increased exposure to natural disasters), impotence (choices, adaptation).”

It is now well understood that a wealth-centric view of developmental progress is insufficient, and that poverty alleviation goes well beyond providing for material needs. But while there is already clear academic consensus around this multidimensionality of poverty, there is an apparent disproportionality in the conversation specifically around energy poverty, despite the fact that it is inextricably tied to the ability to overcome each of these other, more directly inhibiting forms of

poverty (Cecelski, 2000; Khandker et al., 2012). By powering medical technology, telecommunications networks, community centers, schools, household appliances and radios, overcoming energy poverty creates a stepladder to escaping other forms of poverty and enabling a holistic sustainable development process.

In line with similar theoretical work for the definitions of economic or social poverty, which qualify poverty in general as inferiority of quality or insufficiency of amount, Barnes, et al. (2011, p. 894) define energy poverty as “the point at which people use the bare minimum of energy (derived from all sources) needed to sustain life.” Measuring and establishing this point can delineate the consumption bands where energy increases welfare and economic well-being (above the poverty point) and where consumption is not high enough to sustain normal lives (Barnes et al., 2011, p. 894). Energy poverty measurements are often based on this energy poverty line or by conducting engineering-based estimations of direct energy requirements needed to satisfy basic needs in a specific location (Pachauri & Spreng, 2003).

Others define energy poverty in terms of one’s level of access to energy services, regardless of consumption levels (see Pachauri & Spreng, 2003; Sen, 1999), but the factors involved in defining energy access are still not uniformly defined in the literature. Modernity of generation technology, affordability of retail tariffs, affordability of capital costs for decentralized generation, grid-specific connectivity, adequacy of supply, connection quality, connection reliability, achieving minimum consumption levels, growing consumption levels over time, and other factors have

been discussed in previous studies as necessary for defining energy access (Brew-Hammond, 2010; IEA, 2011; Kanagawa & Nakata, 2008; Pachauri & Spreng, 2011; Tomei & Gent, 2015; Winkler et al., 2011). A 2015 IIED report synthesized many of these previous definitions into the following definition for energy access: “the ability to connect to and secure affordable, adequate, and reliable electricity supply for basic needs” (Tomei & Gent, 2015, p. 8-9). A more specific definition by Practical Action sets minimum energy use standards for six key categories of energy use (Hunt et al., 2010). See Table 1 below.

Table 1: Practical Action Total Energy Access Standards

Energy Service	Minimum Standard
1. Lighting	300 lumens at household level
2. Cooking and water heating	1 kg wood fuel or 0.3 kg charcoal or 0.04kg LPG or 0.02L of kerosene or ethanol per person per day, taking less than 30 minutes per household per day to obtain
3. Space Heating	Minimum daytime indoor air temperature of 12°C
4. Cooling	Food processors, retailers, and householders have facilities to extend life of perishable products by a minimum of 50% over that allowed by ambient storage All health facilities have refrigeration adequate for the blood, vaccine, and medicinal needs of local populations Maximum indoor air temperature of 30°C
5. Information and communications	People can communicate electronic

	<p>information beyond the locality in which they live</p> <p>People can access electronic media relevant to their lives and livelihoods</p>
6. Earning a Living	<p>Access to energy is sufficient for the startup of any enterprise</p> <p>The proportion of operating costs for energy consumption in energy-efficient enterprises is financially sustainable.</p>

Adapted from (Hunt, et al., 2010)

Importantly, the factors involved in energy access for rural populations with economic barriers are all beholden to the cost and type of access. Rural electrification with distributed generation sources such as pico-solar lighting or solar home systems (SHS) can often prove a significantly less capital-intensive and more economically viable solution as opposed to grid extension for certain geographies, but may not necessarily meet more rigorous or complete definitions, such as the Practical Action standards detailed in Table 1 above. The holistic nature of energy access and energy use, even at the minimum end of the spectrum, ultimately requires a greater degree of energy supply, often from a variety of fuels and sources.

2.2 The Practical Superiority of Renewable Electricity in the Energy Transition

Electricity is a commodity uniquely at the root of systemic poverty, global health and disease eradication, education, gender equality, cultural exchange, economic empowerment, climate change, and environmental sustainability. In a way that other energy inputs are not, reliable access to electricity is essential to the development of modern economies and the removal of disparities in regional

economic development between rural and urban populations. Electricity “gives students access to effective learning environments, makes possible safe storage of vaccines and medicines... drives advances in agriculture, animal husbandry, and agribusiness, [and] it leads to dramatic increases in public safety and health” (*Power Africa Annual Report*, 2014). When energy services are unreliable, firms cannot accurately forecast profits or earnings, meet production quotas, or effectively communicate with contractors and clients. Even where there is access, the variability of the electricity supply requires businesses to spend up to 60 percent of operating costs on imported fossil fuels (Mans, 2014). With few exceptions, most less-developed countries have ample resources available to harness different forms of renewable energy, but lack the governmental, institutional, and structural support needed to create efficient and lucrative energy programs. While clean cook stoves, LPG programs, and pico-solar products address essential components of total energy access, electricity for productive use is ultimately the form and use of energy that drives economic development. Despite the normative mixed-fuel approach to providing energy access, as households climb the energy ladder their consumption changes as it progresses towards reliable access to price-constant electricity, especially renewable, distributed electricity generation sources in forward-thinking nations.

While there is a strong focus on the convincing corollary between electricity and development, it is important to recognize the gradual, stepped nature of the energy transition and that electricity will not completely replace gathered woody biomass or other low-efficiency fuels in the short run. Households may determine their energy consumption patterns based on resource availability, affordability, and cultural preferences rather than simply advancing to the next most advanced fuel, such as

greater electricity consumption or LPG use (Bhide & Monroy, 2011; Kowsari & Zerriffi, 2011). One way this is often manifested is a preference for burning biomass rather than LPG because it is perceived as free and cooks locally-preferred foods in a more traditional way (Bhide & Monroy, 2011). However, as Odarno (2014) observes, increasing electricity access can deepen energy poverty by forcing rural communities to urbanize their development. Additionally, while most conceptualizations of the energy preference ladder consider electricity and LPG to be superior fuels, households may indicate their preferences with behavior that suggests there is an additional social or cultural value to less efficient or inferior energy sources, such as biomass, that would cause them to choose ostensibly suboptimal fuels. However, field research has suggested that relative prices have a lower impact than would seem economically rational on what seems to be a purely economic decision.¹ In contrast, Kirubi, et al. have noted that “for residential customers [in the rural Kenyan context], the WTP (willing to pay) for modern energy to power lighting and television is US\$0.1–0.40/kWh, respectively, which by far exceeds the average long-run electricity supply costs, typically US\$0.05–0.12/kWh” (Kirubi et al., 2009, p. 2). Additionally, the

¹ See Kowsari & Zerriffi: “The energy ladder concept relies on the microeconomic theory of rational choice. It assumes that all forms of fuel (traditional and modern) are available, that there is a universal set of fuel preferences, and that households will choose to move up the ladder as soon as they can afford to do so. The major achievement of the energy ladder is its ability to capture the strong income dependency of energy choice in households, particularly in urban areas. However, the energy ladder concept assumes a linear progression of fuel adoption that implies moving up the ladder means a corresponding abandonment of the lower level fuels. This assumption is inconsistent with the findings from field research...thus, the energy ladder concept can only provide a very limited view of reality” (Kowsari & Zerriffi, 2011, p. 7508).

desired end use of the energy is important in determining consumption patterns and fuel choice; for example, a household interested in access to telecommunications devices, such as televisions, mobile phones, and internet access will likely progress up the energy ladder to using electricity rather than viewing biomass with the same value as one who is interested in selling foods prepared in a traditional manner. In the Nei Mongol region of China, previous work has measured and reported rural user preferences of over 90% for renewables over fossil fuel-based gen-sets due to a much lower maintenance burden and lower failure rates, even at the price of sub-100% availability (Byrne, Shen, et al., 1998; Zhou et al., 2001).

This section justifies the focus of this work on creating a conceptual framework around developing populations and accelerating the deployment and use of solar PV technology using location-specific case studies to briefly illustrate costs and benefits of different rural energy systems. It is important to qualify these observations as case-study specific values that cannot be taken in direct comparison against each other, but rather can briefly illustrate a broad overview of the cost landscape of available technologies as they have been studied to date in the literature, with the purpose of contextualizing solar PV-powered micro-grids as a resilient option for many rural communities.

2.2.1 A Brief Cost Competitiveness Overview of Rural Energy Systems

Energy system cost competitiveness in rural contexts can vary widely by geography, climate, and available natural resources, among other factors. Several studies have shown that levelized electricity prices are lower for renewable energy generation sources than for diesel-based generation sources (Byrne, Shen, et al., 1998; Mahapatra & Dasappa, 2012a; Williams et al., 2015; Zhou & Byrne, 2002). This

section will briefly review key characteristics and recent cost data (adopted from Blum et al., 2013) for solar PV, as well as for diesel gen-sets micro-hydro turbines, the two off-grid generation technologies that have historically been the most popular solutions for providing for rural energy needs.

A tried and tested technology, small diesel generators in the range of 5-10kW have been reliably and consistently meeting rural energy needs for decades. Able to respond almost immediately to a change in demand, a diesel generator in this size category offers no startup time, simple energy storage, and high reliability to match demand. However, the most important economic drawback of diesel generators is the high and variable operating costs due to dependence on diesel fuel (Akikur et al., 2013; Bhattacharyya, 2006; Blum et al., 2013). Especially in oil-importing countries, this often creates a heavy subsidy burden for governments, and can create a threshold above which it is not economically advantageous to run the generator, particularly in locations far away from the fuel distribution network (Bhattacharyya, 2006). For instance Blum, et al. analyzed the cost-competitiveness of diesel-powered remote village grids in Indonesia, and observed a 62% swing in LCOE when using heavily subsidized Indonesian fuel prices and world diesel fuel prices (Blum et al., 2013). Besides the operations costs, maintenance expertise and finding available skilled labor for repairs are often significant concerns for project managers (Akikur et al., 2013). There is also the inherent factor of harmful gas emissions, on a local air quality level as well as a global climate change GHG contribution level. Because diesel-powered distribution systems can closely match demand, they deliver a convincing case for use

in rural micro-grids. However, the external fuel cost factor² causes the efficacy of diesel gen-sets to vary widely, often related to the degree of remoteness from a fuel distribution center.

Micro-hydro turbines can be highly cost-competitive compared to diesel and sometimes solar, mostly depending on the availability of sufficient hydro resources. In Indonesia, Blum, et al. found an LCOE range of 0.14-0.16€/kWh, lower than diesel and even solar PV (Blum et al., 2013). The technology has also seen rapid proliferation in regions with sufficient hydro resources, including many states in rural China. By 2008, about 27,000 stations with a cumulative capacity of about 14GW were installed rural China (*China Statistical Yearbook 2008*, 2008). Additionally, because micro-hydro plants do not have a fuel cost, and their flywheel technology is often simple to repair, the technology faces very few annual costs beyond regular maintenance and silt de-clogging in some regions.

Solar PV systems have seen massive cost reductions over the last five years, a trend that is expected to continue and has driven a proportionally massive amount of cumulative installed capacity growth both in developed countries and emerging markets. Solar PV paired with battery storage for community-level micro-grids as well as individual solar home systems (SHS) has shown itself to be a capable of meeting a

² While kerosene for lighting and biomass for cooking will not be covered in more depth here, it is important to highlight that the external fuel price factor also affects this fuel. It has been observed (in Bangladesh) that “although households may pay more for electricity than for kerosene, the unit cost of lighting provided by electricity (cost per lumen-hour) is much cheaper than that provided by kerosene” (Barnes et al., 2011, p. 895). For biomass, the additional costs of health, fire risk, and opportunity cost of time, to the tune of 1.6-2.0 billion work days a year and about 41 hours a week to collect fuel fall disproportionately on women and children and stifle economic development (Bhide & Monroy, 2011).

significant portion of energy access demand in a cost-competitive manner, particularly in the many high irradiance countries where there are significant unelectrified populations. Additionally, these systems produce zero emissions and zero noise, require minimal maintenance, and are capable of simple modular expansion as demand increases over time, which is especially valuable in islanded micro-grids. However, unlike diesel gen-sets, PV-powered systems face the well-documented renewable intermittency problem shared by other renewable technologies. In that case of solar PV, all electricity is produced when demand is the lowest, and consumed when the sun is not shining. In the case of islanded micro-grids, this necessitates that the PV system be coupled with ample battery storage to provide for evening and early morning demand, which can reduce the cost competitiveness of solar PV-powered systems (Blum et al., 2013). Another approach to this issue would be to provide a village grid with pre-agreed sub-100% availability. This reduced supply contingency significantly reduces battery storage costs and therefore reduces LCOE. For example, Blum, et al.'s case study showed a 10% contingency reduction (from 100% to 90%) reduced LCOE by about 21-25%, to \$0.40-0.45€/kWh (Blum et al., 2013). This is still a high LCOE value, but is cost competitive with diesel at world fuel prices, even in remote areas (Blum et al., 2013; Byrne et al., 2007). Additionally, a different study by Mahapatra and Dasappa (2012) indicated that rural solar PV systems can be cost competitive with distributed diesel and certainly with grid extension, particularly when villages have low load demand and can manage a system with a small battery bank (Mahapatra & Dasappa, 2012a).

It is clear that making wide generalizations about the cost-competitiveness of rural energy systems is not possible due to geography- and policy-dependent variation

in cost advantages. Proximity to fuel distribution, presence of a fuel subsidy, and availability of irradiance or water resources, among other factors, influence the cost advantages of different systems. However, even with wide variations, renewable systems are often cheaper than grid extension and off-grid systems powered by fossil fuels. By recognizing the characteristics of each and assessing local needs, cost-competitive choices can be made on a project-by-project basis.

2.3 Observed Benefits of Electrification

The link between electricity access and economic development has been debated thoroughly, and most conclude that the benefits are substantial. The key challenge is to have electrification designed by the communities to fill their needs and goals rather than so-called “reverse adaptation” (Winner, 1978). From an economic perspective, the case is argued in a growth-focused way and an overwhelmingly positive view is reached. By underpinning the creation and upgrading of value chains, facilitating the diversification of economic structures and livelihoods, and reducing vulnerability to exogenous market shocks, modern electrification can spark modern economic growth (Brüderle et al., 2011). Conceptually, electricity access provides a consumer surplus to the user by lowering the unit cost of energy from what was previously paid for traditional forms of fuel. As noted above, consumer willingness-to-pay for energy can greatly exceed the long-run unit cost of energy. As a result, the consumer surplus has two components: “one arising from the decrease in the unit cost of current energy consumption, and two, that resulting from incremental consumption due to a drop in unit cost” (Kirubi et al., 2009, p. 2; see also: van Campen et al., 2000). Simply put, the benefit of electrification can increase the marginal return to the input of time for many activities, as will be detailed in the next section. However, as Barron

& Torrero note, this also implies an increase in the opportunity cost of an activity as well (due to the increase in marginal value of time in other activities), making the net effect of electrification on time allocated to any given activity theoretically uncertain (Barron & Torero, 2015). This does not, however, eliminate the understanding that there is a strong corollary between electricity and development.

Access to electricity can bring social welfare to remote communities, particularly if other development processes are taking place simultaneously (Kirubi et al., 2009; Mainali & Silveira, 2012). Once a village is electrified, quality of life can improve, providing a strong social motivation behind rural electrification. It has been shown to correlate positively with the Human Development Index (HDI) in case studies of multiple villages in Nepal (Mainali & Silveira, 2012) and India (Bhattacharyya, 2006), as well as globally (Kammen et al., 2014; Martinez & Ebenhack, 2008). Goldemberg, et al. first established a clear correlation between human development and electricity consumption per capita (kWh per capita), which proposed steep gains between 2,000 and 4,000 kWh per capita per year (at the annual level determined necessary for meeting basic needs), with rapidly diminishing returns at greater levels of consumption (Alstone et al., 2015; Krugmann & Goldemberg, 1983). Some consider electricity access a basic human right, and have called upon governments to include it in their package of basic public benefits to citizens, in order to starve many of the core conditions of poverty that come from lack of community services that are enabled by electricity (Kaygusuz, 2011).

However, energy access and electrification initiatives have disproportionately benefitted urban populations over rural populations. The IEA estimates that over 80% of populations without access to electricity or modern cooking fuels reside in rural

areas, mainly in Sub-Saharan Africa and South Asia (*World Energy Outlook 2014*, 2014). This also reaffirms the correlation between income growth and access to electricity and other modern energy services cited above, as the World Bank reports that 75% of the world’s poor live in rural Sub-Saharan Africa and South Asia. This rural-urban divide in term of distributions of energy systems and practices represents a deep, economically motivated inequity.

Despite the clear centrality and benefits of electrification, it can be difficult to fully capture all of the resultant beneficial effects beyond the primary or even secondary benefits of electricity access. Benefits reverberate throughout the local economy, often through the informal sector, making them challenging to capture completely. Table 2 summarizes some of the benefits most frequently cited in the literature.

Table 2: Summary of Observed Benefits of Electrification in the Literature

Social Welfare benefits of Electrification	Sample of Literature Support
Household Benefits	
Lighting for household tasks	Bhide & Monroy (2011); Franz, et al. (2014)
Use of household appliances (ex. clothes washers, space heaters, refrigerators, etc.)	Bhide & Monroy (2011); Barron & Torrero (2015); Davis (1998); van Campen, et al. (2000)
Reduced exposure to indoor pollution from cooking with woody biomass	Bhide & Monroy (2011); Davis (1998); van Campen, et al. (2000)
Refrigeration of food	Bhide & Monroy (2011); Franz, et al. (2014); Deichmann, et al. (2012); van Campen, et al. (2000)
Educational Benefits	
Lighting for studying and reading at night	Bhide & Monroy (2011); Mainali & Silviera (2012); Deichmann, et al. (2012); van Campen, et al. (2000); Bearak (2016)
Education through telecomm outlets	Bhide & Monroy (2011); Mainali &

	Silviera (2012); Davis (1998); Cecelski (2000); van Campen, et al. (2000); Stroup (2005)
Hygiene and education resources for schools	Bhide & Monroy (2011); Kaygusuz (2011); Davis (1998); Cecelski (2000); van Campen, et al. (2000)
Public/Community Benefits	
Water pumping and purification	Bhide & Monroy (2011); Kaygusuz (2011); Davis (1998); Cecelski (2000); van Campen, et al. (2000)
Sterilization, refrigeration of medicine, and modern equipment for clinics	Bhide & Monroy (2011); Mainali & Silviera (2012); Kaygusuz (2011); Franz, et al. (2014); Deichmann, et al. (2012); Cecelski (2000); van Campen, et al. (2000); Lecoque & Wiemann (2015)
Public street lighting	Kaygusuz (2011); Davis (1998); Cecelski (2000); Cabraal, et al. (2005); van Campen, et al. (2000)
Powering of social/community centers	Kaygusuz (2011); Franz, et al. (2014)
Economic Benefits	
Lighting for entrepreneurial income-generating activities, especially for women (ex sewing)	Bhide & Monroy (2011); Mainali & Silviera (2012); Davis (1998); Deichmann, et al. (2012); Cecelski (2000); Cabraal, et al. (2005); van Campen, et al. (2000); Lecoque & Wiemann (2015)
Increase in the amount of working hours per day	Mainali & Silviera (2012); Deichmann, et al. (2012); Cecelski (2000); Lecoque & Wiemann (2015)
Improved agricultural activity	Davis (1998); Cecelski (2000)

The next section discusses productive uses of electricity in relation to the economic benefits of electrification.

2.4 The Productive Use of Electricity

Each year, the global poor spend “\$37 billion on poor-quality energy solutions to meet their lighting and cooking needs” (Bardouille, 2012). The energy needs of these poor, rural populations are a major source of inequity because they require a much more significant portion of a household’s income to satisfy than in the developed world. A 2011 global study found that, “20-30% of annual income in poor households is directly expended on energy fuels, and an additional 20-40% is expended on indirect costs associated with collecting and using that energy, such as health care expenses, injury, or loss of time” (Sovacool, 2012a, 2013). These numbers can total over 80% of household income in extreme cases (Sovacool, 2012a). As incomes increase, the proportion of household income designated for energy-related expenses is likely to decrease (Vera & Langlois, 2007). Indeed, in the United States, consumers spend on average about 5% of their *disposable* (not total household) income on energy needs (Energy Information Administration, 2014). Additionally, the study calculated that the poor pay eight times more per unit of energy than other income groups (Sovacool, 2012a).³

Under a scenario where access to energy is available, as incomes increase, energy consumption increases in quality of fuels (LPG and electricity) and quantity (Davis, 1998; Karekezi & Kithyoma, 2002). The energy transition in rural communities, accelerated by electricity access, allows for categories of energy use

³ To illustrate; Gershenson, et al. (2015) report that “a typical phone with an average battery capacity of 5 Wh, costs an average of \$0.20/charge in East Africa. This translates to an exorbitant price of \$40 per kWh” (Gershenson et al., 2015, p. 11).

beyond subsistence household use. In rural development, energy is often viewed as having two distinct uses: residential and productive:

“Residential uses of energy are expected to positively impact the rural quality of life or improve rural living standards. The productive use of energy in rural areas is expected to result in increased rural productivity, greater economic growth, and a rise in rural employment, which would not only raise incomes but also reduce the migration of the rural poor to urban areas.” (Cabraal et al., 2005, p. 118)

As a rural economy’s energy use begins to divide into these two categories, an economically productive sector emerges, providing space for access to electricity to accelerate rural economic development. While there is still debate on which precedes the other, the link between reliable electricity services and economic development has been clearly established. This two-way relationship begins at the household level, and is accelerated by productive applications of electricity, which can increase the marginal return to time of an activity. So productive use applications of energy in rural areas can serve as a poverty alleviation tool (Barron & Torero, 2015). The surplus time gained in a household as a result of electricity access is significant and should be considered a secondary productive use; a study in Nepal saw that 93 percent of respondents enjoyed time surpluses greater than 90 minutes per day, allowing more time for other chores, attention to children, and study time for school-age children (Wamukonya, 2007).

Productive use applications of energy in rural areas can bring changes to livelihoods in individual households, the local economy, and to the community overall. It is important, though, to come to a clear definition of the productive use of

energy and its operating space. There are a few similar, widely accepted definitions, but most fundamentally, productive uses of electricity generate income and value, either directly or indirectly, through the production of goods or services (Best, 2014; Brüderle et al., 2011; Cabraal et al., 2005; Lecoque & Wiemann, 2015). Fishbein (2003) further defines the conditions under which productive uses must exist, including knowledge and skill to use new-found electricity access for profitable enterprise, a policy environment conducive to new business development, access to new markets as a result of increased capabilities, and availability of a minimum of other complementary infrastructure services, among others (Fishbein, 2003). Additionally, Best (2014) notes that addressing productive uses in rural economy requires investment in capacity building and complementary interventions⁴ for users, access to financing for capital machinery, and identification of bottlenecks in the value chains of rural industries, especially in the agricultural sector.

At the household level, productive electricity use has the power to transform livelihoods. Electricity access can power small household appliances like cook stoves, clothes washers, and refrigerators, which provides a marginal time increase for productivity, especially for women (Cabraal et al., 2005; van Campen et al., 2000). This marginal time increase, paired with electricity access for nighttime lighting and sewing machines (for instance), often results in women engaging in income-generating

⁴ For example: seed purchasing, transportation infrastructure development, land titles and other forms of property rights (Best, 2014).

activities within the household (Deichmann et al., 2011). A recent empirical study by the World Bank Group in Bangladesh estimated income gains from electrification between 9-30% (Khandker, Barnes, & Samad, 2009). Another study in the Philippines found that 25% of households with electricity operated small home businesses, compared to about 15% without electricity, and that the electrified businesses were more productive than the unelectrified ones (D. Barnes et al., 2002). Additionally, Barron & Torrero found that, in El Salvador, electrification leads to a 46% increase in non-farm income-generating activities in adult women and a 25% increase in the likelihood of women to operate a home business, with average profits of around \$1,000 per year (Barron & Torero, 2015). Electricity use is also related to improvements in education levels in rural homes (D. Barnes et al., 2002; Cabraal et al., 2005). In agreement, the same study in El Salvador cited earlier also found a 78% increase in time invested in education from school-age children as a result of electrification (Barron & Torero, 2015). While some studies do not report uniform net benefits of electrification (Odarno, 2014), many have found a clear correlation between lifetime earnings and education, as well as electricity access and life expectancy, energy use that promotes education can be considered economically productive as well as socially productive (Cabraal et al., 2005). Electrification is capable of enabling income generation at the household level, and empowering women and children in the process (Cabraal et al., 2005).

A number of rural electrification projects⁵, especially those recently sponsored by UNDP/GEF, have focused on income-generating uses of renewable energy, in order to jointly meet the goals of poverty alleviation and economic development as well as gender equality⁶. These income generation-focused projects are mostly micro grids, as SHS is too small for productive use and grid extension mainly adds residential sector customers to the national grid, and primarily focuses on agricultural productivity and commercial business productivity. Because many rural communities depend on subsistence agriculture as a livelihood, agricultural productivity increases through electricity access are an attractive market. Tasks such as tilling, irrigation, water pumping, and post-harvest agro-processing can see great efficiency gains with the access to electricity (Brüderle et al., 2011; Cecelski, 2000; van Campen et al., 2000). This will also be discussed in greater detail in Section 3.4. Commercial industries as well as the service sector can also see large increases in productivity because of electricity access. According to Bhattacharya (2006), three economic factors must be satisfied in order for commercial-use energy to “successfully penetrate the energy demand of the poor:”

“(1) The energy should be suitable and perhaps versatile for satisfying the needs of the poor; (2) It should have a competitive advantage that would place no or little demand for money transactions (in other words, the low cost supplies [sic]) in the present circumstances, and/or (3) the use of modern energy should result in supply of adequate money flows to the poor so that they become willing to spend some part of the money on purchasing

⁵ See Lecoque & Wiemann (2015) for nine case study examples.

⁶ Originally championed in tandem with energy poverty by Cecelski (2000).

commercial energies” (Bhattacharyya, 2006, p. 3395).

Under these conditions, carpentry, tailoring, welding, looming, restaurants, and mobile phone service stations, for instance, should see significant productivity gains from access, and because lighting extends the workday, businesses will also be able to extend their hours of production and quality of service beyond sunset (Brüderle et al., 2011; van Campen et al., 2000).

In urban communities, existing social services such as municipal water pumping, refrigeration, public lighting, health facilities, and telecommunications infrastructure can be greatly improved by electricity access (van Campen et al., 2000). In a holistic view of productive use, these should be considered indirect, or secondary, productive uses as they enable other forms of direct, or primary productive uses through the creation of markets, health and increases in life expectancy (and therefore productivity), and overall well-being. The Mpeketoni Electricity Project in rural Kenya provides an excellent case study of a community-level productive use application of an electric micro-grid, studied and profiled by Kirubi, et al. (Kirubi et al., 2009) and excellently summarized by Best (Best, 2014):

“A review of the Mpeketoni Electricity Project (MEP), a community-based diesel-powered micro-grid in rural Kenya, found that the use of electricity and equipment improved the productivity and incomes of local small and micro-enterprises, contributed to the mechanization of agriculture, and supported improved village infrastructure such as schools, markets and water pumps. With access to electricity, productivity per worker among local small and micro-enterprises (like carpenters and tailors) increased by 100–200 per cent, and gross revenues increased by 20–125 per cent depending on the task or product made. Particularly striking is the link between electrification and

increased usage of diesel-powered tractors to clear and cultivate the land. As the mini-grid enabled the local provision of electrical welding services, people in the neighbouring region were more willing to hire out their tractors to farmers in Mpeketoni: they knew tractors and machinery could be repaired in the event of a breakdown. More convenient and timely availability of tractors meant farmers could clear and cultivate more land than was previously possible with hand tools. Electricity also enabled cold storage for farm produce and opportunities for local shops and hotels to buy fruit from farmers and prepare juice for sale.” (p. 15)

This project illustrates community-level productive uses of energy taking place as a result of micro-grid scale development. While SHS provides some of the household and educational benefits of electrification, there is little evidence that SHS-scale electrification has a significant effect on productive economic output beyond small artisanal activities (van Campen et al., 2000). In the case of micro-grids, however, “Developers implicitly expect mini-grids to stimulate productive activities in rural areas because they provide more power than standalone technologies such as [SHS]” (Best, 2014, p. 9). Coupled with the economic development in stimulated productive uses of energy in communities electrified by micro-grids, the degree of cost recovery and therefore the degree of financial viability of these projects is much higher, which improves access to cheaper financing and a greater inflow of investment.

There is a consensus in the literature that productive uses of electricity for income generation, paired with skills enhancement to support microenterprise and ancillary infrastructure development⁷, should be prioritized in rural electrification

⁷ See Brew-Hammond (2010): “Electricity plays an important role but yields the best results when accompanied with ancillary infrastructural development like roads and

programs to promote improved creditworthiness, economic growth, and social development (Brew-Hammond, 2010; Brüderle et al., 2011; Glemarec, 2012a; Gurung et al., 2012; Kirubi et al., 2009; Mainali & Silveira, 2012; Williams et al., 2015; Yadoo & Cruickshank, 2012). Productive, income-generating uses are particularly appropriate when they increase a customer's ability to pay for future electricity consumption (Williams et al., 2015). This case study illustrates how productive uses of energy can be crucial to achieve cost recovery within a robust development framework. Despite present inequities, there is growing recognition that 'base of pyramid' customers can quickly become highly scalable commercial opportunities.

2.5 Electricity as an Accelerator of Development

National electrification programs often have the stated purpose of fostering economic development through providing electricity access, but have failed to recognize that the presence of electricity is not necessarily sufficient, or even necessary, for development to occur (Brüderle et al., 2011). Despite the hurdle of an electrification rate under 30%, Sub-Saharan Africa is home to seven of the top ten fastest growing economies in the world (Mans, 2014). Productive use applications of distributed energy technology should be consistent and reliable in order to promote economic growth. Random blackouts and brownouts can majorly hinder manufacturing and service processes and take major tolls on a nation's economy (Gershenson et al., 2015; Yadoo & Cruickshank, 2012). Countries with erratic grid

telecommunications, and services like SME and consumer finance that spur business and market development.” (p. 2297) Also see Mainali & Silveira (2011).

balancing capabilities should shift away from grid extension as a method of rural electrification and instead focus on distributed resources. Based on a study conducted in India, Khandker, et al. (2012) estimated that each “additional hour of service availability lowers the level of energy poverty by 0.4% points” (Khandker et al., 2012, p. 11). This effect is delimited by the necessity for sufficient resources in order to make an initial investment to get a grid connection (Cecelski, 2000). Many studies have corroborated this by finding that rural electrification initiatives benefit higher income populations more than low income populations (Cecelski, 2000, p. 7). As a household, community, or nation progresses up the energy ladder from traditional woody biomass to fossil fuels to electricity, understanding the role of productive use applications is critical.

Because electrification unleashes a complex chain of interacting events, it is difficult to identify direct causal relationships among the effects of rural energy programs (Barron & Torero, 2015). Even using instrumental variable (IV) analysis or time series data to manage the endogeneity of connection, it is not possible to purely isolate the transformative effects of electricity on livelihoods. It is also important to consider the potential negative effects of electrification, such as child labor due to increased industrialization (Barron & Torero, 2015), worsening of nutritional value, or even cultural dilution due to new media influences. Not an anthropologic or nutritional analysis, this study will not attempt to address these negative cultural or health effects in detail; however, it is recognized that these potential negative consequences are real and present, and that electrification programs and private enterprises should be aware of these when designing business models and policies and planning cultural interaction. Renowned economist Amartya Sen defined development as the process of

expanding the real freedoms that people enjoy (Sen, 1999). Income increases are important in poverty alleviation as a means to expanding freedoms, and are useful only as a metric to that point (Sen, 1999). Likewise, “access to electricity can help households alleviate their energy poverty simply by allowing them to use a much wider range of energy services (and consume more energy as a result)” (D. F. Barnes et al., 2011, p. 903). However, what is also clear is that whether electrification is a necessary precondition for or an expected result of development, it is not alone sufficient to bring about rural economic growth. It is important to recognize the benefits of electrification in the context of an environment conducive to productive energy use.

Chapter 3

THE ECONOMIC MULTIDIMENSIONALITY OF ENERGY ACCESS

3.1 The Economic Multidimensionality of Energy Access

Energy poverty and development are understood under different assumptions, frameworks, and goals, muddying the true links between these complicated global issues even more (Bazilian et al., 2010). Each electrification context is unique and that built assumptions or successfully demonstrated technologies, social structures, agricultural applications, or policy frameworks do not necessarily imply scalability. The deep complexity in scaling up energy access is due in substantial part to the apparent multidimensionality of energy access, which, when overlapped with the economic difficulties of providing capital-intensive services to communities without access to capital or credit and have seasonally-varying incomes, creates stubborn barriers to project implementation. These multidimensional factors are critical to understand in order to carry out successful interventions.

Under a multidimensional understanding of energy access, it is evident that there is no universally scalable solution to provide rural electricity access. In reference to rural populations (“the latter category”), Chaurey et al. argue that “Deprivation for the latter category is indeed multi-faceted: a lack of sufficient attention by government programs is compounded by a lack of access to infrastructure services, markets, and information” (Chaurey et al., 2004, p. 1693). Added to the pressing global problems of energy security and climate change mitigation and adaptation, macro flows of international aid and private investment, and explosive economic growth of rapidly

emerging markets with young populations, the universality of a single solution is increasingly unlikely⁸. The multidimensional framework presented here can assist in interpreting the various dimensions of the energy access problem in order to increase understanding of the nature of the energy access issue and improve the efficacy of solutions-oriented interventions and inform market entry strategies.

Previous literature has recognized the multidimensionality of energy access in the context of its benefits (such as education and health) (Cabraal et al., 2005), gender (Cecelski, 2005), and, quite comprehensively, sustainable development in general (Shrestha & Acharya, 2015). Additionally, the UN's Millennium Development Goals and now the Sustainable Development Goals recognize energy access as a key part of a multidimensional comprehensive development framework. In fact, Kirubi, et al. write that "Within the context of MDGs, productive uses of energy should not, these authors suggest, be limited to activities related to income generation, but should also include application of energy to support important development goals such as access to education, health, communication, and women's empowerment" (Kirubi et al., 2009, p. 3). Moreover, a UNIDO-led study further developed an index called the Multidimensional Energy Poverty Index (MEPI) in 2013, which is based on an assessment of access to different dimensions of energy services, such as lighting, appliances, cooking, and entertainment (Nussbaumer et al., 2013). Further, the Asian Development Bank (ADB) has recently presented a sustainable energy access

⁸ It is valuable to note that, while this analysis will later focus on PV-powered rural micro-grids, it also recognizes that this is not a universal solution on any dimension presented here. Other generation technologies and scales, including micro-hydro, SHS, pico solar, and, of course, grid extension will be left to the work of others.

planning framework index, which identifies a set of similar dimensions to the framework presented below at a highly conceptual level (Shrestha & Acharya, 2015). The ADB’s index scores the level of energy access on each of the sustainability assessment dimensions based on survey criteria (Shrestha & Acharya, 2015). In fact, some other previous efforts at measuring and scoring energy access have indicated the inherent multidimensionality in energy access (Bhatia & Angelou, 2014; Kowsari & Zerriffi, 2011; Pachauri & Spreng, 2011). In 2014, The World Bank’s Energy Practice published a report detailing the a multidimensional framework that scores surveyed participants’ level of energy access based on a series of definitional traits of energy access defined by the Energy Sector Management Assistance Program (ESMAP): “the ability to obtain energy that is adequate, available when needed, reliable, of good quality, affordable, legal, convenient, healthy, and safe for all required energy applications across households, productive enterprises, and community institutions” (Bhatia & Angelou, 2014). See a sample table of the framework below.

Table 3: Simplified multi-tier framework (Bhatia & Angelou, 2014)

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

A comprehensive compilation of other similar rural energy poverty and energy access measurement indices, the World Bank's framework represents a tangential effort to this one, but clearly illustrates the acknowledgement of the literature that the problem of energy access needs to be examined through a multidimensional lens. Also, Pachauri & Spreng (2011) identify a host of energy poverty measurement indicators that represent the various factors involved in energy access in Table 2 (Pachauri & Spreng, 2011).

The literature implicitly recognizes the inter-sectoral linkages between “policy support, social acceptance in the form of community participation, linkages with income-generating opportunities, and technological appropriateness” (Bhattacharyya & Palit, 2014, p. 122; Cecelski, 2000). The emerging field of nexus thinking is also closely related to multidimensionality in that it recognizes that it is at the intersections of multiple goals where solutions are found. This field often relates energy to food, water, climate, and land. However this is also a different type of methodology because it is linking two issues rather than different dimensions of the same issue. This is also true of the MDGs and SDGs. The practitioner must also be cautioned about the unique nature of each context as it varies along the dimensions presented below, demanding rigorous assessment for each project to determine the appropriate intervention strategies (Cherni & Kentish, 2007). When micro-grid implementation accounts for the multidimensional factors, they “provide the policy maker and rural development practitioner with a means of combating poverty, mitigating against increased GHG emissions and improving adaptive capacity to climatic change” (Yadoo & Cruickshank, 2012, p. 600).

However, there is presently a gap in the literature regarding the construction and application of a multidimensional energy access framework to community financing or to micro-grid systems. Filling this gap is one of the main goals of this work. The framework offered here seeks to account for these issues on a community level, which has unique dimensions, benefits, and challenges. Thin rural demand, difficulty arranging finance, and an unsupportive policy environment collectively build the need to navigate the energy access intervention process at the community level (Bhattacharyya & Palit, 2014). However, community-level capacity and participation is often a necessary prerequisite for successful energy access intervention, especially a micro-grid-based system that, due to limited generation capacity, effectively serves as a limited common-pool resource, with brownouts as a response to tragedy of the commons behavior (*see* Quetchenbach et al., 2013). Practitioners must remember that economic development and social change happen in concert with technology adoption, and oversimplifying or even ignoring the cultural factors within the implementation context may lead to inefficient use of resources or even project failure (Murphy, 2001). Murphy argues that when practitioners see their role as filling energy supply gaps, and assume that stable and efficient energy markets will develop to maintain the supplies and sustain technological change, they ignore the influence of existing social institutions and common property regimes; instead they must understand these as well as “come to terms with the constraints on equity and dissemination created by social identities, hierarchies, norms, and rules” (Murphy, 2001, p. 187). When projects prioritize expanding supply over community needs, affordability, or consumer choice, they fail to recognize the multidimensionality inherent in energy access.

By understanding the drivers and barriers of the techno-economic, socio-economic, agro-economic, and institutional-economic dimensions of energy access, practitioners can increase the efficacy of their interventions in a culturally preserving, economically empowering way that ultimately leads to improving the quality of life of rural peoples⁹. For example, planning a multi-dimensional community-scale intervention could consist of a human-centered needs assessment, a resource assessment and system design process, streamlined licensing and permitting process, and tariff design that incorporates crop harvest schedules for rate payment.

Barrier analyses are found widely across the literature, and most are categorized dimensionally, often without recognizing that approaches for addressing the energy access problem require multidimensional solutions in order to address barriers along different dimensions, thereby inadvertently endorsing this theory necessitating multidimensionality of energy access approaches. In addition, the literature easily identifies barriers but has yet to identify a true multidimensional approach that can address them. Here, these barriers are characterized along the same lines as the dimensions below, with the addition of financial barriers and the purpose of identifying commonality of barriers across different countries, cultures, and contexts, and to target solutions to overcome these common barriers. The risk profiles for emerging markets are hard to accurately represent, as they vary along each of these dimensions to volatile degrees (Gershenson et al., 2015).

⁹ Environmental-economic and industrial-economic are important dimensions in understanding the multidimensionality of energy access that are not included in this multidimensional framework due to their implicit nature in rural PV-powered micro-grids, as this framework is designed to inform market entry strategy for this technological sector.

The following sections define each of the dimensions listed above, explain their drivers, and characterize their barriers.

3.2 The techno-economic dimension: Definition, Drivers, and Barriers

The techno-economic dimension of energy access is determined by the cost competition between incumbent forms of distributed energy generation (namely, diesel gen-sets) and new and cost-plummeting solar PV technology, resulting disruptive livelihood changes brought on by electrification, and matters surrounding technology absorption and adoption. Recognizing the inputs of levelized cost, benefits of productive uses, and the patterns of technology adoption in rural communities will yield perceptive insights into this dimension of the energy access challenge.

The **cost of installed capacity** for a rural micro-grid in an emerging market economy can be highly dependent on the selected generation technology, proximity to manufacturing and shipping centers, and financing cost (Alstone et al., 2015). These costs are typically between \$1-3 million per MW_p (Bhattacharyya & Palit, 2014). Additionally, unlike grid-tied systems, rural micro-grids must anticipate that demand will grow behaviorally to an average regional consumption level after about five years¹⁰ (“Energy for all: Financing Access for the poor,” 2011). Access to energy services allows incrementally increased consumption for greater uses. See Figure 1 below.

¹⁰ The United Nations’ SE4ALL Initiative estimated that this level would be about 800 kWh per capita globally in 2030 (SE4ALL, 2011, p. 2)

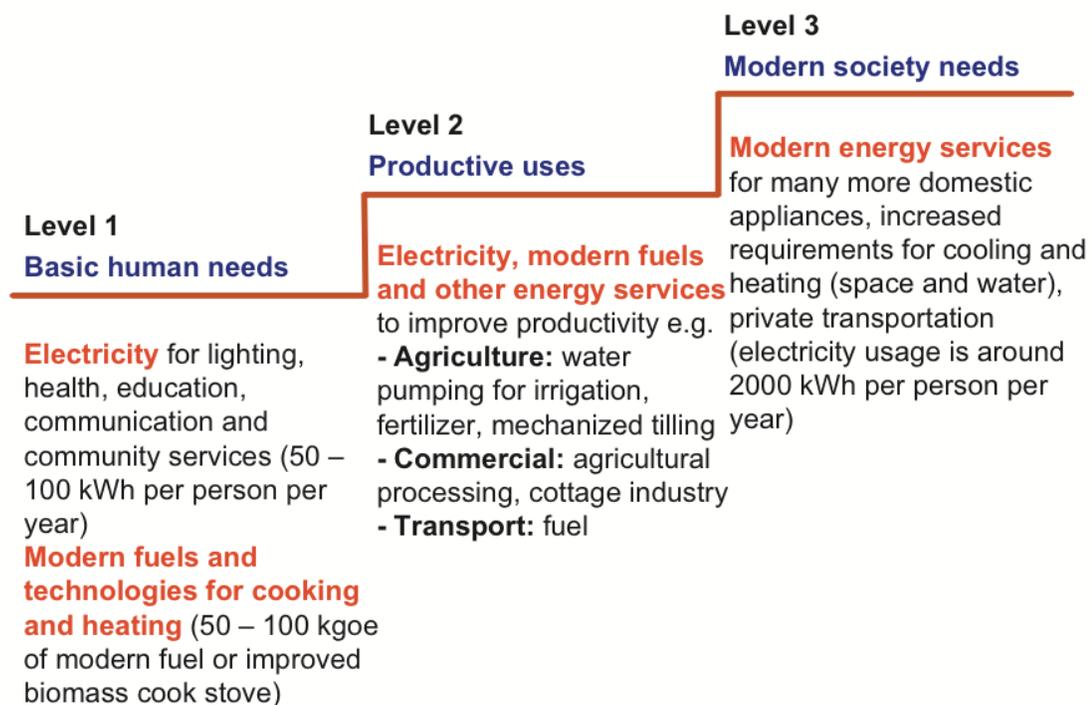


Figure 1: Incremental Levels of access to energy services (Sokona, et al., 2012)

This means that the generation assets of a rural micro-grid must either overcompensate for initial demand at construction, or have modular qualities to allow for the addition of generation capacity over time (this is a major advantage of solar PV). Added cost factors include technical skills training and assistance and ongoing operations and maintenance costs, which are often greatly inflated in remote locations (Brüderle et al., 2011).

Rural energy generation technology can provide **efficiency gains** for household tasks, agricultural processes, and industrial manufacturing processes, as discussed above in Section 2.4. These gains in efficiency are dependent on the functionality of existing technological capital, such as household appliances and personal electronics, farm equipment, and industrial processing machinery.

Technological efficiency gains can be represented by marginal gains to time on tasks and processes, as well as in technology-driven energy efficiency efforts within an islanded micro-grid. Casillas and Kammen (2011) recognized through cost analysis that neglecting energy efficiency measures “misses the most effective means of meeting rural energy needs” (Casillas & Kammen, 2011, p. 4523). Likewise, analysis of a pilot project for the GridShare micro-grid metering device in Bhutan demonstrated that technology-moderated information can reduce peak load by 30% and save enough diesel to extend grid operation by two additional hours per day and a very convincing IRR of 293% on the investment into the meter tech (Casillas & Kammen, 2011, p. 4923).

There are a significant number of factors involved in **technology absorption** and technological change. To begin, technology transfer to much of the developing world has been highly asymmetric, leaving the developing world with little capacity for modern technological development domestically and often leading to a top-down, technology-led approach to energy system design (Murphy, 2001). Capabilities for research and development, design, and manufacture of renewable and energy efficient technologies are weak (Parthan et al., 2009). Both Public and private investment in R&D are essentially nonexistent, and ideas and technologies are often purely imported, if explored at all, in essence removing technical barriers from the hands of the governments of developing nations. Most of these nations simply have inadequate testing and certification labs, which further prevent local product development (Parthan et al., 2009). There is also a dearth of “qualified and experienced manpower for design, manufacture, installation, operation and servicing of the energy efficiency and renewable energy systems” (Parthan et al., 2009, p. 3). As new tech is transferred

to households in the developing community, they are absorbed incrementally as the technological capabilities of users rises incrementally with their capacity for technology adaptation and ability and willingness to take on economic risks and modify their behavior (Murphy, 2001). Technological change happens within social, cultural, economic, and institutional contexts in rural communities and in concert with economic development, not separately from it, and technologies do not cause social and economic development alone (Murphy, 2001). They can drive development at the incremental, stepped pace at which technology is accepted, understood, and used efficiently in the community:

“...technology absorption cannot occur without the proper social, cultural, political, and economic institutions to support adoption, dissemination, and appropriate contextual innovation. Institutions in this sense are not only the agencies, property rights regimes, rules, values, or norms existing in a given context. They also include people’s daily patterns of behavior. These patterns — such as who collects fuel, when and how they do it, or how the energy is consumed — are embedded in rural lifestyles and the cognitive processes that influence the behavior of rural people. For technologies to be absorbed, they must first be connected to these patterns. As the technology is then integrated into rural life, new energy related institutions will evolve provided the technology is effective at meeting local energy needs. Unfortunately, making the connection between a relatively rigid technology and a dynamic social context is often extremely difficult and time consuming.” (Murphy, 2001, p. 187)

Relating these three drivers of the techno-economic dimension (cost competition, efficiency gains, and technology absorption), it is clear that meaningful business models would need to successfully incorporate the effects of fuel choice, policy changes, income linkages, and community roles into the decision-making process. A brief characterization of a number of key techno-economic barriers and risks appears below.

3.2.1 Physical Market Access

Physical market access is a bi-directional barrier. For governments and public utilities, private enterprise, and NGOs that are seeking to reach the unelectrified, logistical difficulty, danger, excessive time or high cost required to reach these communities may be prohibitive for implementation of energy access interventions, especially fuel-based interventions that require regular delivery or frequent maintenance. For farmers and MSME entrepreneurs, limitations of physical market access means lack of access to markets for sale of final products, which can represent a significant bottleneck to the economic benefits of productive uses of electricity (Best, 2014). A lack of physical availability of local energy resources for adequate generation capacity, resulting in brownouts, load shedding, or eventually, the diversion of limited local resources or capacity for operations and maintenance to more efficient or lucrative assets (Balachandra, 2011). Lastly, communities in ecologically sensitive areas face techno-economic difficulties in implementation of energy systems, often due to statutory limitations on economic activity in protected areas (Gershenson et al., 2015).

3.2.2 Supply Chain, Vendors, and Business Models

In limited rural markets, equipment, installation and service labor and expertise, parts, access to price-consistent fuel, and other inputs may be restricted, which can easily limit the performance of an energy access intervention or drastically skew project economics if supply is severely constrained (Best, 2014; Franz et al., 2015). In remote areas, retaining consistent technical staff for a rural energy system is costly and problematic, exacerbated by the far distances and long transportation times between systems in thin rural markets, which drive up service prices significantly

(Murphy, 2001; Schmidt et al., 2013b). Further, because of the historically unilateral technology transfer relationship between the Western world and the developing world, local manufacturing capacity is very limited in most contexts, and depending on other institutional factors elaborated below, such as import tariffs, can significantly constrain component supply, impacting price (Sovacool, 2012a).

3.2.3 Recurring Fuel and O&M Costs

Because of the shortage in skilled technical staff to service rural energy systems, preventative maintenance can often be forgone in order to realize significant short term cost savings, but at the expense of system longevity, performance, and often, more costly repairs in the future (van Campen et al., 2000). This squeeze has fostered a recognition that training and retaining members of the local community to operate and maintain the generation equipment can greatly reduce costs, increase response times, and provide social and other economic benefits to the community, as discussed further below (Chaurey et al., 2004; Schmidt et al., 2013b; van der Vleuten et al., 2007a). In some situations, operations and maintenance risks to lenders can be mitigated contractually through step-in clauses, which allow lenders and project sponsors to fine or replace operations managers if the project's financial or technical health is at risk (Gershenson et al., 2015).

Fuel cost variability is a barrier and risk for all recurring-input activities, but is highly exacerbated in rural settings. Failure to incorporate fuel cost risks into power purchase agreements (PPAs) for diesel-powered systems, especially for long-term contracts, can cause significant issues with local payback and the system's overall financial health (Bhide & Monroy, 2011). Alternatively, tariffs and PPAs can be designed to float with the fuel price, though this could lead to high rates of customer

default if fuel prices spike (Gershenson et al., 2015). This risk is naturally insulated against in renewable energy powered micro-grid systems.

3.2.4 Technology and Installation Costs

Even though module costs for solar PV are plummeting, capital costs for generation technology can still often be prohibitive to energy access. Especially when costs are considered on a site-delivered basis, rural locations can see substantial increases due to the difficulty and time required to reach the project site. Further cost overruns can result from delayed shipments and damaged modules or other equipment can cause construction or commissioning delays, resulting in missed debt service payments or even violated power delivery contracts (Gershenson et al., 2015). When projects face other geo-locational difficulties, such as lower daily irradiance, seasonal weather changes, drainage issues at the project site, or lack of access to appropriate tools or installation equipment, the techno-economic feasibility of projects can be threatened (Gershenson et al., 2015; Sovacool, 2012a; Walker, 2008). Finally, commissioned projects with poorly managed demand may see major battery replacement costs arise before the replacement fund has matured if the batteries are continually drained to low levels beyond C/20 ratings (Luque & Hegedus, 2011). (It should be notes that diesel gen-sets face in parallel many of these issues as well.)

Lack of modular, uniform, or standardized system design or parameters

Variable resource availability, fluctuating load, and socioeconomic disparities can result in highly individualized system designs, which creates difficulty in

establishing baseline design quality standards¹¹ and is a source of investment risk, as well as a human safety risk (Franz et al., 2015; Gershenson et al., 2015, p. 24). Micro-grid projects need to be appropriately designed as islanded systems, and may also provide contingencies for connection to the grid within the years of the project life (the unpredictability of incumbent grid extension is a risk in itself, however) (Gershenson et al., 2015). Additional barriers include low quality, outdated, or damaged equipment, siting and resource assessment standard variability, and lack of clear guidelines for environmental impact assessments (Sovacool, 2012a).

3.2.5 Supply-side and Demand-Side Deficiencies

On the supply side, rural energy systems do not account for increasing demand due to incremental household consumption increases or the potential impacts of improved access to electricity on business development, consumption, and other local conditions (Gershenson et al., 2015). These may face the need to engage in demand reduction efforts in the future or face additional costs to expand generation capacity and perhaps battery storage systems as well. Towards this end, the modularity of some renewable energy technologies, notably solar PV, will lead to continued capital cost efficiency gains (Attia & Latham, *forthcoming*) and allow project managers to increase generation capacity as demand rises incrementally rather than inaccurately predicting demand into the future (St. John, 2016).

¹¹ See, for instance, IEEE Standard 1547.4 for the *Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems* (Gershenson et al., 2015).

Demand-side deficiencies can erode the foundation of a rural energy system's financing. Variable daily demand or weather fluctuations may make it difficult for project managers to balance a micro-grid system and can result in non-technical losses, which can be up to 40% of generated power (Gershenson et al., 2015; Schmidt et al., 2013b).

Rural energy access involves a number of significant techno-economic barriers and risks that can erode the technical feasibility of a project. These vary in their significance by technology, but in the case of PV-powered micro-grids, they demand careful consideration in the project development process in order to ensure successful implementation along the techno-economic dimension.

3.3 The socio-economic dimension: Definition, Drivers, and Barriers

The socio-economic dimension of energy access is determined by cultural understandings of energy use, societal authority structures and roles, and the roles of women. From the perspective of community development work and aid generally, it is critical to understand the socio-economic dimension and operate within an enabling environment in order to meet the needs of the community in a way that is desired and understood in order to avoid doing more harm than good. The socio-economic dimension is the intersection of this enabling environment, which includes supportive land rights and regulations, subsidies and incentives, and accessible credit, and the socio-cultural context, which includes degrees of social cohesion and conflict, local skills, awareness, and preferences, enterprise capacity, and willingness-to-pay (Best, 2014). This is illustrated in Figure 2 below.

Figure 2: The Intersection of the Socio-economic Dimension



Adapted from (Best, 2014)

Because these factors are highly non-uniform even among similar regions of the world, it is critical to recognize and operate within this intersection, which informs the following drivers of the socio-economic dimension of energy access.

The **social structure and norms in a tight-knit rural community** deeply guide the decision-making of isolated populations of consumers. The collective beliefs of the community, often led by local leaders, can determine views towards external influences, receptiveness towards new technology, and future levels of consumption and demand (Franz et al., 2015). However, some of these collective beliefs may be difficult or culturally dilutive to change, and others, such as corruption in local authorities, may even severely impede energy development projects (see Franz et al., 2015). While recognizing these barriers later in this section, this analysis limits itself

to socio-cultural norms that can be feasibly addressed in order to deliver energy access solutions to interested and willing communities. For this reason, it is often highly beneficial to partner with a local business, NGO, or cooperative government body in order to effectively engage more remote populations with energy technologies (Bhattacharyya & Palit, 2014).

Energy consumption behavior and applied uses also vary along the socio-economic dimension of energy access. Individual human behavior is influenced by highly social and collective activity and shifts when broader social transformations occur. As a result, it is unfruitful to focus on household energy demand, but rather to recognize that it is a product of social demand (Kowsari & Zerriffi, 2011). Complex and poorly understood behavioral, cognitive, and social processes influence even the most routine forms of energy use, and there is a significant gap in the literature regarding the behavioral aspects of energy use¹² (Kowsari & Zerriffi, 2011).

Additionally, the livelihood-transforming nature of access to electricity has the power to positively, negatively, and ambiguously modify cultural norms. For example,

¹² “Although some research has attempted to include cultural and habitual factors and has confirmed their importance, there is almost no research that explores these variables and their dynamics in detail. For instance, while an econometric analysis looks at the differences between energy use in households headed by males and females, there is no explanation of why these differences exist and how they may change. As a final note, the growing concern about energy and household welfare, impacts of climate change, and energy security requires a more realistic understanding of household energy use. An in- depth study of the human dimension of energy use is a vital step for improving our understanding of household energy use in rural regions of developing countries” (Kowsari & Zerriffi, 2011, p. 7515).

eliminating the need for young girls to travel far distances and spend the majority of their day collecting woody biomass for cooking the evening meal and freeing them to go to school, can bring positive changes to existing cultural norms. While, in contrast, diluting cultural values or diets with external advertising from products that can now reach new markets may bring negative changes to existing cultural norms. Some norms may see both positive and negative changes with ambiguous magnitudes. For example, a community member of a remote village in Bhutan explained how energy access has socio-economically affected his village with respect to village perspectives about the Migol, a Himalayan yeti in Bhutanese lore:

“In the days before electricity, much of the day would be spent searching for firewood to light stoves and walking up into the high pastures to graze their yaks and goats... ‘Now, says Norbu, people don’t need to go up to the mountain to collect wood or graze their animals. They cook on gas rings, and farming patterns have changed. The villagers spend more of their time growing cash crops such as potatoes and oil seeds... In many ways, lives have improved but the downside, says Norbu wistfully, is that there are no new stories to tell the children.’” (Beveridge, 2015)

This part of local culture is so prominent that most Bhutanese doors are small with a tall threshold in order to prevent the Migol from entering the home (Beveridge, 2015). The value of the net benefit may very well be positive, but extreme precaution is necessary in order to appropriately engage these populations and markets in a culturally-sensitive way.

A third major driver of the socio-economic dimension is the **role of women in energy & economic development**. Rural populations in general are often low priorities on the agendas of national and international authorities, and are just

beginning to be recognized as massive untapped markets for the private sector (van Campen et al., 2000). These untapped markets also contain an enormous quantity of missed human capital, and women are chief among the missed human capital for labor markets. Women and girls spend on average, 2.1 hours per day collecting woody biomass and 1.6 hours per day cooking, time which, if spent on education and income-earning activities could boost sub-Saharan African economies by nearly \$30 billion per year (Lambe & Davis, 2016). If combined with avoided health, environmental, and other economic impacts, the gain is nearly \$60 billion (Lambe & Davis, 2016). It is also estimated that in rural areas, women make up 70 percent of the agricultural labor force (*Power Africa Annual Report*, 2014). Women are the major household users of energy, most often have strong influence or total decision-making power over the purchasing patterns of fuels and household energy-using appliances, and also often are kept from income-generating activity due to the time required to gather woody biomass and the negative health effects of inefficient and toxic fuels (Bhide & Monroy, 2011; Karekezi & Kithyoma, 2002). In fact, they can even be more than key energy end-users, but also “key players in the success of any enterprise that develops and markets them” (Lambe & Davis, 2016).

This gender bias present in energy access should result in the targeting of energy access programs towards women, which would likely increase the incidence of income-generating activities among newly electrified households. Because women may often be more disadvantaged than men in similar situations, designing provisions that expand the decision-making power of women to empower them can facilitate their

own efforts to address their needs and fit their circumstances.

The impact of electrification on the socio-cultural-economic dimension “cannot be overemphasized” or “ignored” (Bhattacharyya & Palit, 2014, p. 152; Chaurey & Kandpal, 2010, p. 2270). The complexities of social power structures and the cohesion and divisions in a community due to political, religious, ethnic, economic, or other factors require careful consideration when planning an energy intervention in a rural community (Bhattacharyya & Palit, 2014). Understanding the social aspects of energy use and the role of women and targeting energy access interventions towards them is also critical in successfully meeting the needs of the community. A brief characterization of a number of key socio-economic barriers and risks appears below.

3.3.1 Lack of Awareness, Information, or Interest

Energy poverty generally persists at least in part due to the geographic isolation of communities. Because of this, low awareness and mixed or unclear perceptions of micro-grid technology, or sometimes even electricity generation technology, may serve as a barrier between the utility, enterprise, or NGO and the community members (Franz et al., 2014; Schmidt et al., 2013b; Sovacool, 2012a; van Campen et al., 2000). Some communities may be difficult to serve due to misinformed views that electricity should be for free, leading to tariff collection difficulties, theft, and other issues (Schmidt et al., 2013b). Along these lines, communities who were previously electrified through free lifeline connections may balk at the prospect of paying for their electricity consumption. Other issues include lack of acceptability due

to inconsistent service, lack of convenience due to livelihood changes in cooking, efforts to correspond with the service provider, and need to learn and understand new technology (Balachandra, 2011). In cooking especially, the entrenched view that woody biomass is free (despite the opportunity cost of gathering it) is a barrier to electricity for cooking, solar cookers, and LPG access. Others may simply not be interested in the observed benefits of electrification and the changes they may bring. These people should not be targeted or followed up with to purchase energy services.

3.3.2 Community Opposition and Culture Clash

When the goals of international development workers or rural energy project developers do not align in value with the community culture, they have the potential to cause controversy, often over property rights and cultural understanding of collective ownership or issues surrounding aid dependency (Rambo, 2013; Sovacool, 2012a). These goals can be based on donor-driven priorities or lack of emphasis on user needs, diverse characteristics, interests, and environmental contexts (Best, 2014), and can result in local opposition, theft, or vandalism (Sovacool, 2012a).

3.3.3 Community Organization and Structure

Community structures can dictate the degree and end use of electricity in rural areas. Communities with central leadership, a common social gathering place, or a particular specialty trade may have specific electricity needs. Socially, women in cultures that depend on woody biomass for cooking may not see significant livelihood changes if the increased energy access is not targeted to cooking applications, for instance (Murphy, 2001). In some communities, it is essential to win over the local

community leadership in order to intervene in a community, as some degree of uncertainty surrounding new innovations may impede initial approval (Nepal, 2012).

In most cases, energy access has socio-economic advantages that can lead to significant improvements in commerce, trade, education, and participation of women in community activities (Bhattacharyya & Palit, 2014).

3.4 The Agro-Economic Dimension: Definition, Drivers, and Barriers

Subsistence farming populations in many developing economies face sharp energy consumption inequities. In Africa, for instance, the agricultural sector employs between 60-80% of the working population and accounts for 25% of GDP in most African countries, but comprises less than 2% of total energy consumption and 3% of total electricity consumption (Kebede et al., 2010; Sokona et al., 2012). Because non-industrialized agricultural operations have an implied low mechanical energy use and efficiency, they require significant inputs of human and animal labor (Karekezi & Kithyoma, 2002; Sokona et al., 2012). This also means that access to modern energy services can have the potential to greatly increase income generation if they are able to economically reach these low-density populations.

Low-density population clusters in rural areas, high per-kilometer costs of transmission and distribution infrastructure, long distances from generation assets, and the fragmented grid infrastructure and policy environment in Sub-Saharan Africa make incumbent large-scale generation technology far from cost effective and represent a **rural-urban divide** in terms of energy. These factors create difficulty in bringing together different interventions for electrification focused on agriculture and household uses (Sokona et al., 2012). Even small agricultural uses of energy provide significant efficiency gains. Modern electricity replaces human and animal labor in

land preparation and tillage, cultivation, weeding, irrigation, harvest, post-harvest processing (grain milling, oil pressing, pasteurization), sawmilling, water circulation and purification for aquaculture, storage, and the transportation of agricultural inputs and outputs, among other needs (Best, 2014; Bhattacharyya, 2006; Franz et al., 2015; Hunt et al., 2010; Karekezi & Kithyoma, 2002; Kaygusuz, 2011). Agricultural mechanization for tractors, tillers, threshers, water pumps, and other farm equipment induces a steady transition towards commercial scale agriculture, when limited energy resources for transportation do not inhibit market access.

A brief characterization of a number of key agro-economic barriers and risks appears below.

3.4.1 Seasonal Variation in Income and Future Yields

The effects of climate change on agrarian economies are significant. Decreased yields, intensity of storms, sea level rise and potential water table contamination, and seasonality changes can cause major disruptions in the crop and harvest cycles of subsistence farmers. The nature of non-mechanized agriculture and unstable commodity markets can leave a near-subsistence farmer without clarity on future incomes, payback periods on loans for equipment, fertilizer, or seed, or trepidation regarding levels of energy consumption. These uncertainties make stable, predictable business difficult, and represent a clear barrier to further growth and income savings.

3.4.2 Illiquid Wealth

In many contexts, agriculturally-subsistent families hold most of their wealth in the form of livestock, unprocessed crops, or mid-stream agricultural products, which can make tariff payment difficult, especially on a regular basis. These contexts

face difficulties when seeking to design monthly tariff rates, consumption-based tariff work. In Nei Mongol, China, for instance, loan payments for rural energy systems were tied to sales of wool through a regional marketing board, and were proportional to yields (Stroup, 2005).

3.4.3 Competing Agricultural and Household Energy Needs

Even droughts, monsoon seasons, and pests, can disrupt the already cyclical nature of agrarian economies that depend on limited amounts of energy to increase productivity and crop yields. Strains to water pumps and irrigation systems, for instance, can overload smaller micro-grids. And as household demand grows to compete with agrarian productivity demand, there can be shortages and blackouts, forcing the farmer to choose between a relatively energy-intensive livelihood and an energy-using lifestyle. This tradeoff can be balanced and managed effectively, but can also quickly become unsustainable when capacity is limited.

The potential economic gains from agricultural energy access are substantial, even on a limited basis. Productive use applications that could facilitate income generation are easily apparent. Increased understanding of demand loads and consumption patterns coinciding with different types of crops, harvests and sowing, and rainy and dry seasons could have a massive impact on the nearly 1 billion subsistence farmers without electricity.

3.5 The Institutional-Economic dimension: Definition, Drivers, and Barriers

Due largely in part to more pressing issues for cash-strapped governments, high-level corruption, and lack of sufficient information, the energy access gap may also be influenced by differing views on the role of renewable energy in a society. In

the Global North, renewable energy policies such as subsidies, tax credits and holidays, and loan guarantees have caused the solar PV market to bloom among the “green-minded middle class and rich,” while in the Global South, decentralized renewable electricity is predominantly used by “disenfranchised communities in distant off-grid counties” (Hankins, 2013). However, these perspectives on rural renewable energy policy implementation are changing as drivers such as energy security and access increase in priority, costs for renewables plummet, and coastal vulnerabilities as a result of sea level rise come to the public’s attention. As has been shown in some of CEEP’s previous work in the Chinese off-grid energy sector (Byrne et al., 2004, 2007), realizing the institutional barriers obstructing widespread implementation of renewable energy technologies for energy access, sidestepping them with clever policies to create strong economic and financial incentives for renewable energy implementation, and allowing energy policy to take a national priority will allow emerging market nations to capitalize on their resources and spur economic growth.

Many ambitious publically-sponsored rural electrification projects have been limited in their ability to implement or finance projects and often get de-prioritized on the national agenda when competing against job growth, corruption, or national security for attention and funds (Sovacool, 2012a). Even in rural states and municipalities, creation of a favorable policy environment is difficult because of low population densities (which represent weak clusters of electricity demand and political capital), ineffective government spending and corruption, lack of civic engagement or

community support (Alstone et al., 2015), and economic barriers to the rural poor that stifle impacts of programs. Struggling to pay interconnection fees, inability to afford upfront costs of household appliances, or fear of making fixed infrastructure investments without property rights and zoned land (Alstone et al., 2015) may prevent some underfunded or poorly-planned government initiatives from reaching their electrification targets. Despite these hurdles, it is clear that public institutions have a major role to play in energy access markets (Jain et al., 2015), especially when policies are contextually targeted to benefit marginalized populations (Madubansi & Shackleton, 2006). Governments can create or influence markets by regulating them into existence (or oblivion) and incentivizing the private sector to fill a market gap by sweetening their returns.

Part of this role is the **institutional regulation of utility energy services**. Many state-owned utilities in developing countries often already face difficulty to maintain financial viability and even just to balance load and avoid unplanned outages with insufficient generation assets, making their often contradictory obligation to subsidize energy prices for the poor a struggle to satisfy (Kaygusuz, 2011). Often, utilities in these situations will limit coverage only to regions and households that will be profitable, suggesting that poor households may need regulatory protection in the form of low access charges, lifeline rates, and low cost wiring (Cecelski, 2000). For example, Nigeria privatized their generation and distribution assets in September 2013 in response to these issues with public sector management of national power assets (Soleye, 2014). However, despite the newly for-profit firms in the industry, reliability

is still abysmal and still over half of Nigerians are without access to electricity (Soleye, 2014). As a result, most electricity consumed is generated by small expensive private diesel and petrol generators, and when prices are fixed, shortages and some of the most expensive electricity in the world result (Soleye, 2014). The power situation in Nigeria is a relevant example of the required balance between good governance and regulation with allowing market forces to work. Renewable energy systems or rural micro-grids may also be poorly understood by regulators, but interconnection policies and the expected timeframe for the grid to reach the village have substantial influence over the business model used to finance and operate the micro-grid (Chaurey et al., 2004). This can also lead to ambiguous legal status for some micro-grid projects, especially those operated or maintained by their communities (Bhattacharyya & Palit, 2014). Clear, contractual concessions for micro-grid service providers can incentivize suppliers and help ensure the bankability of projects (Hornor & van Gerven, 2015). While it may seem that these regulations do not extend to rural, off-grid areas, it seems that a plurality of centralized and de-centralized regulatory schemes cover off-grid projects at the mini-grid scale. Favorable electricity market regulation is a necessary prerequisite for most private sector investors interested in micro-grid projects, whether grid-tied or islanded.

Institutions also have a role of **creating and shaping supportive energy markets to energy access through incentives**, which often take the form of subsidies or tax holidays. If the political economy of a regional or national government's energy

sector is aligned with tackling energy access, market interventions can be carefully enacted (Blum et al., 2013; Khennas, 2012; Mainali & Silveira, 2012). Some recommended incentive-based policies are listed below:

- Eliminate import and capital taxes on rural (renewable) energy systems, exempt capital from import duties and value-added taxes (VATs) (*see* Glemarec, 2012; Mainali & Silveira, 2012; and Nepal, 2012)
- Exempt systems from grid interconnection fees and service tariffs (*see* Glemarec, 2012; and Nepal, 2012)
- Streamline licensing and permitting to reduce balance-of-system (BOS) costs (*see* Glemarec, 2012)
- Redirect fossil fuel subsidies gradually to capital costs of renewable energy systems (*see* Glemarec, 2012)
- Promote entrepreneurship and income-generating activities (*see* Blum et al., 2013; and Glemarec, 2012)
- Sponsor and insure an energy microfinance network (*see* Rao et al., 2009)
- Earmark an ‘Energy Poverty Alleviation’ fund (*see* Sagar, 2005)

Additionally, coordinating the delivery of energy services with other services that require energy, such as education or health initiatives can ensure an anchor load and reduce overhead costs (*see* Chaurey & Kandpal, 2010). Involving stakeholders “ from village residents, via potential investors, the financial sector, technology providers” will help to ensure that the existing institutional structures will adapt to appreciate the specific needs of the populations served (Blum et al., 2013, p. 492; Gómez & Silveira, 2012). As seen in some successful rural electrification programs¹³, these policy

¹³ Some notable examples of rural electrification programmes and helpful references: Nepal’s Biogas Support Programme (Glemarec, 2012); Brazil’s Luz Para Todos Programme (Gómez & Silveira, 2012; Pereira et al., 2010b); India’s Rajiv Gandhi Grameen Vidyutikaran Yojana Programme (Balachandra, 2011; Bhattacharyya, 2006).

measures can create and foster a supportive environment for rural energy development, notably powered by decarbonized energy sources such as solar PV.

Internationally, **global climate change policies** can help to funnel investment into vulnerable countries for renewable energy electrification. Several recent case studies suggest that a number of African countries will be able to capitalize on the “evolving international global climate policy and resources to lower the carbon intensity of their growth while maximizing local and environment and development benefits” (L Agbemabiese, 2009; L Agbemabiese et al., 2012). Further, partnerships between major greenhouse gas emitters and underdeveloped countries, such as the U.S.’s Power Africa initiative, can be leveraged to accelerate clean energy development.

The institutional-economic dimension of energy access faces significant variation across different jurisdictions, but best practices for leveraging policy to create a supportive market environment for rural renewable energy project development to occur are easily transferrable, and vibrant partnerships between relevant stakeholders will ensure that needs are met appropriately and legally. A brief characterization of a number of key institutional-economic barriers and risks appears below.

See (Balachandra, 2011) Table 1 for a comprehensive list of rural electrification efforts in India to 2011.

3.5.1 Lack of Institutionalized Support for Rural Electrification

Creating a favorable policy environment is a necessary pre-condition for successful rural energy access solutions implementation. Without a favorable policy environment, thin rural markets and high, un-moderated risk profiles effectively eliminate the likelihood of a financeable endeavor. Some contexts face barriers because the jurisdiction does not have any institutional capacity dedicated to rural electrification at all (Franz et al., 2014). A lack of supportive import duties or subsidies for rural electrification or renewable energy can also push investors to countries with more lucrative regulatory environments (Bhide & Monroy, 2011; Glemarec, 2012a). Since most rural energy generation technology has a project lifespan of at least 20-30 years, the risk of an institutional paradigm shift is very high; as a result, fluctuating or unstable regulatory environments indicate a high likelihood to investors that tariff structure, subsidies, lack of corruption, and other similar benefits will evaporate before the investment reaches the end of its useful life (Franz et al., 2014; Gershenson et al., 2015). Tariff reform can occur due to governance changes, political pressure, or deregulation of energy markets. Political risk insurance is a common risk mitigation strategy in these cases, and is often required by international debt and equity providers, though generally only for larger scale projects and portfolios of projects (Gershenson et al., 2015). The transactions costs and risks of developing renewable energy projects in countries in the midst of political or institutional change or instability are significantly higher than in stable and supportive regulatory environments.

3.5.2 Institutional Capacity Gaps

In other contexts, institutional capacity is simply inadequate due to lack of clarity, poorly designed incentives, lack of funding, or suboptimal legal conditions. Understaffed or underfunded rural electrification agencies can take nearly six months to grant an operating permit in some countries (Gershenson et al., 2015). Conversely, ineffectual or overly bureaucratic government agencies may prove even less effective, and represent a different form of capacity gap (Schmidt et al., 2013b). Capacity gaps can exist at the government level and the market level as well as at the user level when interacting with policy, especially when it comes to understanding incentive programs for renewable energy systems (Best, 2014). Clearly and simple government policies and incentives can help to close these knowledge gaps. Further, underdeveloped legal and policy frameworks, inability to direct foreign aid receipts effectively, or insufficient enabling policies for technology transfer and local development, importation of debt financing and technology, and cross-border trade may also inhibit rural energy access along the institutional-economic dimension (Gujba et al., 2012).

3.5.3 Unfavorable Political Will or Instability

Another major issue regarding the stability of the enabling environment for rural energy is the political aspect of the institutional-economic dimension. In countries with dedicated and sufficient institutional capacity, regulatory barriers such as inflexible state-sponsored utility regulations, non-uniform or poorly enforced quality standards, corruption, backlogged licensing and permitting processes, and corruption can stifle project development and spook investors (Bhide & Monroy, 2011; Franz et al., 2015; Schmidt et al., 2013b; Sovacool, 2012a; van Campen et al., 2000; Walker, 2008). Uninformed or misinformed politicians, corruption, political

patronage, or economic dependency on fossil fuels may hold political will at arm's length from rural energy access (Franz et al., 2015; Sovacool, 2012a). Additionally, many countries have powerful entrenched interests that actively seek to maintain their market share, such as diesel fuel moguls in many East and West African countries, including The Gambia, Eritrea, and Nigeria. Regulatory red tape and strong social and environmental opposition have stonewalled many renewable energy capacity-building efforts.

In the other direction, unrealistic political commitments can also be barriers to project development because they create instability for investors when they are not kept (Bhide & Monroy, 2011). Political instability can also greatly increase investment risk and allow power purchase agreements (PPAs) or other contracts to be breached or voided (Roy et al., 2010). Alesina, et al. conducted a joint study between Harvard University and Yale University, under direction from the National Bureau of Economic Research, and concluded that in “countries and time periods with a high propensity of government collapse, growth is significantly lower than otherwise” (Alesina et al., 1996). This relationship is logical, as political instability will eliminate investment domestically and from abroad, displace labor, and create price volatility. Political instability and stalled energy sector reforms limit infrastructure investments in contract with sharply increasing demand for power in Egypt, Algeria, Tunisia, Libya, and Morocco (Frost & Sullivan, n.d.). Finally, fragmentation in energy policymaking and integration obstacles for new generation capacity can prevent clear direction and efficacy of political will (Sovacool, 2012a).

Institutional-economic factors are necessary in order to secure financing and allow projects to have stable financial viability with minimal risk. Governments that

support the sector with subsidies, import duty breaks, and clear frameworks to fill capacity gaps for users can greatly accelerate sector growth.

3.6 Why the Multidimensionality of Energy Access Matters

Recognizing the nature of the energy access problem and identifying and categorizing these dimensions and barriers should help policymakers, project developers, and other practitioners understand gaps, ensure protection from risks, and recognize and operate under the understanding that energy access is a multidimensional problem. By appreciating this nature of energy poverty, theory, methodology, and practice can meet to circumvent these barriers, and a multidimensional understanding of energy access powerfully and holistically informs market entry strategies, especially for community-driven solutions.

However, when ignored, these barriers often create a vicious cycle: “high investment costs, lack of financing mechanisms, low volumes of sales, high transaction costs, lack of infrastructure, lack of familiarity, and lack of political commitment and adequate policies” (van Campen et al., 2000, pp. 9–10). Using this multidimensional framework to understand energy access interventions will facilitate greater scalability in public initiatives and attract private investment to energy access projects while nimbly accounting for the variation across each of these four dimensions. Without recognizing the multidimensionality present in the problem, mono-dimensional solutions will unexpectedly encounter barriers in other dimensions not accounted for, and will decelerate or stall in the process. The inherent value of this

framework is to inform the crafting of market entry strategies from both the public and the private sector and promote understanding of the true nature of the problem to more efficiently and deftly reach universal energy access. Figure 3 represents the multidimensional framework presented above:

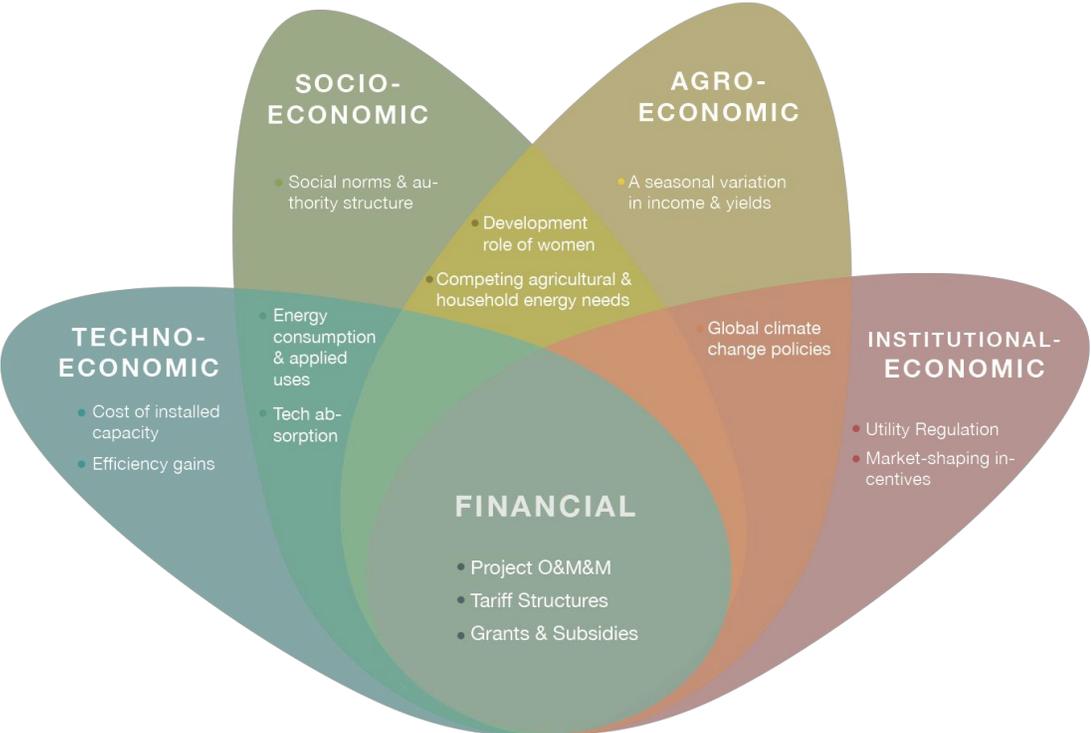


Figure 3: The Multidimensional Framework for Energy Access

Characterizing the barriers inherent for each dimension yields some key lessons for policymakers. First, countries with low electrification rates must prioritize energy access on the political agenda. Balance-of-system (BOS) costs are the largest cost component in many developed countries, including the United States, and can be significantly driven down by favorable regulatory and incentive policies that attract private investment (in stable and politically cooperative environments). UNSE4ALL

calls for \$34B/yr, about 3% of annual global energy infrastructure investment. (Best, 2014; “Energy for all: Financing Access for the poor,” 2011). Clear policy goals, electrification targets, and monitoring and reporting will ensure that investment that’s attracted translates to social change through implementation (“Energy for all: Financing Access for the poor,” 2011). To realize the considerable potential for stepping up the proportional involvement of the private sector, national governments need to adopt strong governance and regulatory frameworks and invest in internal capacity building. This will help them to identify bottlenecks in the rural energy value chain and design smart incentives to support micro-enterprise and improve access to rural credit (Best, 2014; Nepal, 2012).

More generally, this multidimensional framework provides lessons for a deeper holistic understanding energy access. First, in order to understand needs, start with women. They often hold greater responsibility for backbreaking household or agricultural tasks, and access to electricity can have a likely larger marginal impact on their livelihoods than men.¹⁴ Second, energy use and energy needs vary widely, and homogenizing solutions ignores constraints on technology and cost, social structure and roles, smallholder efficiency gains, and policy environments, which can lead to

¹⁴ In fact, the UN FAO estimates that if women generally had the same access to productive resources as men – including energy and equipment – they could increase yields on their farms by 20–30%, raising total agricultural output in developing countries by 2.5–4% (*The state of food and agriculture*, 2011).

ineffective public programs or overly risky private investments. Kaygusuz (2011)

supports this view eloquently:

“Energy services for poverty reduction are less about technology and more about understanding the role that energy plays in people’s lives and responding to the constraints in improving livelihoods...Energy needs should be considered within the overall context of community life, and energy policies and projects should be integrated in a holistic way with other improvement efforts relating to health, education, agriculture and job creation. Policies, programs and projects should start from an assessment of people’s needs rather than a plan to promote a particular technology. The needs of different rural communities vary widely, and finding appropriate technologies and effective implementation strategies can be very site-specific” (Kaygusuz, 2011, p. 947).

In context, this view points to the pivotal significance of the community in the decision-making process for energy project development. Rural energy needs and technology preferences, cultural factors, acceptance of project, demand and willingness to pay, end-user financing, and recurring operations and maintenance costs all intersect with community-driven decision making processes. Practitioners, then, would do well to partner with local banks, microfinance organizations and NGOs who know the specific target population and their needs. It is impeccably clear to the author that the role of community-driven decision making on both a theoretical and practical level is disproportionately underrepresented in the literature. Ultimately, however, any scalability or duplicability of a (capital-intensive) energy access intervention in this scale is dependent on financing in order to come to fruition, which will be addressed in the next chapter.

Chapter 4

MICROGRID PROJECT FINANCING AT THE INTERSECTION OF MULTIDIMENSIONALITY

Financing is a key to unlocking new rural markets for micro-grids, and, for this study, it plays a central role in designing this multidimensional framework of energy access. Due to their capital intensity, the long-term sustainability of rural energy programs is highly dependent on the degree of cost recovery realized by the project sponsor, especially with respect to recurring costs such as operations costs and preventative and corrective maintenance costs (see Franz et al., 2015; Kirubi et al., 2009). As Williams, et al. (2015) argue, the role of private sector investment in micro-grid- based rural electrification projects is critical due to the large amounts of capital relative to the public sector and philanthropic agents for this type of capital-intensive development (Williams et al., 2015). The often high cost of components and various physical vulnerabilities of a local distribution system such as the micro-grid schematic pictured below can exacerbate the need for innovative business models¹⁵. The degree of cost recovery and the nature of the project sponsor are determined by the business model and ownership structure used to implement the project, discussed further below.

¹⁵ The schematic below represents one of many kinds of community-scale energy access intervention. Other schemes, including centralized battery and lantern charging stations, interconnected rooftop PV, etc are also feasible though not explored in this study.

However, these implementation strategies depend fatally on their ability to secure financing, with few exceptions. The centrality of both financing and community is inherent in the successful implementation of the economic and energy poverty combating PV-powered micro-grid.



Figure 4: Simplified Schematic of a Rural PV Micro-grid

Source: (Enterprise, 2014)

4.1 Mobilizing Investment to Address the Current Financing Gap for Rural Micro-grids

Traditional rural electrification initiatives have been focused on extending the centralized grid infrastructure to rural areas. However, due to factors that have been detailed in previous chapters (such as low population density, low ability to pay, low access to credit, low demand, and high system losses and transmission and distribution costs, among others), private or investor-owned utilities are nearly always hesitant to engage in this type of expansion because it threatens commercial profits. Instead, recent rural electrification efforts have focused widely on SHS and pico-solar

interventions. However, micro-grid scale investments have fallen into a “grey space” of financing: too small for project finance, due to the thin market density, they are outside the realm of corporate finance, and they are in between World Bank funding¹⁶ and NGO-scale work (Gershenson et al., 2015; Kraemer, 2015). It is only within recent years that islanded, rural micro-grids have come into focus as a viable private investment to cost-effectively support productive uses of energy.

Estimates of the scale of the micro-grid-based energy access market vary, but ultimately tell the same story. The IEA estimated that about 140 million people will gain access to electricity through micro-grids by 2040, requiring the development of between 100,000 to 200,000 new systems and an enormous amount of capital (Franz et al., 2015; *World Energy Outlook 2014 Factsheet: How will global energy markets evolve to 2040?*, 2014). Currently, the SE4ALL initiative estimates that in the absence of significant total energy access investment between 2010 and 2030 will average \$14 billion per year, mostly devoted to new urban grid connections. (IEA, 2011; UN Sustainable Energy For All Initiative, n.d.). However, the report calls for an increase to \$48 billion annually (\$12 billion of which is for micro-grids) in order to achieve universal energy access across all methods, for a total price tag of \$1 trillion through 2030 (IEA, 2011; UN Sustainable Energy For All Initiative, n.d.). Bazilian, et al. put the gap between \$12-134¹⁷ billion per year (Bazilian et al., 2010). In Sub-Saharan

¹⁶ General project minimum investment is \$20 million (Kraemer, 2015).

¹⁷ “While \$134 billion may seem an impressive number, this is less than 0.2% of the asset base of institutional investors world-wide and slightly less than 1% of US GDP. To put this into further perspective, the annual sales of Wal-Mart, and 10 other multinational corporations (including Royal Dutch Shell, BP, Volkswagen, and Chevron), all exceeded \$200 Billion each, in 2013” (Gershenson et al., 2015, p. 14).

Africa specifically, the World Bank estimates (a bit disproportionately) that \$11 billion per year of investment is required for universal energy access by 2030 (Brew-Hammond & Kemausuor, 2009). While these numbers reported by the IEA, the World Bank, the SE4ALL initiative, and Bazilian et al. do not fully align in synchronized periods of analysis, geography, or technological scope, they are clearly illustrative of the need for a massive capital infusion into a market that represents an enormous proportion of the global population. It is clear that the current resources and attention devoted to energy access are “not at all commensurate with the magnitude of the problem” (Sagar, 2005, p. 1368). Inflows from financial markets, which total \$511 million to date (though largely to small pay-as-you-go (PAYG) companies), have increased sharply in recent years, but mobilizing the enormous quantities of financing that are needed, especially from public sources, however, will be quite difficult (Glemarec, 2012a; “Off-grid solar market trends report 2016,” 2016).

On the other side of the debate, oil subsidies in Africa alone total an estimated \$50 billion per year, and 65% of subsidies in Africa benefit the richest 40% of households (Munang & Mgendi, 2015). Because these values also represent nearly 6% of Africa’s GDP and outpace spending on health interventions, Munang & Mgendi, among others, argue for a reallocation of fossil fuel subsidies towards economically inclusive and environmentally sustainable renewable energy technologies (Munang & Mgendi, 2015). It is also estimated that institutional investors currently have approximately 71 trillion dollars in assets (Gershenson et al., 2015), which could be redirected towards a massive, untapped market.

However, access to capital for investing in rural markets is a major barrier because the financial risks of rural markets can exceed the risk appetite of most

investors. As a result, initial solutions have often been achieved under donor-push strategies rather than market-pull strategies (Chaurey & Kandpal, 2010). Prohibitively high initial costs, the difficulty in securing no-recourse debt domestically, and importing international debt financing stifle the process and result in inefficient development (Alstone et al., 2015; S. N. Rao, 2016). Financing barriers will be discussed in more detail below in Section 4.4. Despite the financing gap, it is important to recognize the dynamics of these project economics in order to build a clear financial case for community-scale micro-grids. The following few sub-chapters will build this case.

4.2 Factors in the Creditworthiness of Rural PV Micro-grids

4.2.1 General Project Economics

Financial viability for islanded micro-grid systems is, in principle, the ability cover all investment costs and operations, maintenance, and administration & management (O&M&M) fees with electricity sale revenues through connection fees and tariff structures and through subsidies or grants (where applicable) for the duration of the project life. Investment costs can encapsulate fixed capital costs, other variable costs, and financing and transactions costs. Fixed costs typically include the capital costs and depreciation of generation and distribution assets, local management, operation and security costs, monthly tariff collection costs, fixed technical losses¹⁸, debt payments, infrastructure taxes and fees, and overhead costs for the project (Franz et al., 2014). Overhead and transactions costs “accrue through administration,

¹⁸ Fixed technical losses include the “self-consumption of inverters, batteries, iron losses of transformers, etc.” (Franz et al., 2014, p. 42).

coordination, social and technical problem solving, bookkeeping, reporting (to donors, lenders and authorities), and hospitality to high-ranking guests” (Franz et al., 2014, p. 42). Variable costs for micro-grids increase with demand, and include such costs as fuel costs (in the case of diesel systems), output-specific maintenance costs, battery depreciation, revenue- or energy-related taxes, and load-dependent technical losses¹⁹ (Franz et al., 2014). Variable costs depend on factors that influence demand, such as seasonality and its influence on lighting, cooling and heating and agricultural loads (crop cycles), efficiency of appliances and productive use machinery, and special community events such as festivals or weddings (Franz et al., 2014). Supply factors are obviously technology-dependent, but in general they can include weather data (e.g: irradiance or wind resources), fuel cost, output-improvement measures (such as adjusting tilt of solar array seasonally, and regular maintenance and inspection to minimize outage times.

.WTP surveys in some parts of Africa have indicated a high correlation with the quality of service, up to the cost of self-generation, even if it is above the grid tariff rate (Franz et al., 2014). Because of the high costs of kerosene and LPG, consumer WTP is almost always at or above levelized supply cost (Torero, 2014). Though many regional factors can skew this number, typically, micro-grids deliver power between \$0.20-\$0.50 per kWh (Bardouille, 2012). This is quite a high price range compared to much of the developed world, but prices even in this range often represent significant cost savings to households that use low quality energy sources. At minimum, tariffs

¹⁹ Load-dependent technical losses include the “conversion losses of inverters, copper losses of transformers, [and] battery storage losses” (Franz et al., 2014, p. 42).

must encapsulate operating costs in order for an energy access program to be sustainable (Brew-Hammond, 2010).

4.2.2 Tariff Structures

Tariffs rates and structures are dependent on the project economics because the levelized cost of energy (LCOE) plus, perhaps an overhead markup, is likely to dictate the rate charged to customers. In an off-grid micro-grid, the project developer, rather than the public utility, will set the tariff, which is not necessarily the same rate set by the utility. The third-party developer will often pay concessions or reach a public-private partnership with the state-owned utility, such as the case of PowerHive and the Kenyan national government (Hornor & van Gerven, 2015). Because of the financial unattractiveness of rural markets, some countries have bundled concessions for urban and rural markets to private generators and independent power producers (IPPs) (Williams et al., 2015). Connection fees are also an important part of the tariff structure to ensure the commitment of customers to payment (Williams et al., 2015). Stable, reasonably priced tariffs that can undercut currently high cost, low quality energy expenditures and ensure sustainable and predictable growth in micro-enterprises. In context of simple economic theory, the most fundamental feature of a successfully implemented tariff structure is that it is proportional of consumption on a per-unit basis. Without this structure, there is very little incentive to conserve electricity. See Casillas & Kammen (2011) for a case study that draws similar conclusions. Table 4 below breaks down some different possible tariff structures:

Table 4: Possible Islanded Micro-grid Tariff Structures

Tariff Structure Basis	Design
Energy Consumption	Depends on the measured kWh consumed
Stepped Consumption	Tariff rate varies depending on tiers of consumption.
Expected Power	Flat monthly rate based on expected power consumption, which can be based on number of appliances or bulbs.
Customer class	Tariffs vary depending on consumer group, i.e. households, small and medium enterprises (SMEs), or community uses. Used most often to cross-subsidize residential consumption.
Progressive	Tariff rates rise as consumption rises. Used by utilities to cross-subsidize lifeline ²⁰ households' connections.
Regressive	Higher consumption results in lower tariffs. Used to encourage medium-to-large scale industry growth, and generally not applicable to rural contexts.
Time-variable	Tariffs vary based on peak loads for the purpose of demand-side management.
Flat-rate	Not based on consumption. Simply a fee for connection with unregulated use.
Flexible	Tariffs change according to demand, incentivizing off-peak use. Requires advanced energy metering systems.

Adapted from Franz, et al. (2014)

²⁰ A 'lifeline' electricity connection is a heavily discounted utility-set electricity rate for basic levels of consumption for very low-income communities, which ramps up progressively if consumption exceeds the threshold (Burgess & Paglin, 1981).

In a community management setting, tariff structures likely will also take ability-to-pay into consideration, and therefore may reach operational viability while struggling to reach financial viability (Bhattacharyya & Palit, 2014). From experiences in South Asia, community boards often decide to use flat-rate, expected power, and energy consumption to meet costs of the project (Bhattacharyya & Palit, 2014). For a project manager, repayment risk would theoretically be minimized in a prepaid flat-rate tariff structure, but because this tariff does not incentivize energy conservation, it may pose greater risks, such as load management risks.

In rural settings, per kWh tariffs can range widely from \$0.08 to \$1.40 depending on generation technology, business model, regulatory environment, incentives, and sources and costs of financing, but in most cases fall in the \$0.20-\$0.50/kWh range, as stated above (Bardouille, 2012; Franz et al., 2014). An often overlooked cost that can affect these LCOE values is the transaction cost elements associated with government interaction, community engagement, and negotiation with financiers. Tariff rate design can play a significant role in navigating the risks associated with thin rural markets.

4.2.3 The Role of Grants and Subsidies

Subsidies and grants from governments, rural electrification agencies, development banks, and NGOs often greatly improve the project economics of a rural micro-grid system and make them viable. Especially for debt-laden projects, grants and capital expenditure subsidies can accelerate the breakeven point and open doors to cheaper financing or improved project economics. These often support the capital or operating expenses of projects (Williams et al., 2015) to achieve equity IRRs of 15-20% in order to attract matching investments, and can be delivered for any stage in the

project from pre-investment to construction to covering connection fees for lifeline customers (Bardouille, 2012; Franz et al., 2014). Support can look like a government cost partnership such as the Community Rural Electrification Program or the Subsidy Policy for Renewable (Rural) Energy in Nepal (Gurung et al., 2012). Williams, et al. (2015) also advocate for coupling public subsidy programs with an enabling environment for private investment (Williams et al., 2015). For community-led micro-grid projects, donor grants often bolster the IRR to an acceptable level to attract matching investments. These donor grants, which generally comprise 40-50% of project costs, are especially effective when the grant disbursement rules are not too rigid to be able to adapt to local realities in rural areas (Mainali & Silveira, 2012). When community-led projects depend on subsidies to maintain solvency, the policy has created an unsustainable livelihood, which can put future quality of life increases at risk as subsidies are scaled back over time (Mainali & Silveira, 2012). Further, these capital subsidies have come under criticism, primarily in the context of community ownership, as “there is evidence that indicates that projects fully financed by the owners and beneficiaries are more likely to be well taken care of” (Williams et al., 2015). However, as communities experience economic growth as a result of electrification, local equity can replace the currently keystone necessity of external aid. In India and Nepal, as is likely indicative elsewhere, credit from local financing institutions and development banks is most often matched through subsidies, other government contributions, and community equity (Bhattacharyya & Palit, 2014; Mainali & Silveira, 2012). While rural markets may be thin and savings rates may be low, communities are often able to contribute their own personal equity into development projects to help bridge the cost gap with respect to energy access. In fact,

some communities go so far as to reject operational subsidies because they create recurring government dependency (Franz et al., 2014). In Nepal, communities have been recorded contributing about 18-20% of personal equity, and in Liaoning, China, 96% of household rural energy investments were self-financed (personal savings or intra-family loans), and in Yunnan, communities matched government subsidies 20:80 (Byrne et al., 2004; Mainali & Silveira, 2012). This will be discussed in more detail in Section 5.3.

Due to the long-term and heavily regulated nature of subsidies, transparent subsidy (and tariff) setting processes are critical for providing certainty to concessionaires and protecting consumer interests (Williams et al., 2015). Subsidies are meant to be phased out in the long run, and lowering transactions costs and involving community stakeholder resources can accelerate sustainable livelihoods without dependence on subsidies for projects to be viable.

4.3 Micro-grid Project Financing

In this study, the social purpose of injecting financing into rural energy markets is to remove barriers that affect marginalized people and address gaps in support services (Hunt et al., 2010). One of these major barriers is access to cheap financing, which can be difficult because micro-grids often have low margins and high risk and are not large enough for many forms of cheap financing, such as mezzanine capital structured as unsecured debt or preferred stock with specified payments (Gershenson et al., 2015). It is also helpful to understand the profiles of social entrepreneurs and private equity investors who may have interest in these projects. Most socially motivated equity investors are looking for an IRR of at least 12 percent and an equity IRR of 16 percent, and would only accept lower IRRs for a project with

highly stable and predictable cash flows, which is not necessarily the case with rural micro-grids (Franz et al., 2014). The risk/return profile of these projects is the ultimate determinant of the availability and price of financing, as well as the operating model, track record, perceived scalability, and potential market size (Franz et al., 2014; Schmidt et al., 2013b). Of course, from the project's perspective, the most appropriate type of financing solution and source varies by similar factors (*see* "Energy for all: Financing Access for the poor," 2011, p. 32). Public organizations, private financiers, local credit unions, and international investors all have important roles to play in developing mature financial markets in developing nations that can provide the project finance needed at the "scale and tenor of infrastructure projects of this type" (Brew-Hammond, 2010; Fischer et al., 2014, p. 14; Gujba et al., 2012).

Because different types of financing mechanisms are appropriate for different projects, it is important that financing addresses the full range of possible consumers. The most commonly used forms of private financing for energy infrastructure are equity, debt, and mezzanine finance, and the SE4ALL Initiative estimates that between 5-20% of funds in this category go toward providing energy access ("Energy for all: Financing Access for the poor," 2011). However, because there are information barriers on the technical and financial feasibility of micro-grids, debt for these projects from local financial institutions is often prohibitively expensive, with offered interest rates from 10-24%, often averaging around 16% (Franz et al., 2014; Mainali & Silveira, 2012). For this reason, technical advisory paired with secured financing is a worthwhile expense (Gujba et al., 2012). Financing on the scale needed for universal energy access by 2030 as estimated by the SE4ALL initiative will require many different sources and types of financial support in order to realize this possibility.

Some of the most common types of financing instruments for infrastructure development projects are summarized in **Table 5** below:

Table 5: Types and Sources of Financing Instruments for Energy Access

Financing Mechanism	Brief Description	Possible Sources
Debt financing	Borrowed capital on which an interest rate is levied. As confidence in the technology increases, longer-term debt structures may lead to non-recourse debt.	Development Finance Institutions (DFIs), International banks, Local banks (though terms are often unfavorable), development funds, impact funds, and ‘crowd funding,’ which can provide loans at about 5% (Franz et al., 2014; Gujba et al., 2012; Kraemer, 2015).
‘Base of pyramid’ Consumer financing	Capital and small loans for small-scale investments for end-users, often under flexible lending conditions. Works well with women’s groups (e.g. Grameen Shakti, Vietnam Women’s Union, Uganda Women’s Bank).	Despite high transactions costs, microfinance institutions (MFIs) have the potential to scale financing of small, pooled investments in clean energy systems. (Cecelski, 2000; “Energy for all: Financing Access for the poor,” 2011; Gujba et al., 2012).
Revolving Fund	Mainly used towards capital-intensive activities such as infrastructure development, a revolving fund replenishes itself with its own funds, allowing it to continually grant new loans, using the interest to offset risks and manage the loan pool.	Development organizations and NGOs can construct revolving funds by linking small MFIs or savings and lending groups. Not often used by governments and not often allowed to result from donor grants. (Franz et al., 2014; Gujba et al., 2012).
SME Financing (Loan Guarantees)	A guarantee to assume part or all of the debt of a borrower if they default. Require no upfront cost to the guarantor but represent a heavy financial burden in the event of default. Can contribute to long-term local financial market development.	Multilateral and bilateral DFIs, state-owned or commercial loan guarantee agencies, as well as development banks, often grant preferential loan guarantees to companies deemed ready for expansion, replication, or scale-up (“Energy for all: Financing Access for the poor,” 2011; Gujba et al., 2012; Williams et al., 2015).

Equity Financing	Trading capital investment for a vested and proportional ownership stake in a company.	Equity investors include angel investors, hedge funds, and private equity firms, development banks, and national governments. Also more active in decision-making and expect a ROI greater than 20% (Gujba et al., 2012).
Venture Capital	A partnership between firms investing in capital and participating in early stages of enterprise development and management.	Venture capital-specific firms are very involved in early strategic management and demand a very high return in response to high risk and uncertainty. (Gujba et al., 2012).
Combined Instruments	Combined financing instruments such as debt financing and through loans and investment bank bonds may allow for cheaper financing costs or greater overall scale of financing.	Credit agencies, investment banks, development banks, and even state-owned utilities may be interested in this option, but combined instrument financing would be difficult to secure for a community-scale micro-grid project. (“Energy for all: Financing Access for the poor,” 2011; Gujba et al., 2012).
Carbon Financing	Revenue is raised through sale of carbon emissions credits under the Clean Development Mechanism (CDM) or other voluntary or regulatory carbon credit programs.	Multilateral development banks, foundations, investment funds, represent a very small proportion of energy access financing (0.2%) (“Energy for all: Financing Access for the poor,” 2011; Williams et al., 2015).
Concessional Financing	Development loans for less developed countries with subsidized terms and flexible repayment in order to spur development. Can hold first-loss position to improve structured finance prospects. Lender assumes default risk at reduced premium.	Multilateral and Bilateral DFIs, impact investors, commercial investors, (Bardouille, 2012; “Energy for all: Financing Access for the poor,” 2011; Franz et al., 2014; Gershenson et al., 2015; Williams et al., 2015).
Grants and subsidies	Grants and subsidies are targeted funds used to reduce capital costs, operating costs, or financing costs for infrastructure projects.	National and provincial governments, rural energy agencies, state-owned utilities, and multilateral and bilateral development banks, foundations (“Energy for all: Financing Access for the poor,” 2011; Williams et al., 2015).

It is difficult to match these financiers with the risk and reward profiles of these projects, even as they vary from construction financing to performance subsidies to ensure operational viability. Often, when the business case for a micro-grid project is marginal, governments or DFIs can step in to enhance the deal or guarantee investment returns in order to leverage private sector resources. The following section will address the barriers to financing energy access through a multidimensional lens.

4.4 The Financial Dimension: Barriers and Risks

Barriers to adequate financing can smother the impact of energy access interventions and are key constraints to accelerating market development in these areas. For reasons discussed below, capital intensity, high transactions costs, underdeveloped domestic financial markets, financial remoteness, and carbon financing barriers have the ability to limit capital from reaching these projects.

4.4.1 Capital Intensity of Energy Development Projects

As with nearly every other form of infrastructure development, renewable energy micro-grids are highly capital-intensive development projects, often costing between \$2.00-\$5.00 per W_{dc} of installed capacity (Franz et al., 2015). Most community-led or start-up projects lack sufficient capital for investment, defining these projects dependence on loans to defray the high capital costs (Nepal, 2012). One of the major financial bottlenecks for these types of projects is the construction phase, which usually locks up cash, preventing debt and equity payments from being made, and exposing the project to exacerbated risks such as institutional risks, civil conflict or instability, and force majeure events (Gershenson et al., 2015). While this period is

generally rather short for micro-grid projects (a matter of a 2-4 weeks), a locked cash position increases the vulnerability of the entire project. Capital intensity as a whole makes financing more difficult to secure, however, due to thin rural markets that may have fluctuating demand, willingness-to-pay that varies by community, and a climate or geographic location that demands repairs more frequently than normal.

4.4.2 Transactions Costs

Because of the multidimensionality of energy access, nearly every rural renewable micro-grid project requires an entirely unique set of pre-investment costs. Because it can be quite onerous for financial institutions to truly evaluate risk under the burden of these costs, it is likely that many bankable (or grant-eligible) projects are overlooked due to their smaller size (Gershenson et al., 2015). The diligence costs associated with deploying capital in high-risk environments such as rural developing markets are often cost prohibitive. These costs include identification costs to source potential projects, diligence costs²¹ to know creditworthiness and contextually-appropriate operational models, development of legal, accounting, and insurance platform costs, and tax and corporate structuring to enable the project company to exist and operate legally in the proper jurisdiction (Gershenson et al., 2015). Once pre-investment transactions costs are addressed, there are yet still significant transactions costs in the securing of financing from multilateral and bilateral sources. These include the regulatory capacity necessary to enable countries to absorb increases in development financing and private investments and apply them within the applicable

²¹ Gershenson, et al. (2015) report that diligence costs are estimated at 30,000-150,000 Euro per project (p. 43).

criteria and the reordering of development priorities that may be required of governments (“Energy for all: Financing Access for the poor,” 2011).

4.4.3 Financial Remoteness

A lack of end-user financing is possibly the longest-recognized challenge in energy access. Even other small loans in rural areas for non-capital-intensive uses are often tied to exorbitantly high rates and aggressive and sometimes even violent loan sharks. Low levels of economic activity, high levels of income poverty, and general lack of physical or information infrastructure development create situations where access to any form of consumer credit, let alone project financing, is prohibitively expensive (Bhide & Monroy, 2011; Franz et al., 2014; Schmidt et al., 2013a; van Campen et al., 2000). The sparse, underdeveloped, and prohibitively expensive investor network can isolate knowledge and prevent implementation of best practices, or even simply awareness about effective rural electrification projects using micro-grids. In many rural areas with low population density, there is rarely a banking system at all.

Lack of affordability of rural energy projects without access to financial resources and credit can be fatal factors to successful implementation (Nepal, 2012). Especially for smaller micro-grid projects, interest rates are often prohibitively expensive. Those from micro-financiers can near 30%, and rural banks can approach 15% for medium-term loans (Tomei & Gent, 2015). And even this overpriced capital is often in short supply, and competition for limited resources can drive these prices even higher (Sovacool, 2012b; Walker, 2008). Contexts like these are often where international finance and multilateral development organizations get involved, though even

international infrastructure finance is often constrained, and can sometimes even be viewed as crippling to the local market, as in Indonesia (Schmidt et al., 2013a).

Financial remoteness can also be a barrier to financing even after projects are constructed. Intermittent service and unpredictable outages causing poor system maintenance due to longer distances from certified technicians and distant management can reduce fee collection and put project revenues at risk as well (Tomei & Gent, 2015). Providing reliable service and maintaining a very close relationship with the community or communities in the micro-grid's service territory will "enable project owners to understand local energy and livelihood needs, as well as their capacity and willingness to pay" (Tomei & Gent, 2015, p. 35).

4.4.4 Carbon Finance Barriers

Many forms of carbon financing have the advantage of being specifically targeted towards low carbon using entities, which may funnel them in the direction of rural, unelectrified communities. However, getting project approvals is a long and expensive process, with no guarantee of success, and high transactions costs make it difficult to apply to small and medium-scale electrification project (Williams et al., 2015). Carbon finance creates a market for the value of avoided emissions from clean development, "giving the holder the ability to offset emissions in developed countries where such emissions are capped or regulated" (Williams et al., 2015). Substantial obstacles such as rigid Clean Development Mechanism (CDM) rules on project performance, monitoring & verification, and registration of CDM-sponsored projects prices smaller projects out of the race for these funds ("Energy for all: Financing

Access for the poor,” 2011; Fischer et al., 2014; Glemarec, 2012b). Uncertain future carbon trading prices, which have been seen to be unstable in US SREC markets for instance, add further risk (Williams et al., 2015). There is also a crediting and market sale period in the CDM that can delay the actual delivery of promised carbon finance funds an average of two years (Bardouille, 2012).

Additionally, regulatory complexity, technical and cultural implementation risks, and policy uncertainties (Williams et al., 2015) can overlap the financial dimension into other areas of the multi-dimensional framework. The most significant obstacle to energy access financing, however, is simply the risk profile of rural populations. In order to take on the risks of thin rural markets rather than mature and stable urban markets without an understanding of the multidimensionality of energy access, a financier must currently have a social motive to investing or a government incentive such as a grant or subsidy to objectively sweeten the deal. However, this is changing rapidly as access to energy becomes more accessible, hardware costs plummet, and new business models are innovated. Section 4.5 analyzes some of the most feasible business models used to deliver energy access using micro-grids.

4.5 Feasible Business Models and Ownership Structures

Each of these business models presented takes unique advantage of the types and sources of financing discussed above. It is important to contextualize and distinguish the models presented in this section by classifying them as service-based models

rather than long-term capital ownership-promoting models. As will be elucidated further in Chapter 5, the ultimate purpose of Chapter 4 and this section in particular is to demonstrate the need for innovative community-based approaches to energy access, and one major goal of this work is to demonstrate the Because traditional end-user financing mechanisms are often characterized by high interest rates up to 20% and short loan periods (3-9 months), passing all project costs directly on to poor, rural end-users is not a financially viable option (van der Vleuten et al., 2007b). Many different operating model mechanisms have been piloted, with varying successes and failures depending on techno-economic, socio-economic, agro-economic, and institutional-economic factors. Some of the most categorically feasible business models for rural micro-grids are discussed briefly below, with an eye on community-based approaches.

4.5.1 Public Utility Operator Model

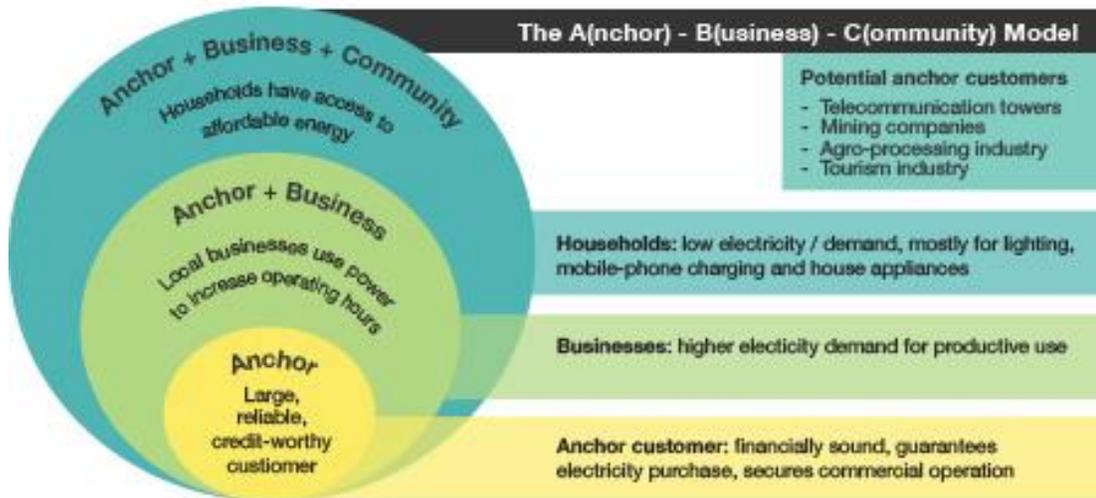
When a public utility is operating a rural micro-grid, it is often a publically funded and publically managed asset that is operated in the same way as the utility distribution network (Franz et al., 2014). This model is often dependent on cross-subsidized tariffs in order to charge an equal rate to the rest of the grid, and is most likely to occur when a national grid extends to a region where a previously existing micro-grid is already servicing customers and integrates it into the existing grid system. In other, more common cases, utilities facilitate and regulate privately-owned or operated systems (Franz et al., 2014).

4.5.2 Private Enterprise Operator Model

In a private enterprise based model, “a private entity plans, builds, manages, and operates the mini-grid system” (Franz et al., 2014). Most often financed by private equity, commercial loans, and government-facilitated grants, subsidies, or loan guarantees, this operating model can take a few different forms, each a different approach to capitalize on different forms of financing and minimize operating costs. The **franchise approach** ties management costs to the franchiser rather than the franchisee who manages the project to capitalize on economies of scale in management (Franz et al., 2014). Similarly, the **clustering approach** bundles the operations and maintenance costs, administrative burden, and overhead of nearby islanded micro-grids in order to capitalize on scale economies (Franz et al., 2014). This is very similar to the Mini-grid Pooling Facilities (MPF) proposed by Gershenson, et al. (2015) and holds up similar base principles as the Sustainable Energy Utility (SEU) model developed at the Center for Energy & Environmental Policy, which could serve as a “point-of-contact” for rural energy enterprise developments (L Agbemabiese, 2009). The **local enterprise** approach designates a well-connected local entrepreneur to operate and manage the system in exchange for a portion of revenues (Franz et al., 2014). The **ABC approach** sites projects based on **A**nchor loads (often a telecom tower, local industry, factory, etc.) and local **B**usinesses with high potential, allowing residential **C**ommunities to be relieved of the burden to maintain high, consistent, and predictable demand in order to secure financing (Williams et al., 2015). Because these anchor customers have flat, predictable loads, high ability to pay, and rural locations, they provide a strong creditworthiness aspect to rural project development (Williams et al., 2015). This community-based model is designed to meet the needs of the anchor load source rather than the community but is

a lower-risk way to provide electricity services at the village-level. This model is illustrated in Figure 5 below.

Figure 5: The Anchor-Business-Community Approach



Adapted from (Rosenbusch, n.d.)

This is a favored model because it can be much easier to negotiate power purchase agreements with telecomm companies and factory owners than with villagers with information asymmetries (Williams et al., 2015). The REPRO project in Rwanda and BUC in Nigeria have ensured steady, predictable demand, and have even been able to cross-subsidize tariffs for low-consumption residential customers using this approach (Bardouille, 2012). In general, a private sector investment framework is often the most preferred model because private actors are incentivized to better quantify project benefits and costs, efficiently price output, collect tariffs, and optimize performance of the system and therefore the investment (Gershenson et al., 2015). Indeed, purely

private models are less impeded by the unavailability of capital than other operating models, especially when debt is sourced from local sources or DFIs (Gershenson et al., 2015).

4.5.3 Hybrid Operator Models

Public-private partnerships are based on the contractual involvement of a private entity in public sector investment work. This is often manifest in Renewable Energy Service Companies (RESCOs) or Renewable Energy Service Stations such as were implemented in Nei Mongol, China (Zhou & Byrne, 2002). In most hybrid operator models, the state-owned utility finances and owns the equipment while these private entities conduct operations and maintenance and collect tariff revenues (Franz et al., 2014). In other cases, utilities will grant concessions to allow a private actor to sell electricity in their service territory on favorable terms in return for various forms of payment (Honor & van Gerven, 2015). Finally, the PPA model involves multiple stakeholders involved in the ownership of an asset that collectively earn shares of tariff revenues over time (Franz et al., 2014).

4.5.4 Community-based Operator Models

Community-based models can transfer ownership, operational support, or project administration and management responsibilities to a representation of the consumers on the micro-grid. These projects are most often viable due to highly grant-based financing, and maintain operating profits by collecting revenues that at least cover operations and maintenance and financing costs (Franz et al., 2014). In the case

studies that have been done in the past, there is a dynamic of a community self-managing a shared resource, which will be discussed in Chapter 5, but often, small communities will create working social and decision-making structures to resolve conflicts (Franz et al., 2014). The configuration and makeup of this group seems to depend on socio-economic factors and the general community dynamic (Bhattacharyya & Palit, 2014; Singh, 2016). This can provide lower management costs, result in less conflict, and enable ownership and self-determination in the service territory (Franz et al., 2014). However, these authority structures may not have sufficient technological or managerial capacity and may create a vulnerability to corruption risk due to the overlap between management of the micro-grid for customers and social and family connections (Franz et al., 2014).

4.6 Solutions for the Financing Gap

Understanding the centrality of micro-grid financing within a multi-dimensional energy access framework can allow for greater access to more forms of financing that may better fit the needs of the populations served. Some key lessons and recommendations from the multidimensional framework for removing financing barriers and enabling micro-grid electrification are detailed here:

- Simplify the debt financing process by giving banks and foreign investors clearly mandated guidelines for priority lending in the energy sector (S. N. Rao, 2016).
- Because financiers often balk at the high-risk, low-return profile of micro-grid investments in some locations, policymakers should introduce risk-stabilizing measures such as clear and simple licensing policies, transparent grid-extension planning and, where the micro-grids can be expected to connect to the main grid before the end of project life, long-term and reliable tariff schemes and even demand guarantees (Franz et al., 2014). Strong governance and regulatory reform are necessary preconditions for international financing flows to begin (Franz et al., 2014).

- Improving financing mechanisms for prospective developers through policy interventions such as performance-based subsidies, partial loan guarantees, which have seen domestic success through the U.S. Department of Energy, and low-interest longer term loans, as well as bank acceptance of physical infrastructure as loan collateral (Yadoo & Cruickshank, 2012).
- Involve women in credit decisions, starting with small microfinance loans with frequent and flexible repayment schedules and alternative collateral requirements, because in many contexts women cannot own property. Lowering transactions costs, creating a respectful banking atmosphere towards women, and simplifying loan application procedures to accommodate illiteracy are simple yet instrumental steps to allow women's participation, even in oppressive contexts will also help women be involved (Cecelski, 2000).

Other best practices have been identified (Best, 2014; Gershenson et al., 2015; Yadoo & Cruickshank, 2012), but a central lesson of the multidimensionality of energy access is that there is no single model or plan or tariff structure that will work universally. Human-centered development (Sen, 1999) inherently creates a varied landscape for energy access intervention delivery models, which varies along the dimensions of the framework presented earlier in Section 3.1.

This chapter has analyzed the financing landscape and business models for community-scale energy access initiative for the direct purpose of identifying the financing gap for community-scale energy access interventions building a case for the contextualized merits of community-based financing and project management, which are illustrated in the following chapters. Implementing tariff structures and payment rates that ensure financial viability, attracting financing, and in many cases, outperforming other business models are clearly possible for community-scale and community-led micro-grids.

Chapter 5

A COMMUNITY-LEVEL UNDERSTANDING OF RENEWABLE RURAL ELECTRIFICATION

The understanding of energy poverty, the multidimensional energy access framework, and the qualities and gap in micro-grid financing presented above offer a case for a community-scale, community-centric, community-driven response to the energy access problem can be a highly effective and efficient method of electrifying rural populations. Because these dimensions determine the efficacy of different technologies, productive uses, tariff structures and subsidies, and ultimate end uses of energy, they suggest that the local community can and need to play a primary stakeholder role in the project development process. There is a theoretical basis for this argument and a growing number of pilots and case studies suggest communities can successfully manage a micro-grid as a common-access resource. This chapter discusses the theoretical power of a community self-managing a common-access resource and presents an illustrative framework for poor rural communities to make a contribution in the financial dimension that can yield a significant financial gain and improve the business case to investors without threatening livelihoods or economic standing. Chapters 6 & 7 will apply these concepts to an illustrative modeling exercise using a case study from a rural region of Nei Mongol, China to demonstrate this framework's potential impacts on project economics and financing.

5.1 Collective Ownership and Common-access Resource Use Theory in an Economically Poor Community

Systemic economic poverty and the nature of rural livelihoods explain the relevance of community-based financing in rural energy interventions. The budget constraints²² imposed on those who are in economic poverty prevent individuals from making significant financial decisions on an individual basis, and can thereby necessitate joint-use rights, elevating them beyond “a virtuous bit of cooperation” and avoiding the burdensome transactions costs of formally defined and enforced property rights regime (Bromley & Feeny, 1992, p. 19). The lack of defined property rights, poverty and subsistence agriculture result in high uncertainty of future income streams because the cushion of accumulated wealth does not exist. For subsistence farmers whose income depends on “the rain’s falling or the hunt’s succeeding,” there is added income uncertainty (Bromley & Feeny, 1992, p. 20). As a result, common property regimes often naturally form as a rational hedge against the common income uncertainty resulting from direct resource dependency (Bromley & Feeny, 1992).

Likewise, because usage is not theoretically (and rarely practically) restricted in these scenarios, community-based management of an islanded rural micro-grid would, in most cases, mirror a common-access resource use scenario in terms of the joint-use rights regime. Therefore, for the purposes of this thesis, a rural PV micro-grid will be considered as a common-access resource. What might this look like?

Elinor Ostrom’s career work gives rise to the most foundational open-access resource

²² In most contexts, village life in a remote and underdeveloped economy is also critically dependent on indigenous agriculture and natural resources, a fact that only changes as the economic development process becomes multiplicative and higher value-added goods can flow bi-directionally through the local economy (Bromley & Feeny, 1992).

management theory in recent times (Ostrom, 2012). Under an Ostromian framework, it is primarily important to state that a tragedy of the commons outcome is not assumed by any means. Ostrom notes many instances “where communities of resource users have managed to develop exclusion methods and evolve effective rules which have avoided the tragedy of the commons without external regulation” (Ostrom, 2012, p. 24)²³. In her seminal work, *Governing the Commons*, Ostrom identifies the importance of locally-adapted and exclusionary rules, the importance of local monitoring, and the importance of dispute resolution mechanisms for the effective community management of a common-access resource, among others detailed further below (Ostrom, 2012). It is important to note that these are all necessities that would all be represented as cost items for an external manager to facilitate. For example, in some cases, it may be quite costly for an external, distant manager to ensure that customers who do not pay are excluded from obtaining the benefits associated with payment (despite the lack of disincentive and their potential bargaining power), while a local project administrator could accomplish this exclusion more easily. On a project-specific basis, local ‘institutional innovation’ can dictate the ownership regime and where the particular community may fall on the spectrum in terms of individual rights. When these conditions hold, decisions for collective action place a premium on mechanisms that coordinate community decisions, ensure that others will not misuse

²³ Conversely, a village with even minimal social cohesion can easily avoid the free-rider problem because of the interdependency of individual choices in a village, which recognizes that the “benefits and costs of resource use [are] a function of the total actions of the groups...[and] the expected decisions of others” (Bromley & Feeny, 1992, p. 27).

common resources, and thus make it economically rational to operate under a common-property regime for these types of open-access resources.

Likewise, it is important to note that community-based approaches are not always the most appropriate institutional form,²⁵ and that the most successful models of community resource management are often mixed regimes between private and community rights regimes (Ostrom, 2012). Mixed regimes may be instituted where the scale of the resource is too small or too large for purely individual private property rights, or where there is “cultural hostility to the concept of individual property” under the socio-economic dimension (Ostrom, 2012, p. 30).

However, these principles can be applied to micro-grids in practice. Under different ownership and management structures, micro-grids mirror these theoretical principles and present a fascinating case for the application of the valuable work of Elinor Ostrom. This theoretical discussion of community-management of micro-grids is applied to understanding possible ownership and management structures in the next section.

5.2 Community-centric Ownership & Management Structures

Community-centric development naturally requires the participation of relevant stakeholders, in this case, the community. Well-organized, socially cohesive communities with genuine interest in project operation and management are able to

²⁵ “In many cases, individualized property institutions may be better placed to incentivize resource conservation and to allow greater scope for innovation than more collective structures. Similarly, [Ostrom] appreciates that in some circumstances neither private nor communal management may be feasible and that there may be no alternative to relying on state regulation.” (Ostrom, 2012, p. 25)

guide decision-making in the design and development process that will prevent future inefficiencies, implicit benefits which can then be passed along to their members at large and encourage operational sustainability (Bhattacharyya, 2012). Indeed, community participation can establish a “transparent, efficient, and effective management organization responsible for the system’s upkeep, provide[s] training to ensure that the system can be locally maintained, and to promote holistic development” (Yadoo & Cruickshank, 2012, p. 600). A development process without the community as a key stakeholder could result in significant economic leakage, in which the investors net all of the economic benefits and leave only the indirect benefits of electrification for the community. Moreover, because humans make collective social decisions, energy infrastructure deployment models that intend to understand social behavior need to take into account social context, and focusing on individual decision-making and behavior delimits the importance of socio-economic factors; household energy demand is a product of social demand (Kowsari & Zerriffi, 2011). Social context can represent varying interests, however, and an essential feature of community participation is the ability to manage and counterbalance varied interests within the community. With this customer service aspect, in the form of dispute resolution and community-level decision-making, community-led micro-grid projects can account for the needs and preferences of a community and avoid costly transactions costs of external litigation (Bhattacharyya & Palit, 2014; Blum et al., 2013; Schmidt et al., 2013b).

The size of community-scale systems is advantageous and conducive to local management or ownership. Because of their medium scale and the presence of multiple stakeholders (rather than a single household for SHS or a state-owned utility

for grid extension), community-scale micro-grids are often favored for their use of local governance, as well as capacity for productive use applications (Gershenson et al., 2015; Schmidt et al., 2013b; Yadoo & Cruickshank, 2012). Community management of micro-grids in socially cohesive communities can be a vehicle to accelerate scaling-up of electricity access, but the practicality of the approach is dependent on the structure of the relationship. Because communities often lack technical and financial expertise to develop and implement micro-grids, most community-based projects assume the third party developer will handle procurement, installation, and commissioning before handing the reins to trained members of the local community for operations, administration, and maintenance. It is essential that the community has adequate technical capacity, clarity of responsibility, and a sense of ownership over the system.

In terms of decision-making and general oversight, the most effective management structure likely depends on the size of the community's population. For smaller communities, this may be a form of co-operative or referendum model, where the community can collectively make decisions in a way that is often not highly distinct from the existing culturally-defined authority structure in the village. In some regions, such as West Africa and parts of Asia, decision-making may rest in the hands of a village chief or matron, or a group or tribunal of elders. In these cultural contexts, and in larger communities with information deficiencies, it is often infeasible to have a fully democratic process. In these settings, it may be more effective to create an elected, education-based, or status-based oligarchical representation to form a committee to manage the micro-grid on behalf of the community in order to ensure quality service delivery and operational and financial viability of the project. Termed

here the ‘micro-grid management committee’ (MMC), the committee may be responsible for identifying and donating land for the construction of the micro-grid, overseeing construction and installation labor and directing community involvement through labor to the installation process, identify and support system operators who will be trained, represent point of contact for external agencies responsible for monitoring and maintenance, the collecting, recording, and remunerating of tariffs and the redress of grievances within the community surrounding energy use, which have been demonstrated to be more efficiently redressed at the local level using comparative institutional analysis (Bhattacharyya & Palit, 2014; Duke & Attia, 2016). Depending on technical and managerial capacity and training, the MMC may be assisted by or have representation from a local NGO or rural electrification agency in order to ensure accurate financial records and prompt and safe equipment maintenance. Fundamentally, the MMC also facilitates Ostromian management of the micro-grid as a commons, as seen in Figure 6 below.

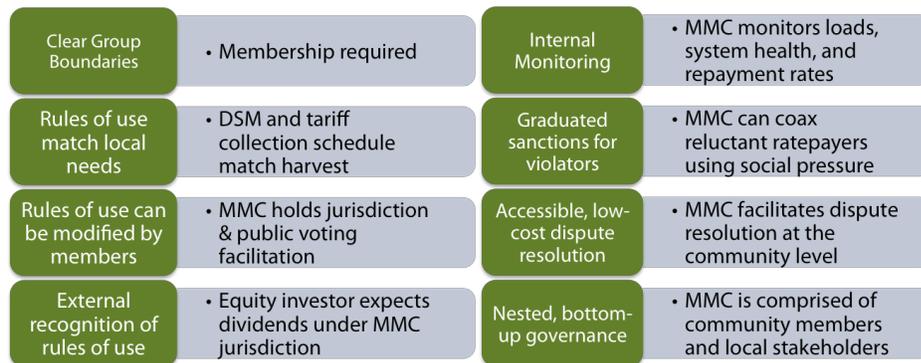


Figure 6: MMCs facilitate Ostromian Management

Mainali & Silveira (2011) report a community decision-making arrangement of a micro hydro project with low technical and managerial capacity that was vulnerable when managing financial, social, and technical problems and recommend institutional

capacity building of locals to help enable these projects (Mainali & Silveira, 2011, p. 2198). Some limited experiences have shown that operational and commercial viability can be strengthened if the community is central to the decision-making process. For instance, a case study of a biomass gasifier in Uganda shows that villagers contributing agricultural waste and woody biomass in return for below-market power prices significantly contributes to local development and increases social interest, buy-in, and appreciation of the system, especially when paired with training (Yadoo & Cruickshank, 2012).

At the social level, a community's perceived ownership of a community energy system may be more important than actual legal or financial ownership (Yadoo & Cruickshank, 2012). This is an important distinction that resides between the ownership- and service-based models, and effectively translates to long-term asset management and administration responsibilities being shouldered by the community in addition to operations and maintenance. This often comes in the form of a cooperative model or a split-ownership model, wherein the community and the supplier divide ownership of generation, transmission, and distribution assets and associated responsibilities (Franz et al., 2014). Long-term and consistent tariff payment and community engagement with the upkeep of the project can be incentivized when local economic benefits stay within the community, and a system can grow with demand over the life of the project due to solar PV's modular capacity. However, depending on the regulatory climate, this split-ownership model can lead to ambiguous legal status, especially when project financing is not used.

Community-driven decision-making processes are necessary to effectively implement an energy access intervention that accounts for the market entry barriers in

the multidimensional framework presented above. After the project has entered commercial operation, it may, in certain contexts, be beneficial for the community to have full- or split-ownership rights to the capital equipment and include trained and locally-based operations and maintenance (O&M) services in the retail price per kWh. Most of these target populations, due to techno-, socio-, agro-, or institutional-economic factors do not have the ability to pool significant liquid financial assets towards the purchase of a PV micro-grid system. However, communities can leverage their own latent economic potential (Franz et al., 2014; Hunt et al., 2010) as well as their remoteness to add significant value to both fixed and recurring costs of rural energy systems, improve project economics, and attract further private investment. This takes the form of what has been termed here as ‘participatory equity’.

5.3 Community Participatory Equity

This section defines, identifies, and offers guidelines for the various forms of Community Participatory Equity (CPE) that may be possible in a community targeted for this type of project. It will seek to answer the question, “What does it actually look like for one of these communities to participate as a form of equity stakeholder in the PV micro-grid project development process?” In many cases, the lack of financial capital and measured creditworthiness in these settings can often be compensated for with targeted injections of human capital and local resources. Some more simply than others, communities can contribute land, raw materials, a small cash buy-in or membership fee, local market development services, installation labor, and long-term asset management and administration, each of which is evaluated in terms of the multidimensional energy access framework in the following sections.

5.3.1 Contributions of Land

Community donation of land could, in many cases, be seen as a symbolic gesture to the project developer that the community is socially and financially invested in the project (Bhattacharyya & Palit, 2014). These land costs are often rather insignificant, as most rural communities are surrounded by at least some degree of non-populated, empty land. In any case, the amount of area covered by a small to medium sized PV array within the scope analyzed in the following chapter (up to 77kW), would likely not exceed 0.5 square km. Within the socio-economic dimension, the responsibility of identifying and donating an appropriate plot of land may often fall to the MMC, depending of the authority structure in the community and the concentration of social influence on the MMC. This can limit agronomic yields if the energy system must be sited on arable land, and can also depend on the regulatory climate and rigidity towards land ownership and property rights.

5.3.2 Contributions of Raw Materials

In some cases, community members can contribute raw materials to help build the micro-grid or its distribution system. In one case in Thiba, Kenya, for instance, an NGO-initiated micro-grid required the contribution of two Eucalyptus shoots as poles for the distribution system (Yadoo & Cruickshank, 2012). Other contributions could include fencing for the panels and inverters, building materials for a battery storage and parts shelter or small administrative office, or concrete or gravel for access roads or similar ancillary infrastructure. These contributions often require a low to medium amount of manual labor, and have multiplicative benefits because the cost is removed from the balance sheet of the project, but also because the delivered costs of external materials and labor to remote areas is markedly higher than the cost of using locally-

sourced materials and labor that has no travel time or transportation cost. Further, these raw materials may use local methods designed for the climate or fauna of the region, such as fencing made of bamboo to fence yaks out and withstand cold temperatures, for instance. Especially in reference to ancillary infrastructure, the benefits of community contributions of raw materials can have spillover effects that extend beyond the economics of the micro-grid, such as increasing access to markets for agrarian populations or lower delivered costs of other goods not relevant to the micro-grid.

5.3.3 Contributions of Small Cash Payment as a Membership Fee

While most populations relevant to this analysis likely have relatively illiquid wealth (in the form of stored crops or livestock) and very low cash savings, a small cash buy-in can often serve as a way to incentivize commitment to regular tariff payments and responsible use of the system in some cases. This could happen in the form of a membership or connection fee paired with benefits of membership, such as a member-price tariff or the ability to reserve higher quantities of power for events such as weddings or festivals. Further, a membership fee implies social inclusion, which may spur further signups in a socially microcosmic community. Of course, this fee may not be affordable by all members of the population, and may face additional pushback from the community regarding social perceptions of electricity costs. Membership fees could range from a small nominal fee to a relatively considerable investment, depending on system capital costs and ability to pay. Of course, for an average rural village of 50-350 people, a fee of that magnitude could comprise a small but not insignificant percentage of capital costs, or be contributed towards the payment of the local O&M&M provider.

5.3.4 Contributions of Local Market Development

Because of the observed benefits of electrification detailed in Chapter 2, a micro-grid can quickly become the lifeblood of a community's economic activity, with household demand increasing over time in accordance with educational attainment, hygiene, and appliance use and dependence (Khandker, Barnes, Samad, et al., 2009) and demand for productive uses facilitated as a result of the latent economic potential and the additional capacity of the micro-grid. However, energy demand is also influenced by community-level socio-economic factors, such as uniform tariffs, existing economic growth potential and wage structure, and associated costs for carbon-based fuel sources (D. Barnes et al., 2002). Similar to the social cohesion that can result from membership fees, Barron & Torrero (2015) observed in a case in El Salvador that when households observe their neighbors connect to the grid, they may be more likely to imitate them and connect themselves (Barron & Torero, 2015). A third-party developer operating outside of the multidimensional energy access framework presented above may outlay significant expenditure to canvass the neighborhood, generate signups, collect and likely negotiate membership fees, and explain the merits and operational details of the system. In contrast, a community-led decision-making process places this cost onus on a few key stakeholders or community representatives that can interface with the project developer, reducing business development and, as will be elaborated below, site administration and management costs.

5.3.5 Contributions to Installation Labor

One of the most straightforward and direct ways for households to contribute to a village-wide energy project is through installation labor. Under the supervision of

an electrician and a work foreman, able-bodied community members can provide significant upfront cost savings to the project by assisting with digging ground mount stubs, building fencing, installing and racking modules, and erecting the battery and equipment storage shelter. The paid skilled laborers (engineer, electrician, and PV technician) can conduct the racking assembly, wiring and conduit assembly, combiner box and inverter connection, and system testing to ensure project reliability and safety. The MMC can encourage or even mandate contributed installation labor in exchange for membership. These cost savings can be significant, especially for larger-scale systems, and certainly contribute to the community-wide sense of perceived ownership. Of key importance, however, is the enforcement of high standards of quality in system design, installation, operation, and maintenance, giving weight to the necessity of skilled labor supervision and intensive training for skilled laborers (Cattelaens & Fromme, 2014). Unskilled installation labor can represent a significant portion of fixed capital costs, between 4-22% in the case study region.

5.3.6 Contributions to Long-term Asset Management and Administration

When the project is completed, there can be high costs and low effectiveness for a third-party asset manager or maintenance technician to regularly visit the project site, maintain reliable functioning service, collect tariff revenues, and guard against vandalism or theft. Along a similar vein to other identified contributions, community-led long-term asset management, operations and maintenance, and site administration on a recurring basis can provide significant cost savings with the potential to significantly lower retail electricity prices for the micro-grid. As alluded previously, this likely comes in the form of 1-4 members of the local community receiving training as system operators, maintenance technicians, and asset managers, usually

from a local university or UNDP Solar-style training and certification program (Yadoo & Cruickshank, 2012). The training of local residents lowers transportation costs, increases administrative presence, reduces production downtimes when corrective maintenance is needed, and retains more economic benefits within the local community (Cattelaens & Fromme, 2014). Furthermore, this consistent and locally-known presence reduces theft and distribution losses, improves billing and revenue collection, and allows for local dispute resolution, which represents a measureable efficiency gain in transactions costs (Duke & Attia, 2016; Franz et al., 2014). Further, these MMC members should likely be the intermediary for regular debt service payments between the individual households and the project developer or lender (Bhattacharyya & Palit, 2014), though the logistics of remittance of payments can be difficult in financially remote areas, especially those that may not have strong transport or cellular networks (Muchunku & Ulsrud, n.d.). These trained asset managers, technicians, and site administrators would be gainfully employed by the project. The municipal government can be asked to provide an annual subsidy covering the O&M cost and skilled labor cost for the first 2-5 years of the project life, to allow the quick payout of the equity investor at lower risk, who in many cases will be a multilateral development bank. The model currently has the functionality to delay the start of O&M fees from the project's perspective; in the illustrative section below, a three-year municipal payment period is used. From a legal perspective, this would either be through the project company if project finance was used or through the developer if traditional capital financing was used. Additionally, in most cases, it would be sensible for these community members to be a part of the MMC, as they are familiar with the micro-grid's financials, foreseeable future costs, and other issues.

With the rest of the MMC, this governing body could also provide further added benefits, including building consumer WTP, improving O&M cost recovery and tariff revenue payment rates, and minimizing theft and non-technical losses. The MMC can build local WTP by ensuring reliable service and leveraging the community's social cohesion to encourage timely repayment. Additionally, tying access to markets for agricultural yields, as occurred in the case study region of Nei Mongol, China, can be facilitated by the MMC in partnership with the local government (Byrne et al., 2007; Byrne, Shen, et al., 1998). Further, there can be clear benefits to a community-led, multidimensional understanding of asset management in terms of O&M cost recovery, which can be improved by understanding the agro-economic and institutional-economic factors that affect capacity to pay, ability to pay, and timing of payment. A multidimensional understanding of these factors could facilitate the design of tariff collection schedules to coincide with harvests or represent a percentage of yields, as in the Nei Mongol case (Byrne, Shen, et al., 1998). Other strategies, including pay-as-you-go or pre-paid schemes, such as the Adinelsa, Peru case (Yadoo & Cruickshank, 2012) or joint liability groups (in which delinquent lessees are covered by their neighbors), have proven effective in some contexts (The Philippines) (Tomei & Gent, 2015).

In any remote collection and administration scheme, a close relationship with the community is critical (Bardouille, 2012). Along the socio-economic dimension, informal social pressure from the locally-recognized community members with authority over the micro-grid (in various forms) have been shown to reduce system losses through theft by 10-20% in Mugling, Nepal (Yadoo & Cruickshank, 2012). When meters are installed on the generation side of individual household feeders, the

nature of the theft is altered: “rather than stealing from a utility, you are stealing from your neighbor” (Gershenson et al., 2015, p. 30). Local management also minimizes non-technical losses, which can represent a considerable portion of electricity output, in some cases up to 30-40% in developing countries (Gershenson et al., 2015). Mismanagement of the grid, deficient maintenance schedules and misdemeanor conduct can lead to lower system performance, but these issues are often minimized due to the social premise that these losses are detrimental to the entire community (Yadoo & Cruickshank, 2012). In India, Bhattacharyya & Palit (2014) identified a reduced threat of consumer exploitation in community co-op management models for distribution franchisees (Bhattacharyya & Palit, 2014). Active community engagement, such as through stakeholder meetings, in-kind support for villagers, co-operation with existing income-generating organizations (such as farming co-ops), and of course, the implementation of an MMC-esque structure (Bardouille, 2012; Glemarec, 2012a; Schmidt et al., 2013b; Yadoo & Cruickshank, 2012).

In plain terms, when operations, maintenance, management, and administration costs are passed on to the community (excepting the wages of the trained MMC members, which would be paid through tariff collection revenues), the vast majority of recurring costs for the project are eliminated. This can create huge value in changing the capital structure towards debt and long-term community ownership, cheaper financing, and faster repayment to the equity investor, as will be illustrated in later sections. Where applicable, the MMC may hold considerable responsibility for facilitating this portion of the community’s participatory equity contribution to the viability of the micro-grid project. See summary concept in Figure 7 below.

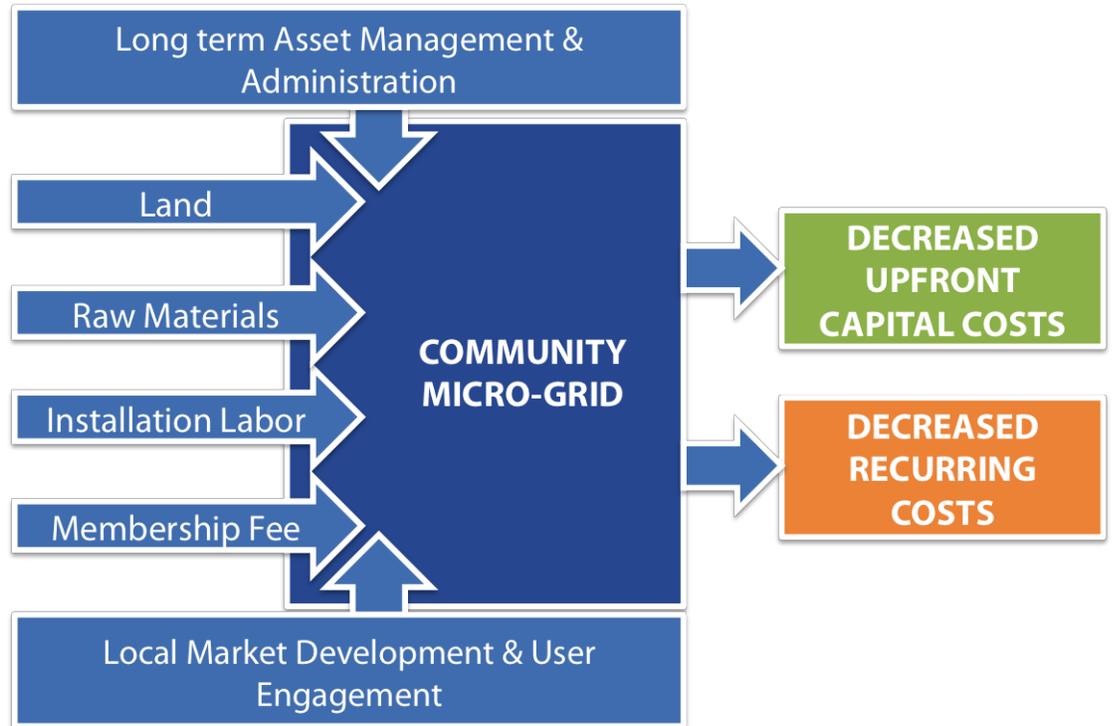


Figure 7: Community Participatory Framework (CPE) Concept

A relatively recent and relevant case study example of some of these principles in action is found in the diesel-powered Mpektoni Electricity Project in Kenya that was profiled in Section 2.4. Kirubi, et al. highlight some of the key practices and lessons of this community-managed pilot project. This \$40,000 diesel-powered system was 30% financed by the local community in cash and labor, and contributed significantly to integrated infrastructure development and productive use applications that allowed rural MSMEs to be competitive with urban markets (Kirubi et al., 2009). In 2009, this community-managed project begged “further research to explore the likely incentives and constraints of initiating and managing electric micro-grids collectively...[and] understanding the factors likely to make individuals participate and contribute toward collective action” for community-managed models (Kirubi et

al., 2009, p. 12). This multidimensional framework and community participatory equity theory seek in part to satisfy this gap.

5.4 Barriers and Risks to Community-managed Micro-grids

This theory butts against a significant number of barriers and exacerbated risks that may hinder the framework's effectiveness in contexts where these risks are present. Recognizing and addressing these risks systematically will minimize failure of the model in implementation. At the core of these barriers is simply the capacity constraint among rural communities, in which poor training, skewed social incentives, and local level conflicts can erode otherwise effective common property resource management strategies. In a review of 74 different rural electrification interventions in India, about one fourth of which involved some form of community-managed systems, one study recognized at least two projects (Radhapura and BERI) that had been deemed to have failed (Bhattacharyya & Palit, 2014).

Scalability of any system in a varied and multidimensional landscape is difficult. Currently, there is a wide variety of funding sources for off-grid projects, including private equity, multilateral development financing, national government grants, and others (See Table 5 on p. 78). However, a major portion of this financing is directed to supporting large projects, in part because of the creditworthiness of off-takers and scale benefits of administrative and coordinating costs compared to multiple smaller projects (Hunt et al., 2010). Another key point of questioning lies in the amount of decision-making power and ownership (real or perceived) that the community has over its own development process and the amount of economic leakage, when little to no economic benefits are retained in the local economy (Fortin, 2014). Especially for systems that serve smaller communities, even the economic

benefits of a few trained micro-grid employees can be significant, let alone the benefits of the electrification itself.

Stalled scalability due to hidden costs

While in an ideal situation, the complete costs within the CPE framework would be covered by the community as previously described, in reality, capacity constraints and physical and financial remoteness may result in context specific hidden costs that may eat into the scalability of this approach. Barriers to local capacity building, mainly socio-economic barriers, such as lack of managerial experience, social discord, and perception and interest, may be project risks that are very difficult to quantify. Time intensity to develop a local market (Glemarec, 2012a) and establish the MMC may be a costly endeavor. Transactions costs, in the form of creating legal status for the project (Bhattacharyya & Palit, 2014), collecting delinquent revenues, or resolving micro-grid related disputes are also contextually specific and difficult to quantify. However, because of the potentially devastating effects failed projects can have on local savings rates and future support of renewable energy initiatives, these potential hidden costs should not be ignored in detailed community assessments using this framework.

Potential hidden costs would be a great candidate for future research in this area, Nonetheless, community-centered development processes seem to offer substantial benefits. Elements of both a project's fixed capital and its recurring costs can be reduced through the CPE framework with marked improvements in project economics. In addition, involving all of the stakeholders in the project and tapping the value of the community as a participant in their own development may markedly contribute to a holistic sustainable development process.

Chapter 6

ILLUSTRATIVE MODELING OF COMMUNITY PARTICIPATORY EQUITY: A CASE STUDY OF RURAL NEI MONGOL, CHINA

This chapter will seek to apply the CPE framework developed in Chapter 5 in an illustrative modeling exercise for the purpose of representing the possible improvements in project economics that may result from the community shouldering some of the costs included in the CPE framework. Using a case study near Hohhot, Nei Mongol, China informed by recent cost data from the Chinese Renewable Energy Society (CRES)²⁷, a community-driven financial model for PV micro-grids was built to estimate the possible range of cost savings resulting from the CPE framework. This case study builds on research conducted in 1993-1998 in the same region by the Center for Energy & Environmental Policy, the National Renewable Energy Laboratory, the World Bank, and the Chinese government (Byrne, Shen, et al., 1998). This study developed a tool called the Rural Renewable Energy Analysis and Design (RREAD) tool, which is briefly profiled and understood in context of the Inner Mongolia Autonomous Region (IMAR) in the sections below. Because this model lacked a CPE-specific financing component, this work seeks to reinforce the time-tested analytical power of this resource assessment and system design model by allowing the daily demand estimates from the original RREAD model to be translated

²⁷ The author would like to recognize Li Yuan Pu and the rest of the CRES team for their invaluable help in obtaining this data. See 0 for more details.

into a standardized, modular system micro-grid design (up to 77kW) and an estimated financing structure based on the assumptions detailed in the following sections. By using a simple with-without methodology applied to the complexities of the model, it is possible to estimate the feasible scale of contribution of communities managing their micro-grid projects under the CPE framework. The results of this illustrative modeling exercise are presented in Chapter 7.

6.1 Case Study Context: Brief Background of Rural Electrification and Solar PV in Inner Mongolia (IMAR)

Nei Mongol (IMAR) is one of five minority jurisdictions with autonomous administrative authority in China (Byrne et al., 2007; Byrne, Shen, et al., 1998). About three quarters grasslands, IMAR is home to approximately 14 million rural dwelling citizens in one of the least densely populated regions in China (Byrne et al., 2007; Byrne, Shen, et al., 1998). The region has abundant renewable energy resources²⁸ in the form of hydropower, solar, and wind, and as well as significant coal resources (Uyunqinmg, 2000). See solar PV resource data and monthly clearness index values for Hohhot, IMAR from the NREL Solar Radiation Database in Figure 8 below.

²⁸ Wind resources in Inner Mongolia can reach a consistent 6m/s and PV modules in the region can see up to 2200 sun-hours annually (Stroup, 2005).

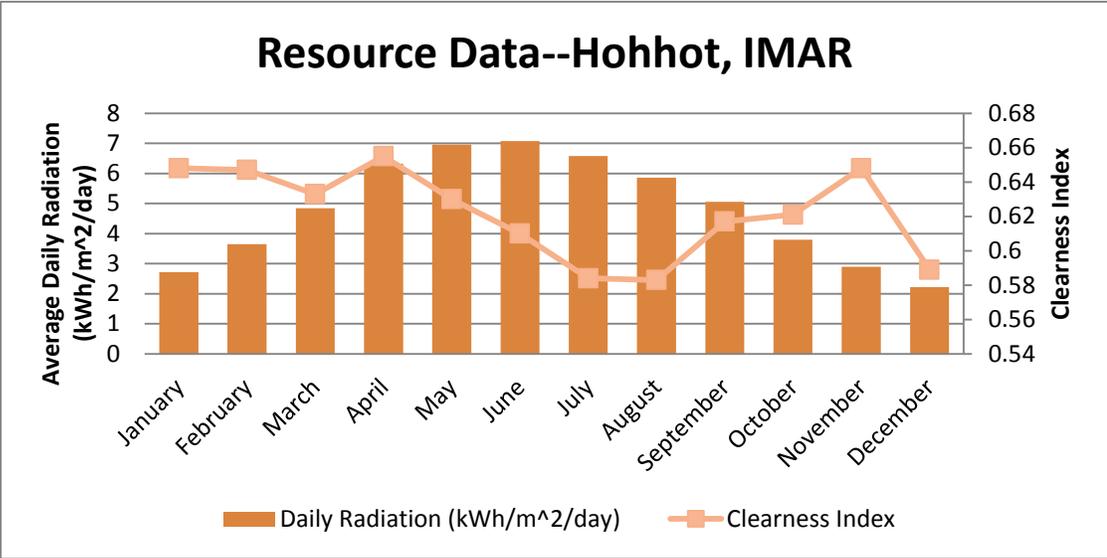


Figure 8: Solar Resource Data in Hohhot, IMAR (NREL)

As a result of the renewable resource abundance, in recent years, the solar industry in IMAR has boomed. Since 2006, utility scale solar projects began being installed with rapid frequency (Yuanyuan, 2016). In 2013, state-level performance-based solar subsidies were rolled out from the central government, and IMAR’s regional government supported this effort with favorable regional policy changes to foster the growth of the industry (Yuanyuan, 2016). However, the utility-scale sector is facing a major slowdown in 2016 due to an incomplete supply chain, difficulties in raising funds due to the Chinese anti-dumping investigations, excessive tax burdens, and complex subsidy remittance procedures, which require power purchase and sale contracts, land use, water conversion permits, fire control, and power generation licensing to occur prior to application for or remittance of subsidy (Yuanyuan, 2016). Likewise, the distributed PV market is hindered by interconnection delays and lack of suitable rooftop space (Yuanyuan, 2016), but the region has a pre-existing PV industry and distributed populations with low electricity demand, representing significant potential for PV powered micro-grid systems. Additionally, the region’s foreign

investment policy framework is significantly more beneficial than domestic tax policy, with exemptions or holidays on property taxes, value-added taxes, and income taxes, preferential loan treatment, wage determination, and permitting fees (Uyunqinmg, 2000).

In 1995, the U.S. Department of Energy formally entered into an agreement with the Chinese Ministry of Science and Technology (MOST) called The Protocol for Cooperation in the Fields of Energy Efficiency and Renewable Energy Technology Development and Utilization (Stroup, 2005). This agreement included the Inner Mongolia Household PV/Wind Hybrid Systems Pilot Project, which led to a Chinese focus on the scales of off-grid renewable energy generation technology, including a particular interest in village-scale micro-grids (Stroup, 2005). In 1998, the Chinese government established its Brightness Rural Electrification Program Project Implementation Planning initiative by allocating about 50 million USD of central government funding, regional government funding, and foreign aid to provide 23 million unelectrified Chinese citizens with at least 100W of renewable electricity (NREL, 2004). The program's policy mechanisms included establishing national and local government bureau financing approaches and practical financing mechanisms, establishing industrialized production enterprises which could meet market demand, setting up an distribution and service network and power marketing vehicle, and founded a technical training system providing different level of training for local technicians and engineers (NREL, 2004). From 2001 to 2005, the program installed 1,780,000 household energy systems, 200 renewable energy service stations, and 2,000 village-scale renewable energy systems in Gansu, Qinghai, Tibet, Xinjiang, and Inner Mongolia (NREL, 2004). The Inner Mongolia 2004 capacity targets included

518 wind-PV hybrid systems, 1 wind-PV-battery system, for a total of 165kW of small wind capacity and 632kW of PV capacity (NREL, 2004). A post-program assessment conducted in 2005 (that fits quite nicely into the multidimensional framework for energy access) revealed that household uses, television and indirect educational benefits, and improved social connectivity and market information through telecommunications were successfully achieved in the majority of the newly electrified households (Stroup, 2005). The assessment also argued for further qualitative research in renewable energy literature to develop a holistic view of energy access and sustainable development and pointed to the necessity of a mechanism to assign responsibility for project upkeep, perhaps through collective ownership, to maintain the long-term operational viability of systems (Stroup, 2005).

In 2003, the Chinese government also initiated its National Township Electrification Program (“Song Dian Dao Xiang”) to build on the success of the Brightness program by electrifying townships through PV-powered micro-grids. At the time, this was the world’s largest renewable energy-based rural electrification program (Stroup, 2005). In two years, the program installed 1065 village-scale micro-grids with a total of 20.84MW of capacity, and in 2005, the program was expanded to target the remaining 29,000 unelectrified villages in China under the program name Sending Electricity to Natural Villages (“Song Dian Dao Cun”) (Stroup, 2005).

It was under the umbrella of these major central government initiatives, the joint CEEP & NREL team performed its cost-competitiveness analysis in the region, using their RREAD model to show the cost advantages of solar PV and small wind in the region (Byrne, Shen, et al., 1998). The study also suggested effective policy

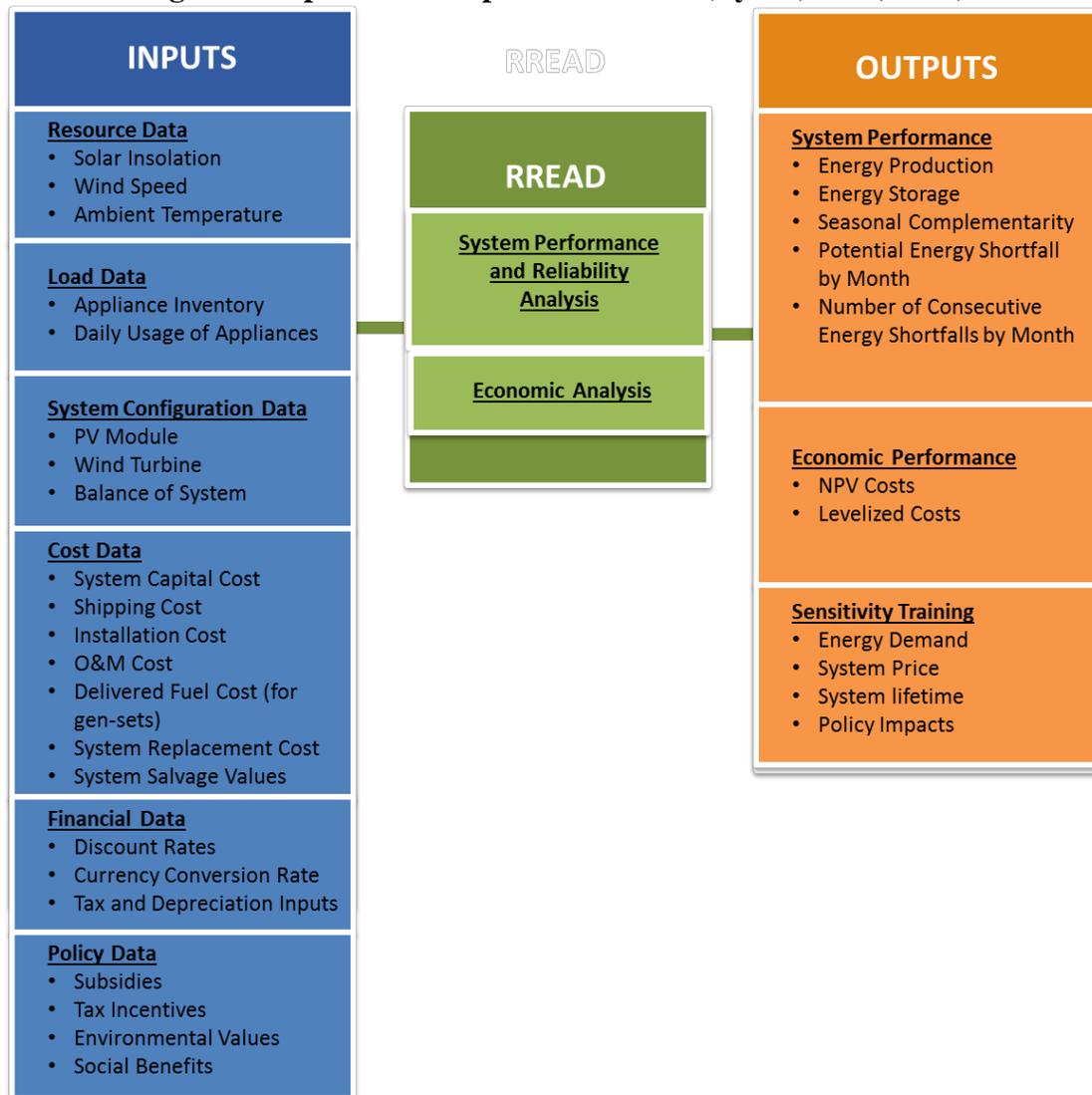
recommendations to spur market growth, reduce initial cost, and effectively manage demand (Byrne, Shen, et al., 1998).

6.2 The Rural Renewable Energy Analysis and Design (RREAD) Tool

The RREAD model was developed by the Center for Energy & Environmental Policy, in concert with the National Renewable Energy Laboratory, the World Bank, and the Chinese government to test case studies for a representative sample of 41 households from the IMAR region in China for household-scale solar PV and wind household-scale systems²⁹ (Byrne, Shen, et al., 1998). The RREAD model's data input module processes renewable energy resource profiles for solar and wind, household load data, technical specification of system configurations, system component costs, preliminary financial information (discount rates, currency conversion, and taxes and depreciation), and policy incentive scenarios (Byrne, Shen, et al., 1998). In turn, the RREAD model outputs include a system performance and reliability analysis, an NPV and LCOE-based economic performance analysis, and sensitivity testing for energy demand, costs, project lifetime, and future policy impacts (Byrne, Shen, et al., 1998). See Figure 9 for a diagram of the inputs and outputs of the model, and see Byrne, et al. (1998) for further details regarding its construction and functionality.

²⁹ While the model is focused on SHS and household wind systems rather than community micro-grids, this study and the RREAD model heavily informed this study and these modeling efforts in particular. In addition, this financial add-on can still depend on the resource data for the region and could easily aggregate multiple RREAD-modeled households, though this would ignore community-level factors in demand.

Figure 9: Inputs and Outputs of RREAD (Byrne, et al., 1998)



The economic performance functionality of the RREAD model was not designed for large, capital-intensive micro-grid systems that would need additional financing and optimized capital structure analysis, nor did it include of the perspective of a private developer, equity investor, or multilateral development bank in financing a larger-scale project. The CPE model addresses these gaps, in addition to representing a proxy pricing estimator for driving distance to the site for third-party O&M&M based

on the author's professional experience in solar asset management, providing eight pre-designed modular configurations for systems up to 77kW (Sarsoza, 2012) to reduce system design costs, providing pro forma cash flows for the project, and presenting updated cost data from 2016, courtesy of CRES, among other features.

6.3 Methodology of the CPE model

The purpose of building the CPE financial model was to provide a perspective on the type and scale of improvements on project economics that result from the CPE framework. By building a robust model for a wide range of project sizes and using modern, region-specific cost data, the model can be built to isolate potential community contributions in a cost-accurate way. Then, but using simple with-without analysis, the CPE model can give an illustrative picture of the types of effects CPE can have on project economics. This model also represents the basic engine behind what could become a vehicle for customized post-assessment modeling exercises for individual community-scale projects in the future, and is designed to be used to estimate financing component for villages under the CPE framework in tandem with the resource and load assessment capabilities of the RREAD model, though other resource assessment models with similar output could be applied.

The CPE model takes inputs in the project and cost assumptions module and assigns one of eight modular, standardized PV-powered micro-grid system configurations to the project based on the daily demand value from the resource assessment. These pre-designed system configurations represent cost savings in system design time and come from a study done in Amazonas, Brazil (Sarsoza, 2012). See Table 6 below for the Modular Configuration Table used in the CPE model:

Annual Cost Element	Modular Design 1	Modular Design 2	Modular Design 3	Modular Design 4	Modular Design 5	Modular Design 6	Modular Design 7	Modular Design 8
<i>Daily Energy Demand Minimum (kWh)</i>	0	31	34	41	49	56	63	71
<i>Daily Energy Demand Maximum (kWh)</i>	30	33	40	48	55	62	70	77
<i>Resultant total System Size (kW)</i>	9	12	15	18	20	23	25	30
<i>Associated Battery Storage Capacity (kWh)</i>	144	192	240	288	288	384	384	480
<i>Associated Number of 48kWh Battery Inverter Blocks</i>	3	4	5	6	6	4	4	5
<i>Associated Number of Micro-grid Inverters</i>	3	3	3	4	2	2	3	3
<i>Multiplier</i>	1	1	1	1	1	1	1	1
Equipment and Implementation Costs	-----	-----	-----	-----	-----	-----	-----	-----
<i>Total PV module cost</i>	\$26,000.00	\$34,666.67	\$43,333.33	\$52,000.00	\$57,777.78	\$66,444.44	\$72,222.22	\$86,666.67
<i>Battery storage cost</i>	\$14,734.80	\$19,646.40	\$24,558.00	\$29,469.60	\$39,292.80	\$39,292.80	\$39,292.80	\$49,116.00
<i>Micro-grid inverter cost</i>	\$8,307.69	\$8,307.69	\$8,307.69	\$11,076.92	\$5,538.46	\$5,538.46	\$8,307.69	\$8,307.69
<i>Battery inverter cost</i>	\$4,153.85	\$5,538.46	\$6,923.08	\$8,307.69	\$8,307.69	\$5,538.46	\$5,538.46	\$6,923.08
<i>PV Racking, cables, connectors, etc</i>	\$1,255.34	\$1,255.34	\$1,255.34	\$1,255.34	\$1,255.34	\$1,255.34	\$1,255.34	\$1,255.34
<i>Smart energy meters cost</i>	\$380.45	\$380.45	\$380.45	\$380.45	\$380.45	\$380.45	\$380.45	\$380.45
<i>Manual Labor Cost</i>	\$2,453.85	\$2,453.85	\$2,453.85	\$2,453.85	\$2,453.85	\$2,453.85	\$2,453.85	\$2,453.85
<i>Engineer and Foreman Labor Cost</i>	\$1,846.15	\$1,846.15	\$1,846.15	\$1,846.15	\$1,846.15	\$1,846.15	\$1,846.15	\$1,846.15
Equipment and Implementation (Fixed) Cost Total:	\$59,132.13	\$74,095.02	\$89,057.90	\$106,790.01	\$116,852.53	\$122,749.96	\$131,296.97	\$156,949.23

Table 6: Modular Configuration Table using CRES Data to Generate IMAR Costs for PV Micro-grids
Based on methodology developed in (Sarsoza, 2012)

Using the cost data and one of the eight modular configurations, which is automatically selected based on daily demand and 5-day battery contingency, the CPE model moves to the financing assumptions module, where, based on an input for equity IRR, minimum debt service coverage ratio (DSCR), and debt costs in the country, it can optimize the projects capital structure, calculate levelized cost of energy (LCOE), the first year electricity price, the energy price escalation rate, and total life cycle costs (TLCC) of the system. It can also generate a pro forma cash flow sheet for the project on a real and levelized basis. See Figure 10 below:

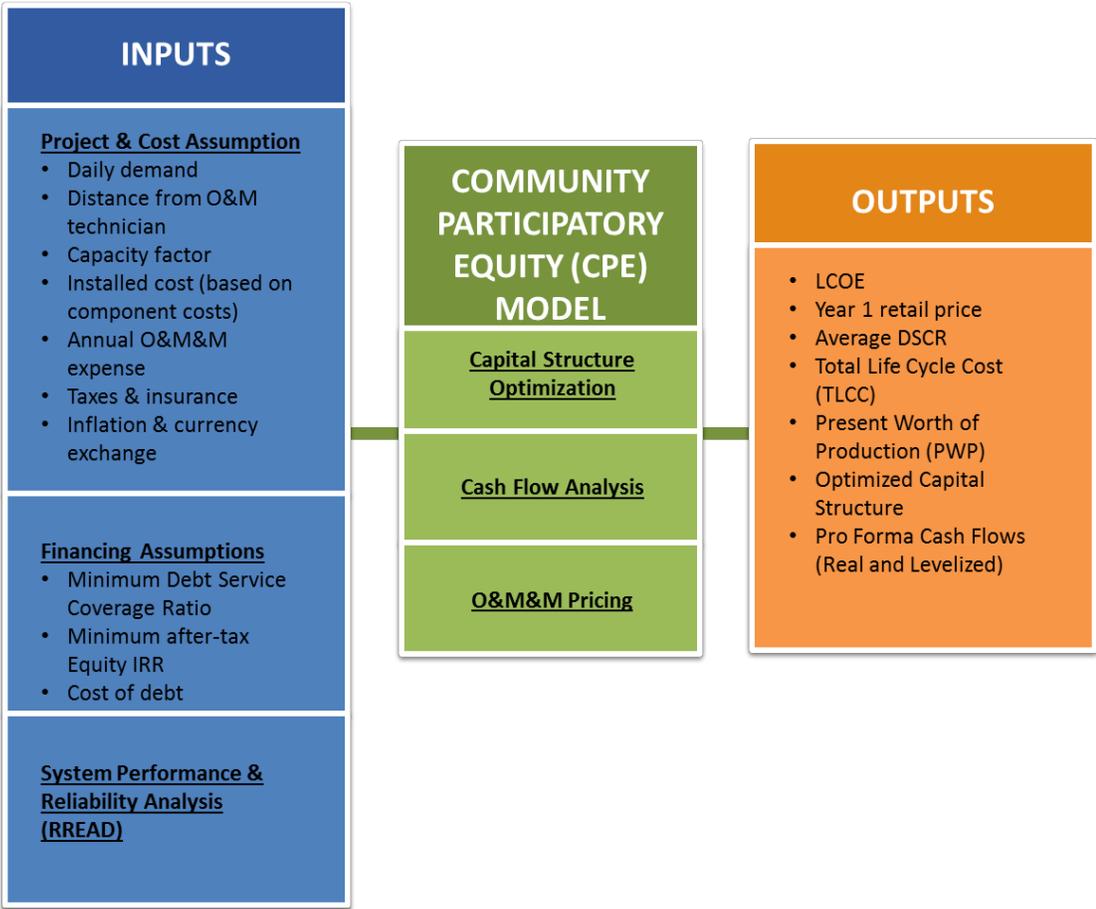


Figure 10: Inputs and Outputs in the Community Participatory Equity Model

As previously stated, the results presented are based on a number of assumptions and data points for project costs, component costs, financing costs, O&M costs, and other factors. These assumptions are summarized in Table 7 below. The entries with values that vary are included in the table in order to give a more complete representation of the model’s methodology.

Table 7: Fixed Equipment & Implementation Costs, O&M Costs, and Financing Costs Model Form

Project Variable for CPE Model	Comments and Sources for Value	Assumed Fixed Value or Range for Base Case
Community Daily Energy Demand	Input Value based on RREAD resource assessment	Variable, between 0-77kWh
O&M Technician Drivetime (hours)	Input Value based on RREAD resource assessment	Variable, model specified for up to 10 hours drive time
Project Size	Resultant Value from Daily Demand and Modular Configurations Table (See Table 6 above)	Variable, from 9kW to 30kW
Capacity Factor	PVPlanner© Software estimate for Hohhot, IMAR (Kurdgelashvili, 2008)	18.50%
Pre-Grant Installed Capital Cost (Fixed \$2015)	CPE Model auto-selects the total capital costs based on the project size and the Modular Configurations Table	Variable
Grant Value	Input Value—project grants of this type can range as high as 50% of installed costs, though here we assume no grant	0.00%
Net Installed Capital Cost after Grant (Fixed \$2015)	Pre-Grant Installed Capital Cost-Grant Value	Variable
Post-Grant Net Installed Capital Cost in \$/kW (\$2015)	(Net Installed Capital Cost after Grant)/ Project Size	Variable
Annual O&M Expense (\$/kW/year) (\$2015)	Estimated using O&M Technician Drive time, step function and cost values derived from CRES data	Variable, between \$15,384.62 and \$30,769.23
Land Expense (\$2015/year)	Anecdotally from US International Trade Commission, 300RMB per mu or	\$40

	\$40/acre annually in IMAR ³⁰	
Insurance Expense (\$2015)	Because of IMAR’s regional government-backed loans for infrastructure projects, this cost is 0	0.00%
Administration & Management Fee (\$2015/year)	This fixed fee covers the cost of	\$3,000
Property Tax Rate and Assessment (%/year of project book value)	In China, tax exemptions may be given to land occupied for energy and transportation infrastructure development upon approval of the State (China Tax Code)	0.00%
Tax Depreciation	(“China Tax Administration Guide (4)-Tax Treatment of Assets,” 2012)	Straight-line Depreciation at 10%
Effective Tax Rate	(Boekhoudt & Behrendt, 2014; “KPMG Global Taxation Tool: Indirect tax rates for 2010-2016,” 2016)	17%
Inflation Rate	(“World Bank Development Indicators Database--Inflation,” 2015)	2.0%
Nominal Discount Rate	(“Interest Rates, Discount Rate for China,” 2016)	2.9%
Exchange Rate (USD to CNY)	(“USDCNY Spot Exchange Rate,” 2016)	6.5
Delivered PV module cost (\$/W)	Derived from CRES data; this value recognizes economies of scale in delivered costs	Varies by scale
Delivered Battery Storage Cost (\$/kWh)	Derived from CRES data; 800CNY (122.79USD) for 12V 100Ah lead-acid battery (1200 W-hours)	\$102.33/kWh
Delivered 500kW Micro-grid inverter cost (\$/inverter)	Derived from CRES Data: 2CNY/W	Varies based on Modular Configurations Table
Delivered Battery inverter cost	Derived from CRES Data: 1CNY/W	Varies based on Modular Configurations Table
Delivered PV racking, cables	Extrapolated and assumed from (Mahapatra & Dasappa, 2012b;	Varies based on Modular

³⁰ All land in China belongs to the state, and ownership rights for farm leases are relatively new. The cost of agricultural lands allocated by village leaders to smallholder farmers, typically in the form of 30-year leases, is free or significantly below market value (*China’s Agricultural Trade: Competitive Conditions and Effects of U.S. Exports*, n.d.).

connectors, misc. parts, etc. (\$2015)	Quetchenbach et al., 2013)	Configurations Table
Smart Energy meters cost (\$2015)	\$93/unit for GridShare device (Quetchenbach et al., 2013) Population proxy: system size (kW)/household demand	\$93/unit*village population proxy
Unskilled Man-hours required for project construction	Derived from (Cattelaens & Fromme, 2014)	63.8 unskilled person-hours/kW
Skilled man-hours required for project construction	Derived from (Cattelaens & Fromme, 2014)	40 hours
Manual Labor Cost (\$2015)	Derived from CRES Data: 50CNY/hour*6.5 CNY/USD*hours	50CNY/hour
Electrician, Engineer, and Foreman Labor Cost (\$2015)	Derived from CRES Data: 300CNY/hour*6.5 CNY/USD*hours	300CNY/hour
Number of Years Municipal Government will pay O&M fees	This assumption is in line with previous renewable energy system performance guarantees and warranty periods from the Chinese government in the past under recommended policy changes.	5 years
Required Minimum Debt Service Coverage Ratio (DSCR)	Accepted standard Min. DSCR value for projects with similar risk profiles	1.25
Minimum Equity Return (%)	Average value for development bank financing	10%
Cost of Debt (%)	("Lending Interest Rate (%)", 2015)	5.60%

While there may be additional hidden costs present in the preparation of CPE framework systems that cannot be adequately quantified within the scope of this work, a with-without analysis is assuredly sufficient to demonstrate the effect of CPE in these specific contexts. In IMAR, component costs, taxation, and other inputs detailed above are capable of demonstrating the optimal capital structure and retail prices both before and after the institution of a CPE framework. The purpose of this modeling exercise is not to present definitive numbers for the case study region, but rather to illustrate across multiple project cases what the potential improvements in financial

metrics could be and how this de-risks these investments. This model represents a customizable vehicle for implementation in individual community contexts. Chapter 7 will present and discuss the results of this illustrative modeling work.

Chapter 7

RESULTS AND DISCUSSION

This modeling exercise is designed to illustrate the potential improvements in project economics that can occur as a result of the adoption of the CPE framework. Further, with site-specific customization, fieldwork, and data collection, this model could be a vehicle to deliver effective project financing estimation for projects in the field that have adopted or plan to adopt the CPE framework. While there may be some hidden costs not captured in this illustrative case study, this exercise assumes that adoption of the CPE framework is effectively equivalent to reducing and eliminating the included costs, which represent a significant portion of the project's recurring costs, except for the wages for the trained members of the MMC. These savings mainly occurred within the O&M, administration and management costs, and land lease fees. The fixed cost of manual installation labor can also be eliminated under the CPE framework. The retail prices are also modeled to include covering recurring O&M costs, including wages for the trained MMC members, after the specified number of years that the municipality will cover the O&M fees. When a community absorbs or reduces these costs, the CPE model shows it can lead to substantial reductions in LCOE and 1st year retail prices, especially for capital grant-subsidized projects, which can pay off the remaining principal or equity return much more quickly.

7.1 Brief Snapshot of Typical Modeled Project

While this analysis tested a range of potential project sizes within the community-scale range, it may provide a helpful view to look at the basic input data needed to model a hypothetical project using the CPE framework before the results are discussed. These metric values are all available in full detail in Table 7, but this section provides a very brief snapshot of these inputs to guide the thinking of the reader.

The model operates based on the modular input table shown in Table 6. Based on the community's daily demand, the model auto-selects a modular configuration that fits those needs. The systems modeled here represent the smaller end of the community scale for micro-grids. Average system sizes can be much larger, but for illustrative purposes, the CPE model covers systems up to 30kW. For this case study, based on household use consumption bands for a neighboring Chinese province (Liaoning) set forth by Byrne, et al. (2004, p. 36), this system size can serve approximately 87-133 households in Nei Mongol, which represents a small to medium scale village. Module, battery, and other component costs are also highly specific to location, but average about \$1-\$1.50/W (depending on system size) and \$102.33/kWh respectively in this Nei Mongol case study based on CRES data. For further context, in rural Liaoning, Byrne, et al (2004, p. 32) represent average household income as approximately \$3,900 2015USD per year. See Table 8 below for a hypothetical reference case:

Table 8: Hypothetical Reference Case for Rural PV Micro-grid

Variable	Value
Number of Households	50
System Size	30kW
Average daily use per household	2 kWh
Capital Cost of System	\$156, 949.23
First Year Price (\$/kWh)	\$0.36
Opportunity cost of monthly community contribution	4-6 hrs at wage rate (varies)

These values may help form a contextual perimeter in the mind of the reader regarding the results presented below.

7.2 Comparing the Base Case versus the CPE Framework

After running the model for a range of project sizes in increments of 5kW up to 75kW in both a base case³¹ and a CPE framework case³², it is clear there are measureable differences in project economics under the CPE framework. The key indicators used to measure these changes include LCOE, 1st year electricity price, Total Life Cycle Cost (TLCC), and capital structure (debt and equity proportions). Their values are summarized in Table 9 below.

³¹ The base case was assumed to be 3 hours drive time and to have no municipal payments as a representative project across all sizes in order to prevent polarized results.

³² The CPE framework case assumed to have 0 hours of drive time since the local community holds this responsibility (base O&M cost only) and to have 5 years of municipal O&M coverage.

Table 9: Performance of Base Case versus CPE in Key Metrics^{33, 34}

Avg. Daily Demand (kWh)	Modular System Size (kw)	Avg. Daily Production and (min. Battery Storage) (kWh)	Est. Fixed Equipment/ Installation Cost	Base Case					CPE Framework				
				LCOE	1st Yr. Price	TLCC	Debt	Equity	LCOE	1st Yr. Price	TLCC	Debt	Equity
0-30	9	35.4 (5.4 kWh)	\$59,132.13	\$2.39- \$2.47	\$1.80-\$1.86	\$246,100.93- \$254, 258.58	27%- 34%	73%- 66%	\$1.15	\$0.87	\$118,734.55	21%	79%
31-40	15	59.4 (19.4 kWh)	\$89,057.90	\$1.58- \$1.59	\$1.19-\$1.20	\$271,182.47- \$271,814.00	43%	57%	\$0.78	\$0.59	\$133,544.13	37%	63%
41-48	18	70.9 (22.9 kWh)	\$106,790.01	\$1.39	\$1.05	\$286,694.78	48%	52%	\$0.71	\$0.53	\$145,406.68	44%	56%
49-55	20	78.7 (23.7 kWh)	\$116,852.53	\$1.26- \$1.27	\$0.95-\$0.96	\$289,594.75- \$291, 226.29	48%- 49%	52%- 51%	\$0.64	\$0.48	\$146,635.07	44%	56%
56-62	23	90.6 (28.6 kWh)	\$122,749.96	\$1.11	\$0.83	\$291,305.50	49%	51%	\$0.55	\$0.42	\$145,131.76	44%	56%
63-70	25	98.44 (28.4 kWh)	\$131,296.97	\$1.05	\$0.79	\$299,744.41- \$301, 375.94	50%- 51%	50%- 49%	\$0.53	\$0.40	\$151,724.23	46%	54%
71-77	30	118.3 (41.3 kWh)	\$156,949.23	\$0.93	\$0.70	\$317,862.56	53%	47%	\$0.48	\$0.36	\$166,110.35	51%	49%

³³ Average Daily Production is estimated using an average annual irradiance value of 4.8315 kW/m²/day and the 18.5% capacity factor assumed above.

³⁴ (Minimum energy stored in battery) is a pre-roundtrip losses estimate.

Graphically, Figure 11 and Figure 12 below represent the comparison of the base case LCOE and TLCC and the CPE case LCOE and TLCC. Here, the CPE case is shown to reduce the levelized cost and the TLCC, by an average of 50.82% across all project sizes.

Figure 11: Levelized Cost of Energy (Base vs CPE)

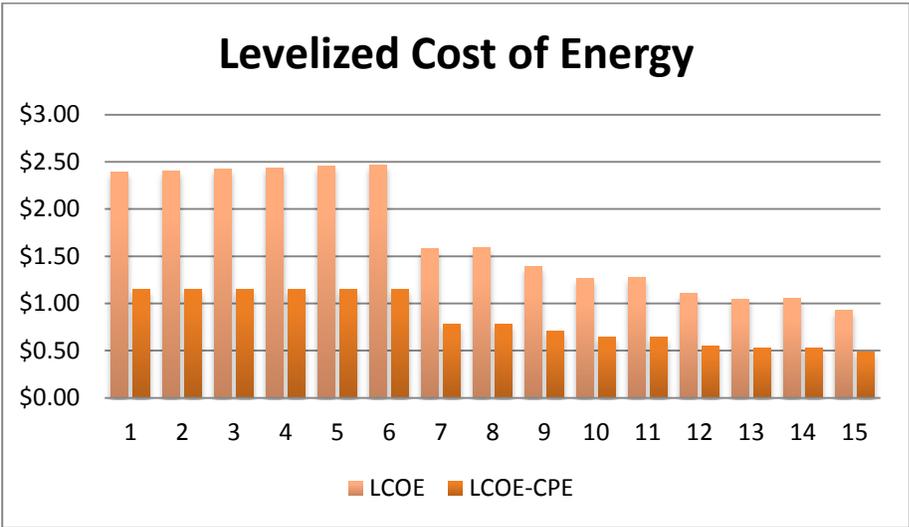
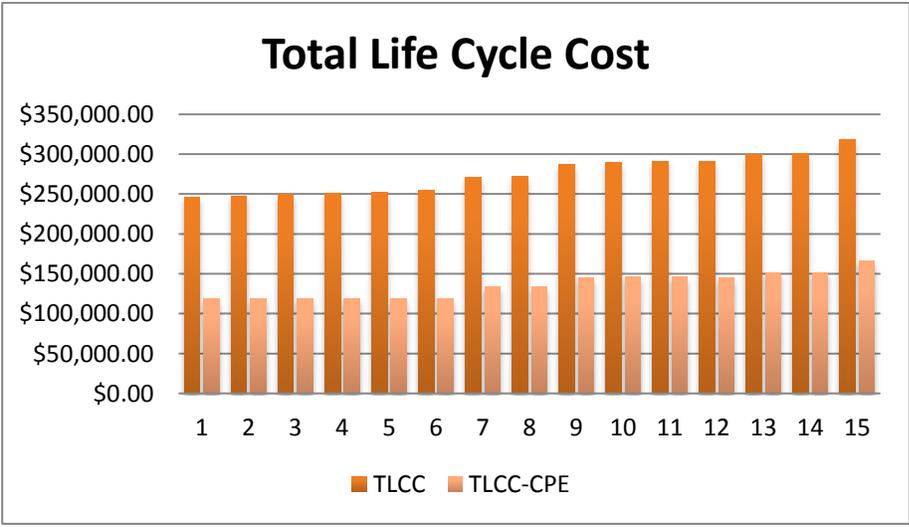


Figure 12: Total Life Cycle Cost (Base vs. CPE)



The capital structure of the project also changes by 26% toward higher proportions of debt as base case project size increases, as is seen in Figure 13 and Figure 14 below. In the CPE case, compared to the base case, this change is 30%. The average difference between the base case and the CPE framework case across all project sizes is a 6.65% increase in equity and an identical decrease in debt in the capital structure. However, when the other key driver of rural energy project economics, remoteness, is factored into this relationship, the findings show that this relationship holds³⁵. As drive time for technicians increases, optimal capital structure tends towards higher proportions of equity. Despite the fact that debt cost is nearly half of the cost of equity in this case study (5.6% versus 10%), this analysis suggests that the more remote a base case community is from O&M infrastructure, the more financially beneficial it is for them to seek equity financing, because recurring debt service payments in addition to high recurring O&M&M costs, in comparison to equity's stake in the project and resultant revenue stream, will drive the LCOE much higher than through tending towards equity financing in the capital structure.

³⁵ “The remoteness of some sites can make maintenance and repairs challenging, with high costs and long lead times for the delivery of replacement parts, which may not be available in local markets.” (Williams et al., 2015)

Figure 13: Capital Structure- Base Case

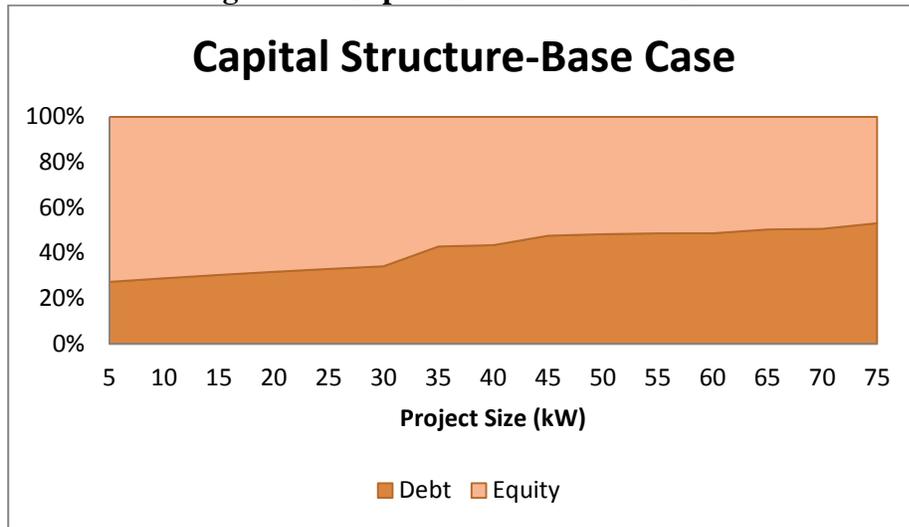
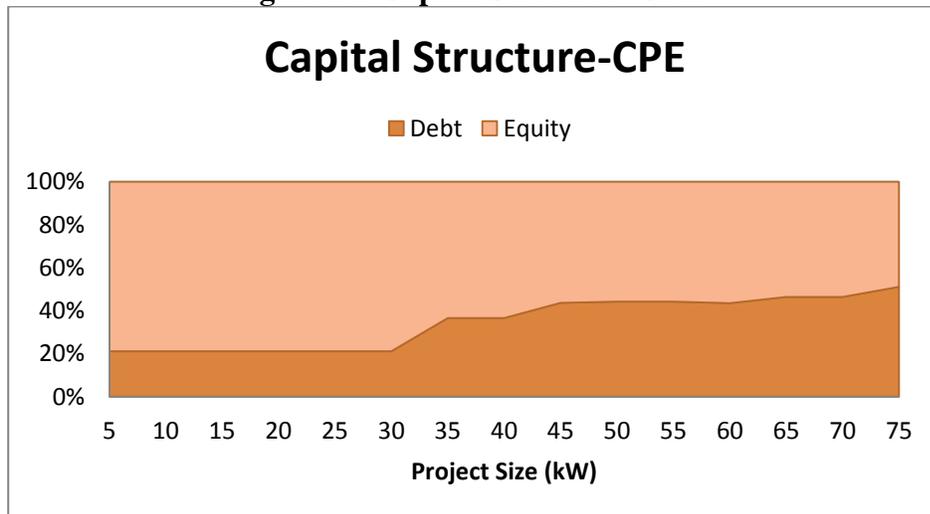


Figure 14: Capital Structure- CPE



Under the base case, remoteness is also positively correlated with LCOE, TLCC, and Year 1 price. This is the effect of increased cost for preventative and corrective maintenance in these remote areas. However, under the CPE framework, remoteness has a much smaller impact on capital structure because recurring annual costs are largely eliminated. Debt and equity proportions remain generally stable. Under CPE, the LCOE, TLCC, and Year 1 price are consistent with system size rather than daily

demand because the location of the project is effectively rendered moot on raising prices. This of course supports the case for community-managed systems. Under CPE, as system size increases, LCOE and Year 1 price decrease due to economies of scale and TLCC increases due to a higher capital cost and of course higher O&M. Table 10 below summarizes the magnitude of the changes in key metrics for rural energy project economics.

Table 10: Summary of Key Metric Changes (\$2015USD)

Key Metric	Average Change
LCOE	-\$0.88
1st Year Price	-\$0.67
TLCC	-\$139,334.42
Debt	-6.65%
Equity	6.65%

Obviously, this analysis would need to be highly customized to each individual context to be replicated in kind, a task that can be done effectively through the multidimensional framework. Some costs, such as debt cost, insurance, labor wages, driving and transportation, and replacement components can also vary dramatically. This study is limited by a few specific costs that were omitted for simplicity, difficulty in quantifying them, or data paucity, including inverter and battery replacement costs, UNDP solar-style training costs, and insurance costs. Overall, these costs might change the results, but not the core findings: CPE lowers user costs, increases the benefits to users with remoteness, and enables investors to enter the market to spur more rapid deployment of PV micro-grids. In addition, some benefits were not

included for similar reasons, such as local market development, a potential cash buy-in or membership fee, raw material values, and non-technical loss minimization. Social benefits of perceived ownership, productive use benefits to the community, and environmental benefits and carbon emissions reductions are also relevant benefits that are difficult to quantify accurately and are not central to the value of this analysis. As was illustrated by the Nei Mongol case, the CPE framework can have substantial impacts on the project economics of an islanded community-managed micro-grid, especially those with grant financed capital costs, which can represent up to 40-50% of installed costs (Mainali & Silveira, 2011). These projects especially are highly responsive to decreases in recurring costs, which is a central benefit of the CPE framework.

Chapter 8

CONCLUSIONS AND RECOMMENDATIONS

This analysis seeks to further the collective understanding of energy access by developing and applying a multidimensional energy access framework that understands the drivers and barriers to successful rural energy implementation through the lens of four dimensions: techno-economic, socio-economic, agro-economic and institutional-economic. The success of rural energy access interventions may ultimately depend on financing, and there is a \$1 trillion financing gap for rural micro-grids, a scale of intervention with significant promise for successful implementation that fosters productive uses of energy, holistic forms of energy access, and a pathway out of energy poverty.

Some suggested directions for further research in this topic area include community-driven SME business development methods to create anchor loads (as suggested by Williams, et al. (2015), the potential value of in-kind electricity-as-a-commodity payments to community-sponsored O&M laborers, clustering communities into larger-scale mini-grids to mitigate risk, and an urban-rural subsidy that feeds a grant fund for CPE-enabled community-based electrification programs as a potential solution to avoid political economy disparities.

The scale and open-access nature of micro-grids allows them to be considered as common property resources capable of attracting financing and lowering costs without a tragedy of the commons for community-managed business models. These community-managed systems have significant socio-economic benefits and can see

significant improvements in project economics through cost decreases that are instead taken on by the community rather than the third-party developer or project company.

Within the context of the multidimensional framework for energy access, this analysis is designed to illustrate a new form of financing for rural PV micro-grids based on community participatory equity. These gains can reduce LCOE by over 50%, increase with the remoteness of the project, and build the case for community-centric interventions to both policymakers and private practitioners, especially the SE4ALL initiative sponsored by the United Nations.

Development organizations, multilateral finance institutions, and governments should target capital grants and cheaper DFI equity financing to projects that have the potential to succeed under a CPE framework. Because this can allow them to have very low recurring cost responsibilities, these grants can help make the equity investor whole in the first few years of project life and therefore achieve multiplicative gains by allowing the maximization of consumer surplus and reinvestment into new projects.

Further, municipal or national governments should target funding to the provision of O&M&M fees for the first 3-5 years of the project life, such as the 3 year government warranty offered in the Nei Mongol case, allowing the LCOE to remain affordably low, even in very remote locations, and allowing project revenues to flow to the equity investor quickly, allowing the community to face the option of long-term project ownership. In doing so, such policies improve the attractiveness of projects for investors.

It is possible for the CPE model to lower the costs to users and thereby encourage holistic development driven by electrification, especially for remote

communities, as the benefits can acutely increase relative to the remoteness of the project due to inflated recurring costs. CPE models may offer the opportunity for communities and investors to design well-performing micro-grids and thereby spur rural-specific energy development, rather than demanding rural communities to urbanize their economies. For the private sector, recognizing that there is no one universally scalable solution to energy access and instead aligning the techno-economic, socio-economic, agro-economic, and institutional-economic factors involved in financing energy access projects and focusing on community-centered development can greatly inform customized energy access solutions. This can also enable an informed, targeted and nimble market entry strategy that can access and empower the enormous latent economic potential, including in women, in the last quarter of the world's population without energy access.

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APPENDIX

CHINA RENEWABLE ENERGY SOCIETY DATA REQUEST (RETURNED)



CENTER FOR ENERGY & ENVIRONMENTAL POLICY

University of Delaware

<http://ceep.udel.edu>

Requested by:

Benjamin Attia, Masters Student
Advisor: Dr. John Byrne, Director;
Distinguished Professor of Energy & Climate Policy
Center for Energy & Environmental Policy
University of Delaware
278B Graham Hall
Newark, DE 19711

Request for Data:

ATTN: Li Yuan Pu

China Renewable Energy Society

To Li Yuan Pu,

The Center for Energy & Environmental Policy kindly requests assistance in acquiring cost data for rural photovoltaic (PV) powered micro-grids in the remote parts of the Inner Mongolia region of the People's Republic of China.

Purpose and Use

This research seeks to identify phases in the project development cycle for off-grid photovoltaic and storage-powered micro-grids, propose a community financing and ownership structure for these systems, model project financing and energy production data for PV-powered micro-grids, and recommend costs suitable for participatory community equity. This research is based on previous cooperative research work done by the Center for Energy & Environmental Policy in this region. See below paper below for details.

Byrne, J., Shen, B., & Wallace, W. (1998). The economics of sustainable energy for rural development: A study of renewable energy in rural China. *Energy Policy*, 26(1), 45–54.

Focusing on the Inner Mongolia region, we are hoping you may be able to provide as many of the following values as possible to aid in our study:

Requested Variable	Units of Measure	Value
Delivered Cost of PV Module	CNY/Watt	About 4yuan
Typical capacity of PV module	Watts	260W for 60 pieces (cells)
Delivered Cost of PV Inverter	CNY/Watt	About 2 yuan
Typical capacity of PV	Watts	500kW

Inverter		
Delivered Cost of Battery Storage	CNY/Watt	12V 100Ah lead-acid battery about 800yuan
Typical capacity of Battery Inverter	Watts	Really depends the system requirement
Typical Equipment transportation cost to typical IMAR off-grid users	CNY/Hour drive or CNY/km	Depends on distance and area
Manual Microgrid Installation Labor Cost	CNY/hour	50yuan
Skilled Microgrid Installation Labor Cost (electrician/engineer/foreman)	CNY/hour	300yuan/300yuan/200yuan /hour
Labor transportation cost to typical IMAR off-grid user site	CNY/Hour drive or CNY/km	Really depends concrete situation
Annual Operations and Maintenance costs (estimate)	Average CNY/year, or based on village distance from nearest renewable energy service station	1000000--200000元/MW, average
Local diesel Gen-set fuel cost (including delivery cost to typical IMAR off-grid user)	CNY/litre	6 yuan

Additionally, if you are able to direct us to statutes or government reports on any relevant renewable energy incentive policies applicable in Inner Mongolia, that would be invaluable help as well.

If you are willing and able to fill this request, we would be deeply in your debt.

Thank you very much,
Ben Attia and Dr. John Byrne