COMMUNITY PARTICIPATORY EQUITY AS A BUSINESS MODEL FOR VILLAGE-SCALE PV MICROGRIDS

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Abstract

This working paper seeks to frame and illustrate the case for a community-based understanding of renewable rural electrification. Because the rapid deployment and acceleration of rural energy access interventions is catalytically dependent on financing, a Community Participatory Equity (CPE) business model that has the potential to de-risk last-mile micro-grid investments, aggregate decentralized rural demand, and provide modular capacity for productive use warrants further exploration. Considering micro-grids as common property resources capable of Ostromian community management without facing a tragedy of the commons, the illustrative modeling detailed here yields significant cost-driven 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 business model, especially when paired with grant financing for capital costs and early-stage operations, maintenance, and management fees, can greatly increase the attractiveness of these projects for both investors and end users and enable an informed and targeted market entry strategy for vast untapped off-grid markets.

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INTRODUCTION

Introduction

At current levels of investment, the global population facing energy poverty, currently estimated between 1.1 to 1.6 billion people, is expected to rise, not fall, by 2030 due to explosive population growth (SE4All, 2016). 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 generation 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 technologies, there is a paradoxical irony to the link between development and climate change which has left the poorest countries with the lowest emissions as the most vulnerable and most susceptible to the effects of climate change (Byrne, Wang, Lee, & Kim, 1998; Yadoo & Cruickshank, 2012, p. 591).

However, approaches for tackling the problems associated with energy poverty are often difficult to scale up because of the challenges associated with navigating this uneven technical, sociocultural, agricultural, and institutional landscape; the multidimensionality of energy access inhibits scalability of any one catch-all scalable solution. National grid extension programs and firms selling small lighting and mobile charging 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 rural electrification and increased economic potential.

In light of the enduring problem of energy poverty, this working paper builds a conceptual framework to analyze the possibility of deploying community-contributed and community-managed rural energy systems. A case study is offered using solar photovoltaic (PV)-powered micro-grids and their financing as illustration of the value of the framework. In addition, a modeling exercise is undertaken to illustrate the stages where a community's low-cost participatory equity could fill gaps where traditional financing does not reach. In rural, agrarian communities, 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.

The Financial Dimension of Energy Access

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). It is now well understood that a wealth-centric view of developmental progress is insufficient, and that poverty alleviation goes well beyond providing for basic material needs. But while there is already a clear research 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, Barnes, & Samad, 2012).

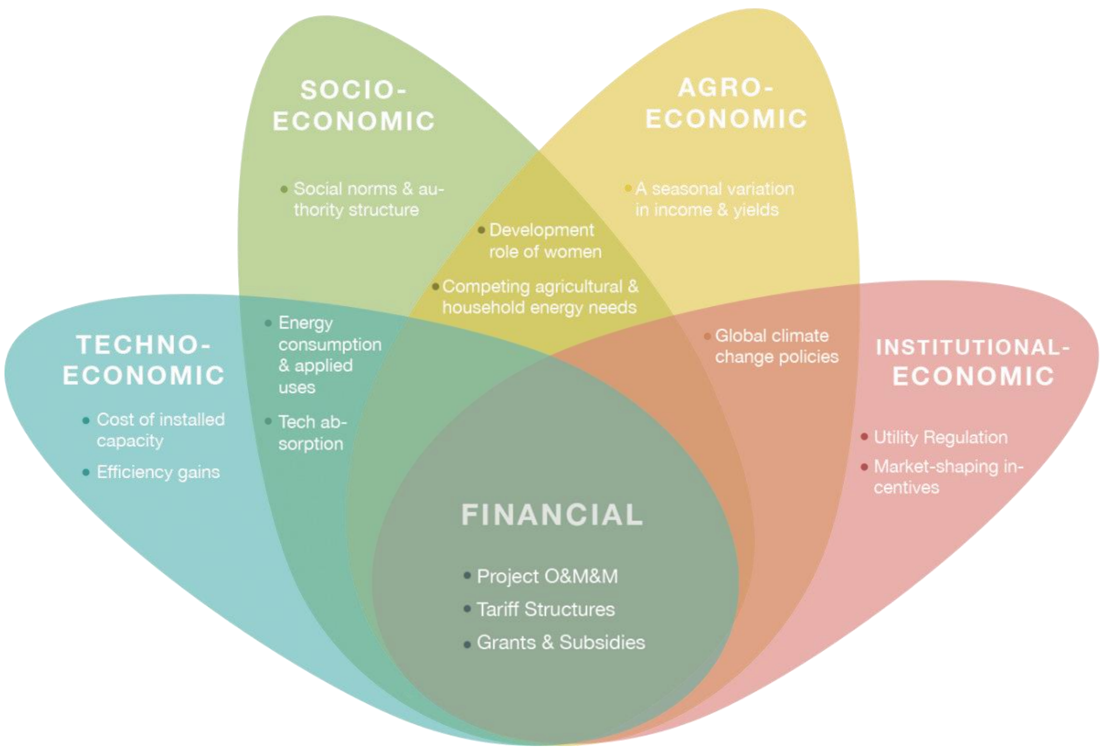
Electricity is a commodity uniquely at the root of systemic poverty, global health and disease eradication, education, gender equality, cultural exchange, economic empowerment, climate change, and environmental sustainability. In a way that other energy inputs are not, reliable access to electricity 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] 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 employees, and clients. Even where there is access, grid balancing issues, surges, and scheduled blackouts often require businesses to spend up to 60 percent of operating costs on imported diesel, LNG, and kerosene fuel (Mans, 2014).

Importantly, the factors involved in energy access for rural populations with economic barriers are all beholden to the cost and type of access. While clean cook stoves, solar home systems (SHS), 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.

Recognizing the nature of the energy access problem and identifying and categorizing the multidimensionality and key barriers to their implementation[1] should help policymakers, project

[1] The thesis upon which this working paper is based details a multidimensional framework for energy access centered on base economic arguments. In the original document, techno-economic, institutional-economic, agro-economic, and socio-economic dimensions are detailed and contextualized in their relationships to the financial dimensions that directly determine the scale of deployment of energy access interventions (see Attia, 2016).

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.



A Multidimensional Framework for Energy Access (Attia, 2016)

Traditional rural electrification initiatives have been focused on extending the centralized grid infrastructure to rural areas. However, due to factors such as low population density, low ability to pay, low access to credit, low demand, and high system losses and transmission and distribution costs, 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. As a result, micro-grid scale investments have largely fallen into a “grey space” of financing: too small for project finance, due to the thin market density, outside the realm of corporate finance, and in between World Bank funding[2] and NGO-scale work (Gershenson et al., 2015; Kraemer, 2015). It is only

[2] General project minimum investment is $20 million (Kraemer, 2015).

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). The SE4ALL initiative estimates that in the absence of significant changes, 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 called to be earmarked for micro-grids) in order to achieve universal energy access across all verticals, 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 and 134[3] billion per year (Bazilian et al., 2010). In Sub-Saharan Africa specifically, the World Bank has estimated that $11 billion per year of investment is required for universal energy access by 2030 (Brew-Hammond & Kemausuor, 2009). While these estimates 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 approximately $511 million to date at the time of writing (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, will continue to pose challenges (Glemarec, 2012; "Off-grid solar market trends report 2016," 2016).

Access to capital for investing in rural markets is a major barrier because the characteristics of rural markets often 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 foreign interest and result in inefficient development (Alstone, Gershenson, & Kammen, 2015; Rao, 2016). Despite the financing gap, it is important to recognize the atypical dynamics of these project economics to build a clear financial case for community-contributed micro-grids.

[3] "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 multination corporations (including Royal Dutch Shell, BP, Volkswagen, and Chevron), all exceeded $200 Billion each, in 2013" (Gershenson et al., 2015, p. 14).

FACTORS IN THE CREDITWORTHINESS OF RURAL PV MICRO-GRIDS

Project-level 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 losses[4], debt payments, infrastructure taxes and fees, and overhead costs for the project (Franz et al., 2014). Overhead and transactions costs "accrue through administration, coordination, social and technical problem solving, bookkeeping, reporting (to donors, lenders and authorities), and hospitability 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 losses[5] (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.

Willingness-to-pay (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). 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.

Tariff Structures

Tariffs rates and structures are dependent on project economics because the levelized cost of energy (LCOE) and the profit margin are likely to dictate the rate charged to customers. In a remote 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 may 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,

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[4] Fixed technical losses include the "self-consumption of inverters, batteries, iron losses of transformers, etc." (Franz et al., 2014, p. 42).

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

2015). Because of the significant financial risks present in thin rural markets, some countries have bundled concessions for urban and rural markets to private generators and independent power producers (IPPs) (Williams, Jaramillo, Taneja, & Ustun, 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 kerosene 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.

ISLANDED MICR0-GRID TARIFF STRUCTURES[6]

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[7] 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 demand-side management.
Flat-rate	Not based on consumption. Simply a fee for connection with unregulated use.
Flexible	Tariffs change with demand, incentivizing off-peak use. Requires advanced energy metering systems.

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). Results from community-based projects in South Asia suggest 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

[6] Adopted from Franz, et al. (2014)

[7] 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).

tariff structure, but because this tariff does not incentivize energy conservation, it may pose greater risks, such as load management risks.

The Role of Grants and Subsidies

Subsidies and grants from governments, rural electrification agencies, development banks, and NGOs can greatly improve the project economics of a rural micro-grid system. Especially for debt-laden projects, grants and capital expenditure subsidies can shorten the payback period 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, Kumar Ghimeray, & Hassan, 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, they create unsustainable quality of life increases which can put future increases at risk as subsidies are scaled back with shifting development priorities (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 because of electrification, local equity will be able phase out the current keystone role 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 through personal savings or intra-family loans, and in Yunnan, communities matched government energy subsidies 20:80 (Byrne et al., 2004; Mainali & Silveira, 2012).

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, Scott, Bates, & Corbyn, 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 twelve percent and an equity IRR of sixteen 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, Blum, & Sryantoro Wakeling, 2013). 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, Dhawan, Schurr, Paschos, & Rathee, 2014, p. 14; Gujba, Thorne, Mulugetta, Rai, & Sokona, 2012).

Because of the multidimensionality of energy access, nearly every rural renewable micro-grid project requires an entirely unique set of pre-investment diligence, which is often cost prohibitive. 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). These costs include identification costs to source potential projects, diligence costs[8] to know creditworthiness and contextually-appropriate operational models, development of legal, accounting, and insurance platform, 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 criteria and the reordering of development priorities that may be required of governments (SE4ALL, 2011).

Financial remoteness can also limit the reach of capital into last-mile environments. 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. 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). Even this overpriced capital is often in short supply, and competition for limited resources can drive these prices even higher (Sovacool, 2012; Walker, 2008). 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

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

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).

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 (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 it is important to remember that there is no single model or plan or tariff structure that will work universally. Instead, these solutions point 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 would do well to partner with local banks, microfinance organizations and NGOs who know the specific target population and their needs. Ultimately, however, any scalability or duplicability of a (capital-intensive) energy access intervention in this scale is dependent on financing to come to fruition.

A Community-based View of Energy Access

Understanding the multidimensional nature of energy poverty and the qualities and gap in micro-grid financing offers a case for a community-scale, community-centric, community-driven response to the energy access problem. 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 communities 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 section discusses the theoretical power of a community self-managing a common-access resource and presents an illustrative framework for poor rural communities to contribute in the financial dimension that can yield a significant financial gain and improve the business case to investors without threatening livelihoods or economic standing.

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 constraints[9] 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 could, in most cases, be assumed to mirror a common-access resource use scenario in terms of the joint-use rights regime. Therefore, for the purposes of this study, 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 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

[9] 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).

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)[10]. 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 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,[12] 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.

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 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,

[10] 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).

[12] "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)

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 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, Sryantoro Wakeling, & Schmidt, 2013; Schmidt et al., 2013).

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., 2013; 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 control to trained members of the village for operations, administration, and maintenance. It is essential that the members have adequate technical capacity, clarity of responsibility, and a sense of ownership over the project.

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 tribune 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 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 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.

Clear Group Boundaries	• Membership required	Internal Monitoring	• MMC monitors loads, system health, and repayment rates
Rules of use match local needs	• DSM and tariff collection schedule match harvest	Graduated sanctions for violators	• MMC can coax reluctant ratepayers using social pressure
Rules of use can be modified by members	• MMC holds jurisdiction & public voting facilitation	Accessible, low-cost dispute resolution	• MMC facilitates dispute resolution at the community level
External recognition of rules of use	• Equity investor expects dividends under MMC jurisdiction	Nested, bottom-up governance	• MMC is comprised of community members and local stakeholders

MMCs facilitate Ostromian Management

Mainali & Silviera (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.

A COMMUNITY-BASED VIEW OF ENERGY ACCESS

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 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’.

COMMUNITY PARTICIPATORY EQUITY

This subsection 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 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 below.

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 attached case study (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.

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 project in Thiba, Kenya, 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.

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 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 right to reserve excess 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.

Contributions of Local Market Development

Because of the observed benefits of electrification, 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, & Minh, 2009) and demand for productive uses facilitated because 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 (Barnes, Domdom, Peskin, & Peskin, 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.

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 discounted tariffs or even eligibility 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.

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 measurable 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.[14] 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, Shen, & Wallace, 1998; Byrne, Zhou, Shen, & Hughes, 2007). 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, such as in The Philippines (Tomei & Gent, 2015).

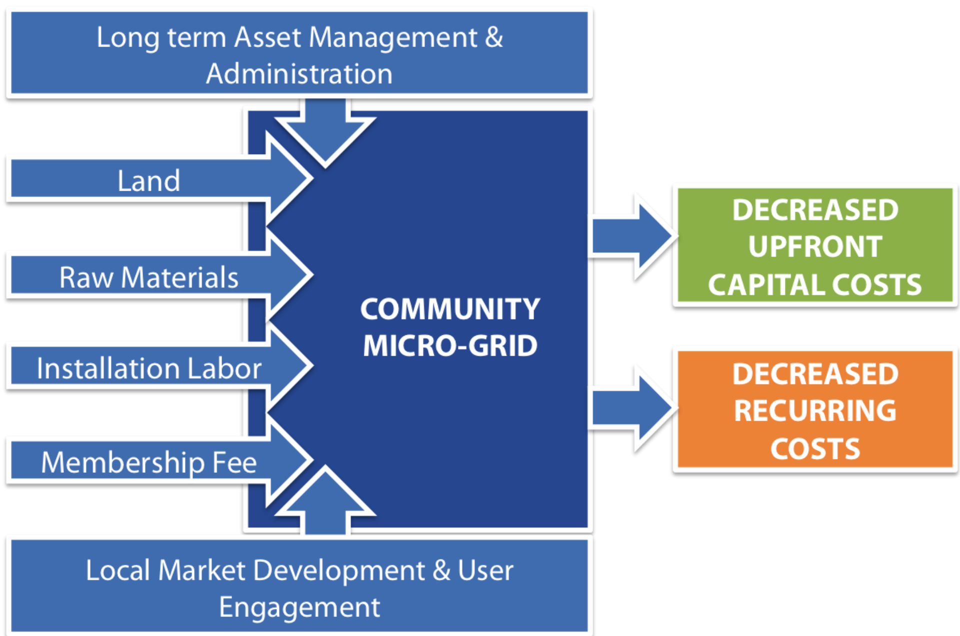
In any remote collection and administration scheme, a close relationship with the community is critical (Bardouille, 2012). Along the socio-economic dimension, informal social pressure from the locally-recognized community members with authority over the micro-grid (in various forms) have been shown 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

[14] The CPE 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.

organizations (such as farming co-ops), and of course, the implementation of an MMC-esque structure (Bardouille, 2012; Glemarec, 2012; Schmidt et al., 2013; Yadoo & Cruickshank, 2012).

In plain terms, when specific 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 clear 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 later. 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.

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. 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, Jacobson, Kammen, & Mills, 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.

Case Study Analysis: CPE in Nei Mongol, China

Using an illustrative case study near Hohhot, Nei Mongol, China informed by recent cost data from the Chinese Renewable Energy Society (CRES)[15], 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 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.

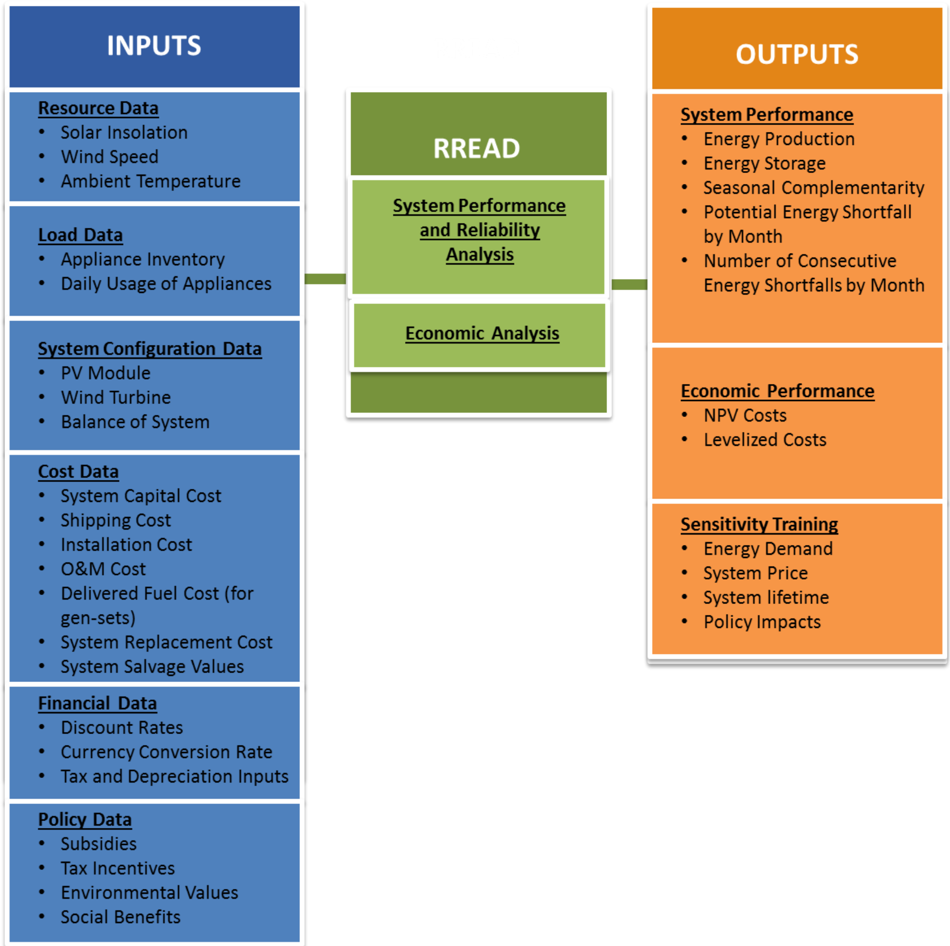
THE RURAL RENEWABLE ENERGY ANALYSIS AND DESIGN (RREAD) MODEL

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 systems[16] (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).

[15] The author would like to recognize Li Yuan Pu and the rest of the CRES team for their invaluable help in obtaining this data.

[16] 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.

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.

CASE STUDY ANALYSIS: CPE IN NEI MONGOL, CHINA

METHODOLOGY OF THE CPE MODEL

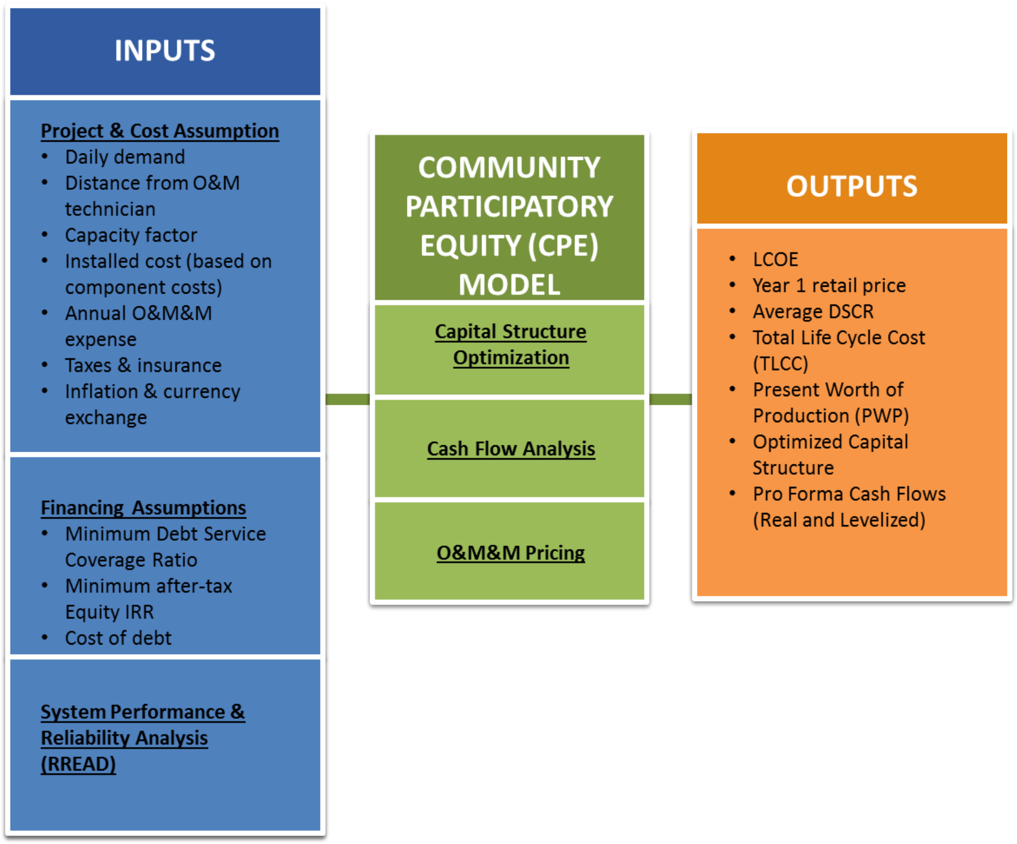
The purpose of building the CPE financial model was to provide a perspective on the type and scale of improvements on project economics that result from the CPE framework. By building a robust model for a wide range of project sizes and using modern, region-specific cost data, the model can be built to isolate potential community contributions in a cost-accurate way. Then, using simple with-without analysis, the 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 are idea-sourced from a study done in Amazonas, Brazil (Sarsoza, 2012).

MODULAR CONFIGURATION TABLE USING CRES DATA TO GENERATE IMAR COSTS FOR PV+STORAGE MICRO-GRID

ANNUAL COST ELEMENT								
Daily Demand Range (kWh)	0-30	31-33	34-40	41-48	49-55	56-62	63-70	71-77
Resultant System Capacity (kW)	9	12	15	18	20	23	25	30
Associated Storage Capacity (kWh)	144	194	240	288	288	384	384	480
Associated Number of 48kWh Battery Inverter Blocks	3	4	5	6	6	4	4	5
Associated Number of Micro-grid Inverters	3	3	3	4	2	2	3	3
EQUIPMENT IMPLEMENTATION COSTS (2015USD)								
PV Modules	26,000	34,666	43,333	52,000	57,777	66,444	72,222	86,666
Battery Storage	14,734	19,646	24,558	29,469	39,292	39,292	39,292	49,116
Micro-grid Inverters	8,307	8,307	8,307	11,076	5,538	5,538	8,307	8,307
Battery Inverters	4,153	5,538	6,923	8,307	8,307	5,538	5,538	6,923
Racking, Cables, Connectors, etc.	1,255	1,255	1,255	1,255	1,255	1,255	1,255	1,255
Smart Metering	380	380	380	380	380	380	380	380
Unskilled labor	2,453	2,453	2,453	2,453	2,453	2,453	2,453	2,453
Engineer & Foreman Labor	1,846	1,846	1,846	1,846	1,846	1,846	1,846	1,846
Equipment & Implementation (Fixed) Cost Total:	59,132	74,095	89,057	106,790	116,852	122,749	131,296	156,949

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 also generates a pro forma cash flow sheet for the project on a real and levelized basis.



Inputs and Outputs in the Community Participatory Equity Model

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

FIXED EQUIPMENT & IMPLEMENTATION, O&M, AND FINANCING COSTS MODEL FORM

PROJECT VARIABLE IN CPE MODEL	COMMENTS AND SOURCE	BASE CASE VALUE
Community Daily Energy Demand	Input Value based on RREAD resource assessment	Variable, 0-77kWh
O&M Technician Drive time (hours)	Input Value based on RREAD resource assessment	Variable, model specified for 0-10hrs

Project Size (kW)	Model-determined based on daily demand and modular configurations table	Variable; 9-30kW
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, model specified
Post-Grant Net Installed Capital Cost in $/kW ($2015)	(Net Installed Capital Cost after Grant)/ Project Size	Variable, model specified
Annual O&M Expense ($/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/acre annually in IMAR17	$40
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

17 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.).

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 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 connectors, misc. parts, etc. ($2015)	Extrapolated and assumed from (Mahapatra & Dasappa, 2012; Quetchenbach et al., 2013)	Varies based on Modular 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%

CASE STUDY ANALYSIS: CPE IN NEI MONGOL, CHINA

In IMAR, component costs, taxation, and other inputs detailed above can demonstrate 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.

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 first year retail prices, especially for capital grant-subsidized projects, which can pay off the remaining principal or equity return much more quickly.

The model operates based on the modular input table shown above. Based on the community's daily demand, the model auto-selects a modular configuration that fits those needs. 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 between 87-133 households in Nei Mongol, which represents a small-medium scale village. Module, battery, and other component costs are also highly location-specific, but are assumed between $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 (2015USF adjusted) per year.

HYPOTHETICAL REFERENCE CASE FOR A RURAL PV MICRO-GRID

VARIABLE	VALUE
Number of Households	50
System Size	30kW
Household Average Daily Use	2 kWh
Capital Cost of System	$156,949.23
Year 1 Tariff	$0.36/kWh
Opportunity Cost of Monthly Contribution	4-6 hours at individual wage rate (varies)

CASE STUDY ANALYSIS: CPE IN NEI MONGOL, CHINA

After running the model for a range of project sizes in increments of 5kW up to 75kW in both a base case[18] and a CPE framework case[19], it is clear there are measurable differences in project economics under the CPE framework.

PERFORMANCE OF BASE CASE AGAINST CPE IN KEY METRICS[20,21]

AVG. DAILY DEMAND (kWh)	0-30	31-40	41-48	49-55	56-62	63-70	71-77
Base Case							
Modular System Size (kW)	9	15	18	20	23	25	30
Avg. daily kWh produced (min. storage in kWh)	35.4 (5.4)	59.4 (19.4)	70.9 (22.9)	78.7 (23.7)	90.6 (28.6)	98.44 (28.4)	118.3 (41.3)
Est. Fixed Equipment/ Installation cost ($)	59,132	89,057	106,790	116,852	122,749	131,296	156,949
LCOE ($/kWh)	2.47	1.59	1.39	11.27	1.11	1.05	0.93
Year 1 Tariff ($/kWh)	1.86	1.20	1.05	0.96	0.83	0.79	0.70
TLCC ($)	254,258	271,814	286,694	291,226	291,305	301,375	317,862
Debt/Equity Ratio Cap (%/%)	34/66	43/57	48/52	49/51	49/51	51/49	53/47
CPE							
LCOE ($/kWh)	1.15	0.78	0.71	0.64	0.55	0.53	0.48
Year 1 Tariff ($/kWh)	0.87	0.59	0.53	0.48	0.42	0.40	0.36
TLCC ($)	118,734	133,544	145,406	146,635	145,131	151,724	166,110
Debt/Equity Ratio Cap (%/%)	21/79	37/63	44/56	44/56	44/56	46/54	51/49

As can be seen in the comparison above, the CPE regime reduces levelized cost and TLCC by an average of 50.82% across all project sizes. The capital structure of the project also changes by 26% toward higher

[18] The base case was assumed to be 3 hours' drive time and to have no municipal payments as a representative project across all sizes to prevent polarized results.

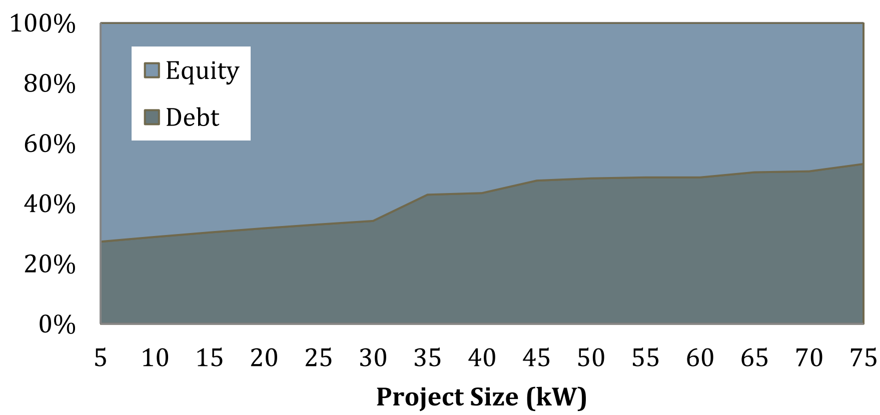
[19] The CPE framework case assumed to have 0 hours of drive time since the local community holds this responsibility (base O&M cost only) and to have 5 years of municipal O&M coverage.

[20] Average Daily Production is estimated using an average annual irradiance value of 4.8315kW/m^2/day and the 18.5% capacity factor assumed above.

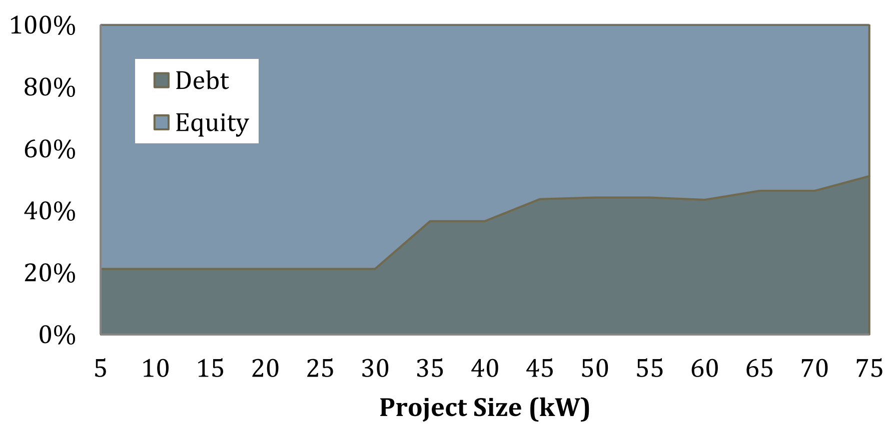
[21] (Minimum energy stored in battery) is a pre-roundtrip losses estimate.

proportions of debt as base case project size increases. 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 holds. 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.

Capital Structure under Base Case



Capital Structure under CPE Framework



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 First year 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.

SUMMARY OF KEY METRIC CHANGES (IN 2015USD)

KEY METRIC	AVERAGE CHANGE ACROSS PROJECT SIZES
LCOE	-$0.88/kWh
1st Year Price	-$0.67
TLCC	-$139,334.42
Debt/Equity Ratio	-6.65% Debt / +6.65% Equity

Of course, 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.

CONCLUSIONS

Conclusions

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 and seeks to unlock the potential of community-managed PV-plus-storage 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.

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 three-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, 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 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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