Microgrids for Rural Electrification:

A critical review of best practices based on seven case studies

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A street with distribution lines at a WBREDA microgrid site on Sagar Island, India.

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Table of Contents

List of Tables

List of Figures

Acronyms

ARE - Alliance for Rural Electrification

BM – Build-Maintain

BOOM- Build-Own-Operate-Maintain

CREDA – Chhattisgarh Renewable Energy Development Agency

DESI - Decentralized Energy Systems of India, or DESI Power

DSM – Demand Side Management

EDH - Electricité d'Haiti

ESMAP - Joint UNDP/World Bank Energy Sector Management Assistance Program

GE/T/P – Green Empowerment/Tonibung/PACOS

HPS – Husk Power Systems

kW - Kilowatt

MDG - Millennium Development Goals

NGO – Non-Governmental Organization

O&M&M – Operations, Management, and Maintenance

OREDA – Orissa Renewable Energy Development Agency

PACOS - Partners of Community Organizations Trust in Sabah

SME – Small and Medium-sized Enterprises

UNDP – United Nations Development Programme

VEC – Village Energy Committee

WBREDA – West Bengal Renewable Energy Development Agency

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Finally, the analysis and views presented in this report are those of the authors and do not necessarily reflect the official positions of the supporting organizations. We are solely responsible for any mistakes and omissions.

A worker loads rice husk into bags at a Husk Power Systems microgrid site in Bihar, India.

Foreword

Mini-grids, or microgrids, depending on one's own personal preference in terminology, have arguably been the fastest changing, most dynamic aspect of the global energy system over the past several years. What started as an interesting set of tremendously diverse and largely locally unique cases of small (systems up to roughly 100 kW, although the range of definitions rivals the number of such systems!) has become scientifically, technically, politically, organizationally, and socially a true hot-bed of innovation. Microgrids are popping up all over the world, from systems that can connect or disconnect from larger 'main' grid systems, to tiny, informally wired connections between very few users.

Some remarkable success stories exist – from high-altitude communities in Nepal anchoring increasingly sophisticated local grids around mountain streams, to solar and biomass powered oases of energy access in rainforests around the globe, to areas in East Africa, India, and the U. S. and Russian arctic that are finding that the reliability, rapidity of development, and flexibility of microgrids makes them ideal resources to improve the quality of life and promote development in areas not slated for large-scale energy connectivity for decades.

These microgrids are building on increasingly modular natural and bio-gas combusting turbines, solar, wind, biomass, hydro and geothermal generation technologies that are improving rapidly in cost and performance. This technical evolution is made all the more exciting by changes in networking technology – both for power management and end-user service, and in the increasingly critical information technology sphere that enables improved billing, load management and remote diagnostics.

All of these changes mean than microgrids are now evolving at a blinding pace, with new technologies and new applications and new companies appearing literally daily. In East Africa new, entirely mobile-phone based banking has changed the financial face of Kenya, with other nations developing their own versions as we write this report.

All of this activity begs the key question: how are the microgrids doing that now exist? Is this wave of excitement a harbinger of a new, distributed energy world, or a 'bubble' that is hugely promising, but needs a much greater degree of care and precision to prevent user disappointment.

This report is a hard-edged assessment of that progress and of the needs in the world of microgrids. With case studies evaluated in detail form the Americas, India, and southeast Asia, we describe on-the-ground challenges, and examine how local communities, public agencies and private sector actors have managed and evolved these systems. A research team consisting of two faculty advisors and project directors (Prof. Apt and myself), and a remarkable and dynamic set of students have engaged in this analysis.

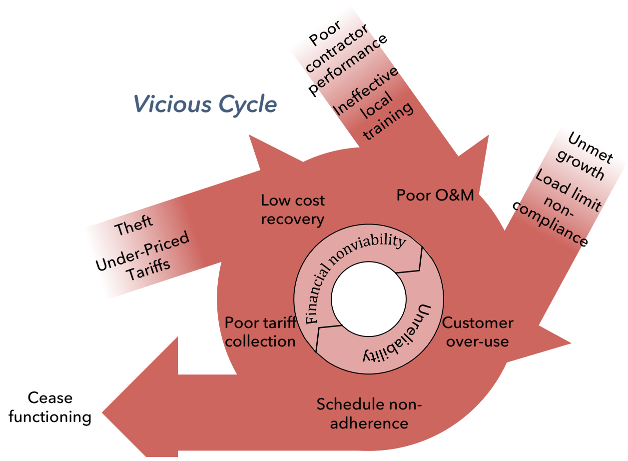
Our findings are detailed in not only the case studies, but in cross-case study analysis that highlights what we call the 'virtuous' and 'vicious' circles of positive, and sometimes, negative technology-human interactions that render some systems and business models exciting examples of a new energy economy – and some cautionary tales that may need some significant adjustments.

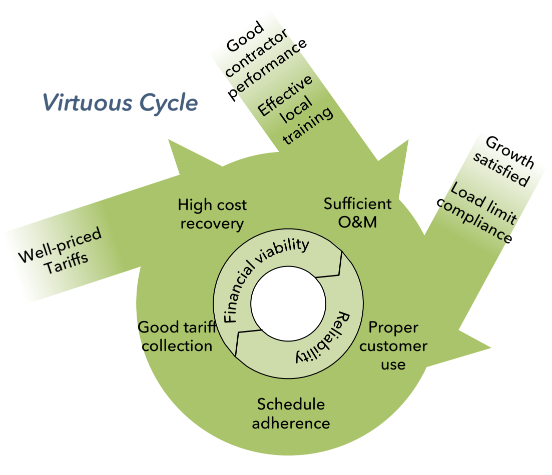
These cases are not complete spatially (Africa is not represented in this set of case studies, but will be covered in a subsequent publication) or in terms of project 'completion' (because the microgrids themselves are always evolving), but they do raise a wide range of key issues that will benefit the entire research and practitioner, and policy community. The lessons range from issues of providing access, to how mini-grids impact larger, regional and national grids, and how microgrids can and could impact global greenhouse gas emissions.

Overall we invite a dialog with the readers as reports like this need to be made into living documents, and to be re-done as new data appears. To that end, I have listed the web and other addresses of my laboratory – the Renewable and Appropriate Energy Laboratory, http://rael.berkeley.edu – as one way to network and work together to that microgrids can achieve the remarkable promise that we see in their future.

Daniel M. Kammen
Class of 1935 Distinguished Professor of Energy
Founding Director, Renewable and Appropriate Energy Laboratory
University of California, Berkeley

Microgrids – distributed systems of local energy generation, transmission, and use – are today technologically and operationally ready to provide communities with electricity services, particularly in rural and peri-urban areas of less developed countries. Over 1.2 billion people do not have access to electricity, which includes over 550 million people in Africa and 300 million people in India alone (International Energy Agency, 2012). In many of these places, the traditional approach to serve these communities is to extend the central grid. This approach is technically and financially inefficient due to a combination of capital scarcity, insufficient energy service, reduced grid reliability, extended building times and construction challenges to connect remote areas. Adequately financed and operated microgrids based on renewable and appropriate resources can overcome many of the challenges faced by traditional lighting or electrification strategies. This report is intended for microgrid practitioners, or those interested in better understanding real-world challenges and solutions regarding microgrid deployment and maintenance.





In this report we unearth a set of critical components – Strategic Planning, Operations, and Social Context - that explain why the twelve microgrids we visited thrive or struggle, or as we have labeled it, enter **virtuous** or **vicious** cycles. Virtuous cycles are achieved through the production of (i) sufficient revenue to support the grid and (ii) service and schedule reliability to keep consumers as loyal customers. Alternatively, vicious cycles are characterized by a chain of poor maintenance, disappointed customers, insufficient revenue and dysfunctional community support. We find seven critical factors that should be thoughtfully planned for: tariff design, tariff collection mechanisms, maintenance and contractor performance, theft management, demand growth, load limits, and local training and institutionalization. In Chapters 6 and 7 we describe how these factors inform practices that lead to vicious or virtuous cycles and their short- and long-term dynamics.

We find that not every practice is equally relevant, and depends on the type of business model set up by a specific developer: for-profit (FP), partially subsidized (PS), and fully subsidized (FS). The FP category includes developers that need to fully cover ongoing costs from tariff collection, in addition to a return on the non-subsidized portion of the capital cost, if any. The PS category is based in large subsidies for capital costs, but relies on tariff based cost recovery to cover operations and maintenance. The FS category is a model in which the costs are fully subsidized by governments, in-kind contributions from the community are common, and below cost recovery tariffs nominally cover part of maintenance, operation, and administration expenses, but often do not end up being collected over time.

For-Profit Model Insights

In terms of strategic planning, FP developers can secure virtuous cycles by carefully studying and selecting their customer base. For example, effective developers purposefully design their operational model around commercial customers with whom they defined respective requirements and expectations of price, service and reliability. The use of so-called “anchor tenants” – typically larger commercial loads – is becoming increasingly recommended as a best practice for microgrids. Developers find that “diesel can pave the way for biomass," and places with existing diesel-powered microgrids are likely to be good candidates for their systems.

Operationally, FP developers are mostly concerned with adequate tariff collection, for which there does not seem to be a silver bullet. Methodologies ranged from high-tech solutions such as pre-paid meters to frequent tariff collection schedules. Bonuses have been offered to increase rates of tariff collection, although experiences show these rarely induce improved performance from collectors.

Social context is not as critical to FP as to other business models. However, successful developers strive to provide prompt customer service through 24/7 hotlines and consequent on-site visits to solve technical problems, thus ensuring a loyal and paying customer base. Experience suggests that models that rely heavily on local staffing by the developer or involvement with local government in operations should be minimized (Casillas and Kammen, 2010). This perspective is exemplified by a quote from one developer: "rural electrification is not grassroots."

Partially Subsidized Model Insights

In terms of strategic planning, PS developers follow FP ones as they aspire to obtain sufficient funds for O&M through tariff collection by serving customers with reliable power. As such, the strategic planning phase is geared towards forecasting load, planning for load growth, and ensuring resource adequacy. Due to an emphasis on social outcomes, these developers do not heavily prioritize customer selection based on ability to pay, though they tend to strike a mid-point between serving profitable customers and an entire village regardless of ability to pay.

Operationally, PS developers prioritize grid reliability to maintain a steady flow of revenue that covers their ongoing expenses. Since these developers often serve relatively poorer villages and hamlets, it is fundamental for them to strive for schedule and energy service reliability to keep customers loyal. If not, results are disastrous, as in the case of Haiti's municipal microgrids that fell into a classic vicious cycle of schedule unreliability due to fuel and maintenance costs that exceeded tariff collection.

Social context is important for these developers as virtuous cycles have shown to prevail on microgrids with adequate community management. The PS model, which simultaneously espouses private sector values for financial and operational sustainability and public sector values for inclusion, must balance the focus on factors that improve cost recovery with effort on factors that improve community cooperation.

Fully Subsidized Model Insights

Strategic planning for FS operators in virtuous cycles focuses on building local capacity for managing, operating, and maintaining the microgrid prior to its deployment. In India, Village Electricity Committees are used as institutions responsible for nearly all aspects of microgrid operations. Another critical aspect of strategic planning that FS developers are concerned with is scale, as they are often mandated to prioritize service coverage to large portions of their villages, even if many are unable to pay cost recovery tariffs. To meet these goals of scale and service coverage, these developers often deploy many low-capacity grids designed to serve a large number of customers with lighting services only. While this level of service is often sufficient in the near term, customers quickly demand power for larger loads.

Since cost recovery is not a relevant issue for these developers, the virtuous cycle in operations requires dedication to preventive and corrective maintenance, both by contractors and community labor contributions. Competitive bid solicitation for service contracts with very specific tasks and short durations appears to be a useful strategy that produces better results than the long-term, ambiguous and difficult to monitor contracts that are often the norm for government agencies.

Social context for virtuous cycles entails ongoing legitimization of the local committee or its equivalent within its role in microgrid development and operations. However, broader social and cultural historic arrangements will affect a community-based microgrid even to a point where a vicious cycle is inevitable, such as witnessed in cases in India. While community involvement in operations presented difficulties, involvement in microgrid commissioning and development, prior to operations, was often

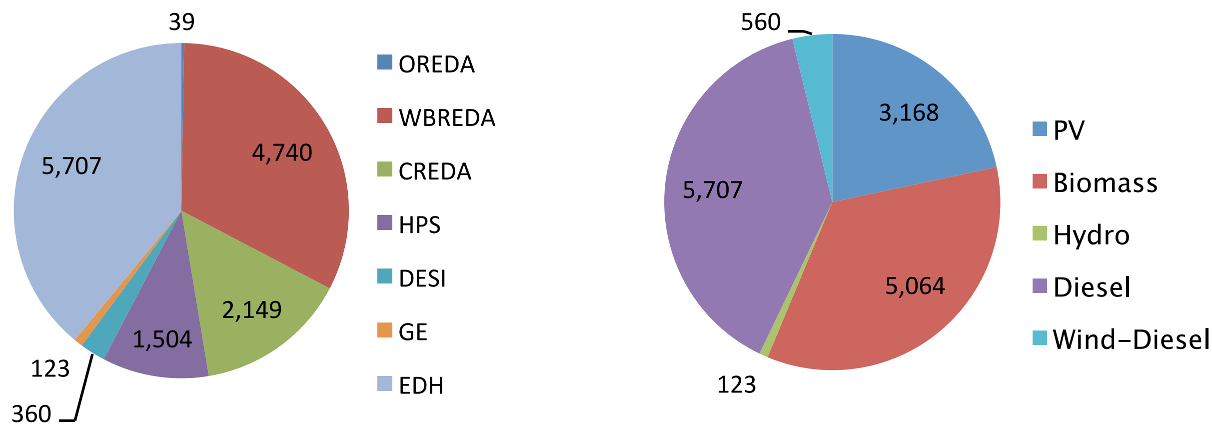


Figure 1: Installed capacity (kW) in 2012, by developer (L) and by generation type (R)

instrumental in establishing a virtuous cycle at the outset. Avoiding a vicious cycle during the operating phase may require an institutional structure that prevents community dynamics from interfering with reliable operations of the microgrid.

Microgrid systems substantially differ in their business, financial and organizational models, as they depend on size, technology, demand, resource availability, social context, and quality and quantity of the service they strive to provide. To grasp the implications for sustainability of microgrid systems' differences, we visited twelve microgrids in India, Malaysia, and Haiti in January 2013 to capture a small sample of this diversity. We surveyed the seven developers who owned these twelve microgrids, ranging from government agencies that completely depend on subsidies to private developers that recover operating costs through tariff collection. The seven microgrid developers included in this research are located in India (OREDA, WBREDA, CREDA, Husk Power Systems, DESI Power), Malaysian Borneo (Green Empowerment) and Haiti (Électricité d'Haïti). The developers themselves represent a significant diversity – from business model to geography to the policies they interact with and the financing sources available to them. Collectively, these developers have installed 787 microgrids with an installed capacity of over 15 MW since the mid-1990s. **Figure 1** presents the installed capacity for the developer portfolios by developer and by generation type. In Chapters 3 and 5 we characterize these systems, their developers, and the lessons they have learned during their operation in detail.

Through the lens of these case studies, we critically reexamine the recommendations in the existing microgrid literature on best practices for microgrid operations. In doing this, we take into account developers' varying objectives, which range from delivering societal benefits to delivering profits to shareholders.

A small number of guides and reports on rural electrification and microgrids delineate "best practices" in microgrid planning, operations and maintenance. This report divides the recommendations from the literature into three broad clusters as shown in **Figure 2.** "Strategic Planning" groups a set of practices that reduce uncertainty and risk for the developer, including market and supply chain assessment, technological choices, and government policy. Under "Operations" we have clustered technical, commercial, and financial practices that pertain to the microgrid enter-

Figure 2: Macro areas for best practices in microgrid planning

prise. Finally, "Social Context" gathers activities relating to community involvement and service.

Microgrid literature emphasizes the importance of considering a diverse set of factors that affect the technical design of the microgrid system as well as the repercussions of a chosen design on its operational structure. Specifically, the consensus "best practice" with respect to design is that developers should not design the system based on "pure technological considerations, but instead adapt to the specific social and economic characteristics of the rural community" (Alliance for Rural Electrification, 2011, p. 51).

While the best practices from the literature offer important insights into microgrid operations, the purpose of the case studies was to use the experiences of developers in the field to assess the value of these practices. We obtain a new set of lessons learned, which incorporate the unique challenges and opportunities that arise in the field and range from insights into government policies and subsidy models to operational considerations like tariff collection. Our objective in publishing these case studies and lessons is to improve the likelihood of success for developers who face the unpredictability and idiosyncrasies of the real world on a daily basis.

We conclude the report by linking these strategic, operational, and social practices with public policy making. Adequate policy design helps microgrids to follow virtuous cycles by guaranteeing access to sustainable revenue streams through: a mix of proper tariff regulation, ongoing subsidies, facilitating access to private capital and supporting grid-injection from microgrid generation once the central grid arrives. We hope that our recognition of specific business models, factors, and the way they interact to produce virtuous or vicious cycles will help both private and public entities in effective and sustainable deployment of microgrids.

An OREDA employee examines the wiring of a PV installation in rural Orissa.

Technological advances and improvements in monitoring, controlling, and payment collection for microgrids have changed the tools available to provide energy services dramatically. As a result, microgrids today have enormous potential as part of the global effort to provide electricity access to the 1.2 billion people who currently do not have access to electricity (Oxfam, 2012; Palit et al., 2013; International Energy Agency, 2012). Governments, private developers, and NGOs throughout the world have been pursuing microgrids to electrify communities that are unlikely to be served in the near- or medium-term by extensions of traditional centralized, grid systems. As a result, the number of microgrids being developed is increasing rapidly.

These microgrids provide a range of services, from residential lighting alone to entertainment, refrigeration and productive commercial uses like milling. Depending on the number of customers served, the types of services provided, and the type of generation technology used, the installed capacity of a microgrid ranges from as little as 1 kW to as large as a few hundred kilowatts.

Micro-grids employ various generation resources that include diesel, solar photovoltaics (PV), micro-hydro, and biomass gasification, as well as hybrid technologies such as wind-diesel and PV-diesel. Diesel-based microgrids are by far the most common throughout the world, given the relatively low upfront capital cost of the generator and its widespread availability. Micro-hydro-based microgrids are typically run-of-the-river type schemes where the water from a river or stream is diverted through a pipe into a turbine to generate electricity. Biomass gasifier systems produce syngas through incomplete combustion of biomass, which is burned in an engine to run a generator. Both micro-hydro and biomass gasifier systems are limited to areas with adequate water and biomass supply respectively. Solar PV systems have become popular mainly due to the recent reductions in the global market price of PV modules and reduced cost of solar PV equipment. Both solar PV and wind systems typically employ a battery storage system to smooth out supply and store the electricity for times when it is needed most. As discussed further in Chapter 3, the microgrids included in our case studies employ diesel, solar PV, micro-hydro, and biomass gasification to generate electricity.

The capital costs of microgrids also vary widely, as illustrated by the costs of many of the microgrids included in our case studies that are provided in this report. Very often, capital costs range from tens of thousands to hundreds of thousands of US dollars (USD). Prices paid by customers for electricity is dependent on several factors, including capital costs, operations & maintenance (O&M) costs, subsidies, and the degree to which a developer needs to recover these expenses. In nearly all cases, though, the price paid by microgrid customers for electricity is far less than the price paid for kerosene and candles for lighting (ESMAP, 2000).

The increased attention and the push to scale up the deployment of microgrids creates pressure for developers to succeed. Disappointing performance results could result in a backlash against microgrids into the suite of energy access options. Such a backlash has been a problem before, with new energy service options such as solar home systems (Duke et al., 2002) that significantly expanded the means to provide electricity, but also saw low-quality hardware and insufficient customer support result in localized market spoilage. In the case of solar home systems, quality assurance testing and reporting to both producers and potential customers improved product quality and supported the expansion of distributed household-based solar energy systems in a number of countries (Jacobson and Kammen, 2007).

This cautionary tale is important to note because further development and sustained operation of microgrids face a similar challenge. Recent reports show that in a number of settings, some microgrids are observed to fall into an under-performing or even into a non-working state far before the end of their expected lifetime (Palit et al., 2013). Such failures are sometimes due to the initial installation of technology not being suitable to local conditions or customer usage but are more often due to inappropriate management of funds, inadequate training and unavailability of parts for proper maintenance of the systems.

New and innovative business and financing models for microgrid development in developing countries have recently emerged, and interest in the sector continues to rise. Multilateral institutions like the United Nations and the World Bank have expressed explicit support for microgrids, and traditional electric utility consulting firms like Navigant and DNV KEMA are beginning to offer microgrid-focused services (United Nations Foundation, 2013). Given this activity, there is tremendous value in investigating what is working as well as what needs improvement in the design, deployment, and operation of microgrids. This report will both examine and present data on prior distributed energy efforts, as well as some of the new models being put forth to provide energy access around the world.

This report is motivated by the unsustainability of many microgrids, and the surge in technical and business innovations from the microgrid sector in recent years. Detailed case studies based on in-person interviews and field visits to microgrid developers in India, Malaysia, and Haiti were the primary data sources. Through the lens of these case studies, we reexamine the recommendations in the existing microgrid literature on best practices while taking into account developers' varying objectives, which range from delivering societal benefits to delivering profits to shareholders. In doing so, we obtain a new set of lessons learned, which incorporate the unique challenges and opportunities that arise in the real world. Our objective in publishing these case studies and lessons is to improve the likelihood of success for developers who face the unpredictability and idiosyncrasies of the real world on a daily basis.

The question of what makes a microgrid "successful" is a necessary starting point for this report (Casillas and Kammen, 2010). To that end, the remainder of this introductory chapter presents a discussion of microgrid performance, and follows with a discussion of the modes through which microgrids fail or succeed. A critical finding related to microgrid success is that microgrids can enter virtuous or vicious cycles as a result of numerous inter-related factors. Virtuous cycles of sustainability can be maintained through diligent maintenance, proper customer use, adequate tariff collections, and operating according to a reliable schedule. Microgrids can fall into a vicious cycle leading to failure through factors such as theft, poor tariff collection, customer overuse, unreliable operation, and poor maintenance. We present frameworks to untangle and identify those factors to improve the likelihood that future microgrid initiatives consistently maintain their virtuous cycles.

The notion of "success" or "failure" in the context of this paper must be understood within the technical, commercial, and financial activities related to microgrid operations. We do not address the political, social, cultural, or environmental implications of operating microgrids as that would require prior judgments on what would be considered successful in the local context. Our assessment includes social and cultural elements insofar they affect microgrid operations and the transitions into virtuous or vicious cycles.

Microgrid Performance Indicators

We propose a minimum threshold for success based on the notions of *reliability* and *financial viability*. *Reliability* can be divided into two types – *schedule* reliability and *energy service* reliability (defined below). To be sustainable, a microgrid meeting the threshold of reliability must be managed in such way that its original reliability and financial viability are maintained or even improved throughout its expected lifetime.

An *energy service reliable* microgrid is one that delivers its planned levels of output to its customers. Microgrids are not typically designed to provide sufficient power for customers to operate any load they desire. As such, this restricts the potential energy services and the levels at which they are delivered. For example, a microgrid might be designed to provide customers only with lighting from CFL light bulbs and power for a cell phone charger. If a microgrid's output is so limited that it does not deliver sufficient power for its customers to benefit from the energy services it was designed to provide, it is less successful. Microgrids do not operate in a vacuum; therefore a number of exogenous factors such as natural disasters, politics, and fuel price fluctuation, among others, may affect its performance. However, we focus on what our research shows to be critical, common, and short-term elements such as improper design, inadequate strategic planning, and lack of proper commercial and technical operation and maintenance.

A *schedule reliable* microgrid is one that adheres to its stated operating schedule throughout its expected operating life. Microgrids are not typically designed to be operated on a 24-hour a day basis. Rather, they have a stated operational schedule to run for a set number of hours per day for some specific days a week. For example, a microgrid might be designed to run from 6pm to 11pm, seven days a week. The less often a microgrid adheres to its stated operational schedule, the less successful it is. If the microgrid was not well-conceived, it is also possible that the stated operational schedule was not aligned with customer preferences and needs.

A *financially viable* microgrid balances financial incentives/subsidies and revenue streams from tariffs with debt, equity, and operational expenses obligations both in the short and long run (Casillas and Kammen, 2012; Deshmukh et al., 2013). This definition does not require a successful microgrid to necessarily be one where those funds are derived solely from tariff collection – it acknowledges that some microgrids have strong public involvement, where a local or national government entity might have planned to provide funds for maintenance and operating costs for some number of initial years or even indefinitely. As such, a microgrid that adheres to its operational schedule, delivers sufficient power and energy for its customers to benefit from the intended energy services, and covers its costs through tariff collection from its customers is no more successful than another that operates just as reliably but uses government funds instead. Both sources of funds are considered financially viable because they were designed to be part of the microgrid operational plan and developers have accounted for the risk of political shifts in the subsidy disbursal from the outset.

Other microgrid performance indicators

One might also look at microgrid performance in terms of factors that are external to the microgrid. These include notions of *availability*, *local affordability*, *environmental impacts*, *support for income generation,* and *service coverage*.

Availability refers to the number of hours per day or week that a microgrid is operating, regardless of its stated operational schedule. This metric of success would result in a microgrid that operates for 40 hours a week being more successful than one that operates 20 hours a week, even if both are in keeping with their respective operational schedules.

Local affordability refers to a microgrid that passes on the lowest possible energy services costs to its customers and considers local ability to pay while also ensuring that the microgrid is reliable and financially viable.

Environmental impacts refers to a microgrid's effects on the environment. A microgrid that utilizes renewable sources of energy, emits little to no carbon dioxide, and does not exacerbate local air pollution or environmental damage would be considered more successful than one that does not.

Ability to support income generation refers to a microgrid that has sufficient capacity and operates reliably enough to enable new enterprises within the community.

Service coverage refers to the degree of penetration of the microgrid within a community. It also refers to the ability to serve even the poorest members of the community as well as differences in usage amongst customers. For example, a high-coverage microgrid might be one that provides nearly 100% of the community households with service and serves a low-income community. Subsidies, donors, community labor, or a larger "anchor" customer can enable service for the poorest members of the community. However, if only a handful of community members or the wealthiest communities are served by the microgrid, this would not be considered as successful in meeting universal rural electrification goals.

Managing Complexity: Drivers Behind Microgrid Operational Modes

Existing literature on microgrid operations and the primary research and case studies conducted by the authors reveal a web of interconnected factors that determine microgrid sustainability. These factors weigh differently on success or failure depending on the microgrid selection of one of three business models. The "For-Profit" or FP model is based on a return over capital invested plus complete coverage of operational and maintenance costs. The "Partly Subsidized Non-Profit" or PS is a model where large portions, if not all, of capital costs are subsidized, but O&M costs are covered through tariff-based revenue stream. Finally, a "Fully Subsidized Non-Profit" or FS is not designed to recover capital nor O&M expenses

Table 1: Relevance of factors determining sustainability for three microgrid business models

	Developer / Factor	For-Profit (FP)	Partly subsidized non-profit (PS)	Fully subsidized non-profit (FS)
		HPS, Desi (India)	CREDA, WBREDA (India), Haiti, Green Emp. (Malaysia)	CREDA, OREDA (India)
Financial Viability	Tariff-based O&M cost recovery	High	High	Low
Financial Viability	Tariff-based capital cost recovery	High	Low	None
Financial Viability	Theft	High	Medium	Medium
Energy Service Reliability	Contractor performance	Medium	Medium	High
Energy Service Reliability	Local training and institutionalization	Low	Medium	High
Energy Service Reliability	Load limits	High	High	High
Energy Service Reliability	Unmet demand growth	High	High	Medium

and often uses in-kind labor contributions from the local population for non-technical maintenance, relying on subsidies or external aid for the rest[1].

We find that financial viability and energy services reliability are central and mutually constitutive to understand long term success or failure for microgrids. On the one hand, the revenue streams that determine financial viability are typically a function of the type of business model chosen by the microgrid developer. PS and FS microgrids often rely on grants or concessional finance from government, multilateral or foundation resources for their capital cost and in some cases for their O&M expenses. While FP developers also often rely on similar financing for some expenses, they tend to attain financial viability through tariff collection. On the other hand, energy service reliability factors are relatively similar across business models, although FS models – that often depend on in-kind local labor – stress the importance of community involvement.

We present below the role that tariff based cost recovery and energy service reliability play with respect to the "virtuous" and "vicious" cycles of microgrid operational modes.

Microgrid Operational Factors in the "Virtuous" and "Vicious" Cycles

In **Table 1** above, we introduced several factors that concurrently determine the success or failure of microgrids. Some of these factors are internally related in a cycle, while others tend to be external and arising from the nature of a particular program or technology.

In those microgrids that are FP or PS based, a first vicious cycle can manifest where poor tariff collection rates from customers leads to poor cost recovery. Poor cost recovery leads to poor operations and maintenance in the short-term, and unprofitability in the long-term – in the case of private, for-profit developers. The short-term consequence of poor maintenance and operations is schedule and energy service unreliability. Such unreliability leads to customers perceiving the microgrid as not being worth paying for, thus exacerbating poor customer tariff collection rates.

[1] This is a narrow classification of business models based on the profit motive of microgrids alone. Other elements that the literature highlights as differentiators among business models are value proposition, cost and revenue streams, customer segments and relationships, logistic model, and partnerships.

A second vicious cycle is similar to this, but starts through a degradation of energy service reliability due to maintenance malpractices, either because of design, cost restrictions, or logistic issues. Customers are unable to realize the value of their payments and quickly divert their scarce expenditure to other goods and services.

The cycle continues until the point at which non-payment is so severe that the microgrid can no longer afford to function at all – the most extreme case of unreliability. At this point, only external stimulus funds could eventually improve reliability to the point that customers will be again willing to pay for the microgrid's services. In this cycle, unreliability leads to a violation of self-sufficiency. **Figure 3** shows this "vicious" cycle with additional external factors that further drive particular factors within the cycle.

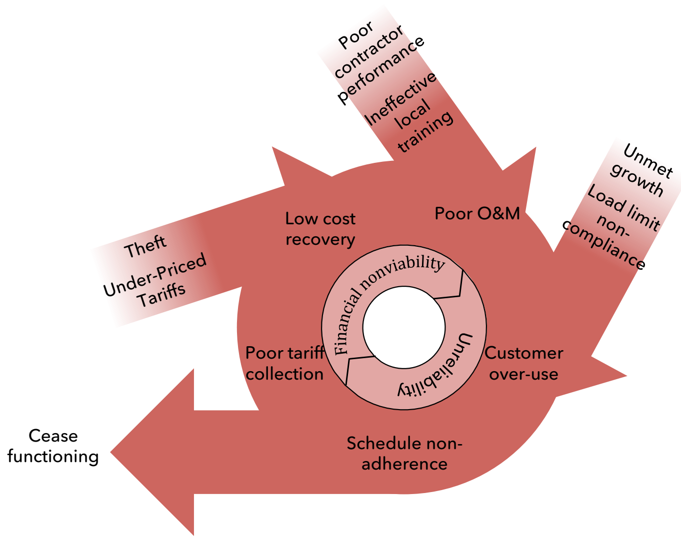


Figure 3: The Microgrid Operations "Vicious" Cycle

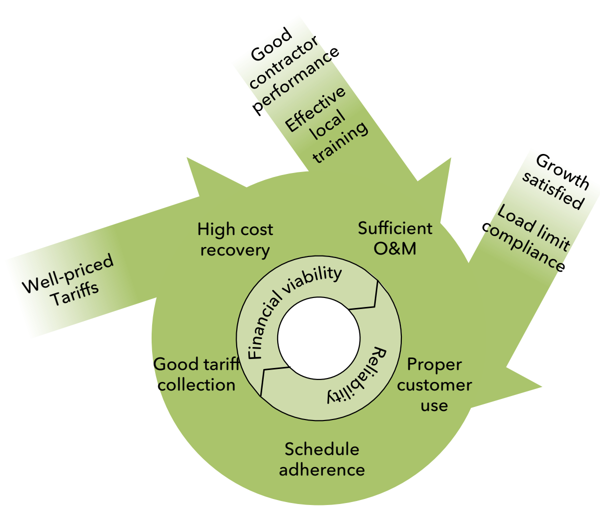


Figure 4: The Microgrid Operations "Virtuous" Cycle

Conversely, a "virtuous" cycle can arise where good tariff collection (as in FP) or steady and transparent ongoing subsidies (as in PS or FS) drive high levels of cost recovery. High cost recovery allows the operator to provide sufficient O&M to ensure energy service and schedule reliability. With a well-functioning system, users cooperate and use the grid responsibly, and when they don't, adequate penalty mechanisms enforce payment. This further enhances system reliability, and customers perceive the microgrid's services as being worth paying for, reinforcing the virtuous cycle. In FS systems, strong community engagement to their duties replaces cost recovery as a central factor, but generates the same effect of ensuring grid and schedule reliability to drive the virtuous cycle.

This cycle and additional external factors is illustrated in **Figure 4**.

As discussed, certain aspects of these cycles are influenced by external factors that are largely a function of the nature of a particular technology, business model or program design. These aspects are discussed in greater detail through the lens of the virtuous and vicious cycle below.

- *Cost Recovery*
  Cost recovery business models are dependent on tariff collection to sustain operations on a daily basis, which is the case of FP and PS models above. In some cases, these models depend on tariff collection to also provide funds for future maintenance and capital reinvestment. Sufficient tariff collection is determined by two factors. Internally, it is determined by the efficacy of physical payment collection – the proficiency of the operator to physically collect payments from customers. Externally, it is driven by the price-level of the tariff and by theft.

  - *Tariffs*
    If tariff levels are too low, then even high rates of tariff collection will be insufficient to earn working capital. If tariffs are too high, customers might be unwilling to pay for the electricity and collection rates will be lowered.

  - *Theft*
    Theft can manifest itself in different ways – from hooking up an "illegal" connection to the distribution system to using more electricity than is autho-

rized for a particular customer. Regardless of the symptom, the underlying result is the same – more electricity being used than what is paid for. This puts downward pressure on cost recovery and is illustrated in the "vicious" cycle diagram.

- *Operations & Maintenance*

In FP and PS models, O&M is financed through customer payments. As such, cost recovery is a crucial input to provide sufficient O&M. If there is low cost recovery, the chance of insufficient O&M being provided increases. In FS models, O&M may be paid for by government or foundation funds, and therefore customer payment rates are less relevant. However, other external factors still persist that can influence the ability to operate and maintain a system well, regardless of "funding source."

- *Contractor performance*
  While not discussed in the literature, our case studies revealed that all three of the Government agency microgrid developers in India included in our review used third party contractors to provide maintenance for the microgrids in their portfolio. The government agencies used a competitive bidding process to contract the maintenance to provider, which is a useful mechanism for contracting a high quality contractor. However, this process does not guarantee that a high quality contractor will be found. As discovered by OREDA, poor performance from one of the contractors led to a vicious cycle. The poor performance included failure to top up batteries with distilled water, failure to replace batteries, and failure to clean solar panels. Separately and in tandem, these failures led to schedule unreliability and pushed the grids into a vicious cycle. It is notable that OREDA used 5- and 10-year terms for their maintenance contractors, effectively locking them into a provider even if the performance was poor. WBREDA, on the other hand, used 1-year terms for its contractors to ensure that if performance was poor they could switch to a different provider. However, 1-year contracts do not encourage the contractor to invest in human capital or in setting up a reliable supply chain in remote areas.

- *Local training and institutionalization*
  Government or NGO developers are often uninvolved with the day to day operation of the microgrids in their portfolios. Rather, these developers seek out existing community institutions or organizations or create new institutions within the community to operate and perform minor maintenance to the microgrid. The nature of such an institution is that it must deal with an internal conflict of interest. As both the beneficiaries of the microgrid *and* the operators, the individuals within the institution could potentially exercise their power to increase their personal benefits to the detriment of the community as a whole. As the WBREDA case study details, in some microgrids, community institutions began to erode as those who ran them began to demand payments from tariff collection. In other cases, the institutions eroded as they began to be used for personal political gain. Regardless of the mechanism for erosion, the operation of the microgrids suffered. Interestingly, other WBREDA microgrids had successful results with community organization for high level decision making for their own grid. These findings reveal that some microgrid operation and administration activities will be performed successfully in certain local contexts, while others may degrade in the long term.

  Community institutionalization can also be ineffective in the sense that the institution simply lacks the knowledge to effectively operate the microgrid. The developer must clearly define the roles and responsibilities of the community and plan to ensure that the community is sufficiently trained. In OREDA's case, as detailed in the case study in Chapter 6, the community institutions were unaware of how to wash the solar panels. They were also unaware that they could simply place a telephone call to the OREDA head office to request service rather than undergo a cumbersome process involving hand-written letters. As a result, dirty solar panels reduced output and therefore reduced schedule reliability. Unanswered letters requesting battery service further resulted in poor performance.

- *Customer Use*
  Sufficient O&M spurs cooperation from microgrid customers, who control their behavior to stay within the consumption rules of the microgrid. Recognizing that the operator is providing a service that is reliable, customers play their part in reliability by engaging in responsible use. However, customer use is driven not only by whether O&M is being sufficiently provisioned. External to sufficient O&M, customers choose whether to obey load limits, and microgrid developers may or may not increase capacity when faced with load growth. These factors are discussed in greater detail below.

  - *Load limits*
    Microgrids are typically designed to accommodate a certain total level of peak or sustained load and it is usually difficult or expensive to expand capacity. In systems that depend on battery storage such as most solar PV installations, unlike micro-hydro, biomass gasification or diesel-powered microgrids, there is also a limit on the duration over which loads can be powered. In other words, there is a limit on how much energy can be used. In real-world terms, these limitations manifest themselves as power (kW) or energy (kWh) limits.

    In the case of microgrid capacity limitations, customer overuse can easily cause brownouts due to instantaneous overloading, or a blackout if energy is fully diminished. Such overuse is also essentially electricity theft, as customers are using more energy services than what they are paying for. Note that "more energy services" can either mean that customers are using "permitted" devices – such as light bulbs or cell phone chargers – for more time or in greater number than they are supposed to, or they are using more energy-intensive devices than allowed.

  - *Unmet growth in demand for energy services*
    It is not uncommon for microgrids to be designed to meet only a certain level of energy service and for a certain schedule. The case studies included in this report include information on the operating schedules and intended levels of service offered by the microgrids in the portfolios of developers we interviewed. Energy services obtained through microgrids may cost significantly less than the energy services used by customers before the development of the microgrid, resulting in significant cost savings - as discussed further in Chapter 2.

    Over time, these cost savings, as well as augmented income due to increased productivity and new commercial opportunities, drive customers to acquire more of their existing loads, such as additional lights; or new loads, such as televisions and refrigerators.

    As this demand growth pushes against the upward limit of power and energy availability in the microgrid, the microgrid developer must choose to expand the capacity of the microgrid or manage the load growth through demand side interventions. If the load growth is accommodated in such a way that customers can access these new energy services they can now afford, then customers may continue to be willing to pay for the microgrid. If the demand growth for new energy services is not met, then customer over-use could become widespread, leading back into the vicious cycle. Our research suggests that the latter may be one of the most relevant challenges in microgrid design.

Report Structure

Chapter 2 provides a background on microgrids, including the definition we use throughout the document and what benefits they provide.

Chapter 3 presents a characterization of the microgrid developers included in this report. Data on the generation sources, number of customers and types of tariffs are included.

Chapter 4 is a discussion of the current "best practices" in the literature on microgrids in developing countries.

Chapter 5 distills the analytical findings of the case studies, namely the key successes, challenges, and lessons learned from the field visits and developer interviews.

Chapter 6 presents the factual findings of the case studies, including information on developer business model, tariffs and load management schemes.

Chapter 7 is a critique of the existing best practices discussed in chapter four in the context of the "real world" lessons learned from chapters five and six.

Chapter 8 concludes the report with an integration of best practices, lessons learned and the factors that drive microgrids into virtuous and vicious cycles.

A group of stepup transformers adjacent to the generator house at a microgrid in Department Sud, Haiti.

Microgrids Defined

Microgrids tend to transmit power over low-voltage distribution networks from interconnected local generation sources such as micro-hydro, photovoltaics or biomass gasifiers to a relatively small number of customers. In all instances, microgrids are capable of generating power locally and supplying electricity to a relatively small number of users who are connected to each other through a shared distribution system. The electricity is usually distributed at a low voltage and the microgrid can function completely independently of the central electricity grid.

In many senses, microgrids are smaller versions of traditional centralized electricity grids. According to one expert, microgrids are defined as "local power networks that use distributed energy resources and manage local energy supply and demand" (Lilienthal, 2013).

The term "microgrid" is not universally defined or distinguished from other terms, such as minigrids or picogrids (Lilienthal, 2013). This report uses the term microgrid, but other terms are often used interchangeably in microgrid literature.

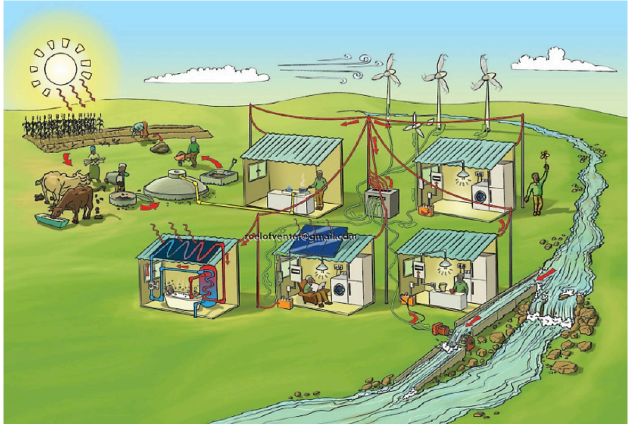


Figure 5: Example Microgrid Schematic (Venter, 2012)

Microgrids have many different applications and can be run either autonomously or in parallel to the central grid. They can serve communities, individual buildings, manufacturing centers, or military applications and are found throughout the world. Military and industrial sites in developed and less-developed countries alike often build microgrids for energy security and reliability. The main benefit to these users is the reliability of power relative to the central grid (or the ability to operate if access to the central grid is unavailable). In military applications, renewable energy microgrids also help reduce the human risk from transporting fuel in war zones. Such highly reliable microgrids serving well-funded institutions or companies usually do not have the cost constraints that microgrids intended for developing country rural electrification efforts face.

Experts and practitioners have not fully agreed on a naming convention or categorization of microgrids. For example, Navigant Research has divided up the microgrid market into five categories based on the end-user (Navigant Research, 2013):

1. Remote systems
2. Commercial/Industrial
3. Community/Utility
4. Institutional/Campus
5. Military

HOMER Energy delineates four categories of microgrids based on grid connection and size (Lilienthal, 2013):

1. Large grid-connected microgrids (e.g. military bases or campuses)
2. Small grid-connected microgrids (e.g. single gensets to back up unreliable central grids)
3. Large remote microgrids (e.g. island utilities)
4. Small remote microgrids (e.g. villages)

Because each microgrid application has a unique set of approaches and associated challenges, this report focuses specifically on Navigant's "remote systems" category or HOMER's "small remote microgrids" category, specifically in rural areas of developing countries and with a particular concentration on renewable energy-based generation. This market is distinguished from the military, industrial and high-income developed country markets by serving a population that generally has few economic resources, has less prior exposure to electricity, and is situated in a less stable political context.

The Global State of Microgrids

The microgrid market is changing and maturing rapidly. Navigant Research, which has developed a database for microgrids, has identified 3,793 MW of total global microgrid capacity (Navigant Research, 2013). Although this database is incomplete, it provides an indication of the minimum size of the market. North America has thus far built the majority of this capacity, as can be seen in **Figure 6**.

Of Navigant Research's five categories, the Institutional/Campus microgrids category has the highest current capacity, but Navigant finds the Commercial/Industrial segment to be the fastest growing. Remote systems, as discussed in this report, constitute approximately 20% of the total capacity, but likely comprise a higher percentage in terms of number of individual projects.

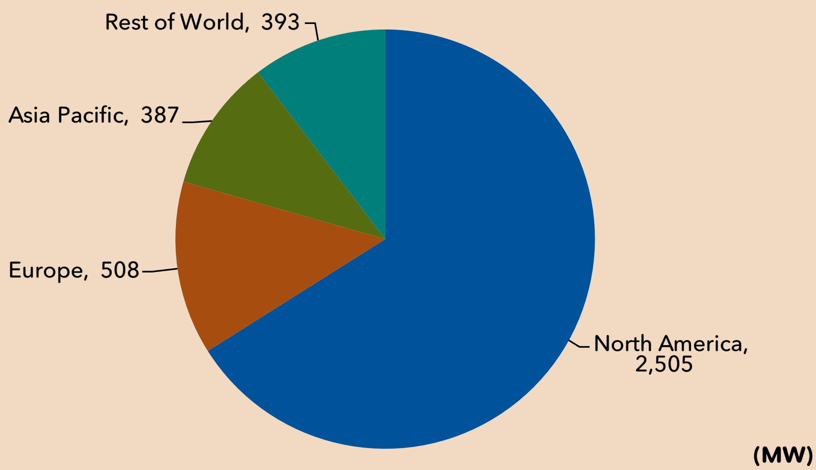


Figure 6: Total Microgrid Capacity by Region, World Markets: 2nd Quarter, 2013
(Navigant Research, 2013)

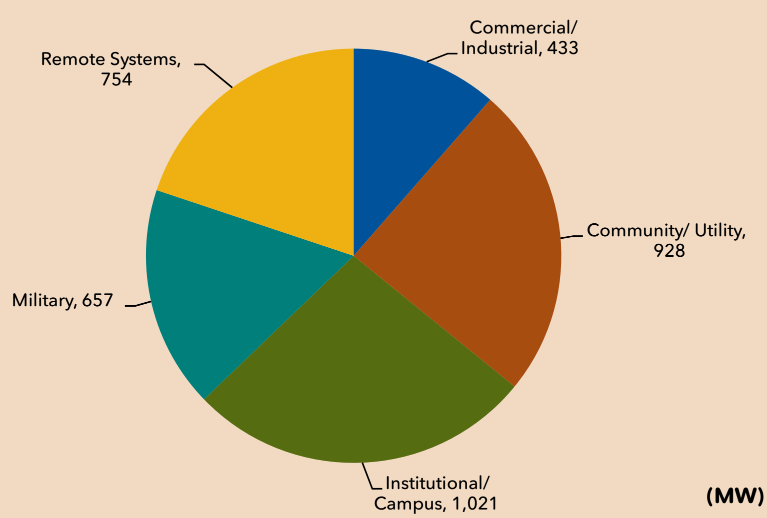


Figure 7: Total Microgrid Capacity by Segment, World Markets: 2nd Quarter 2013
(Navigant Research, 2013)

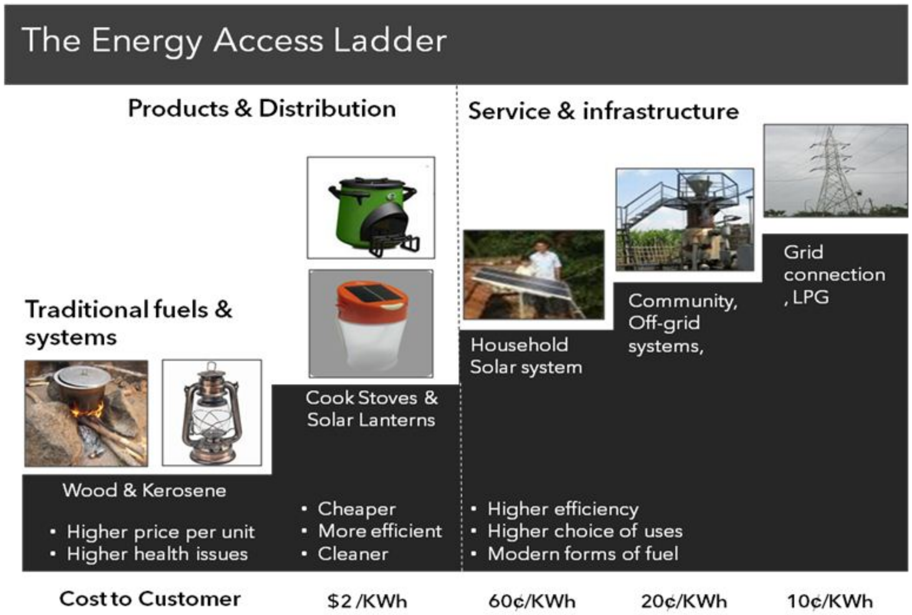


Figure 8: Energy Access Ladder

(Acumen Fund, 2012)

Microgrids in the Context of the Energy Access Ladder

Many households in rural areas of the developing world depend entirely on traditional fuels. Improving energy access results in improved energy services – a by-product of using energy carriers that are cleaner, less time-intensive, and usually less expensive. **Figure 8** shows that customers can pay as little as one-tenth the price per kWh with a microgrid, compared to the per kWh-equivalent energy price of a cookstove or solar lantern.

On the energy access ladder, microgrids are positioned between individual home systems, which are intended to provide only lighting, cell phone charging and a small radio, and the central grid, which is designed to provide unlimited access to electricity at all times (Lawrence Berkeley National Laboratory).

Yet the energy access ladder fails to capture the range of energy access factors beyond price, cleanliness, and capacity. In practice, the following set of additional factors is important to users: energy quantity, energy availability (e.g. by time of day or time of year), efficiency, and sustainability. The energy access ladder provides an initial framework to think about categorizing and ranking energy systems and their capabilities.

However, without a multi-dimensional definition and evaluation of how systems are functioning in practice, it is possible to distort the efficacy of the technologies represented on the energy access ladder. For example, an improperly functioning central grid likely serves users at a much lower level than a properly functioning solar lantern or a microgrid. As such, central grids may not be the best solution for all those who do not currently have access to electricity.

The International Energy Association has projected that 55% of additional connections needed to provide electricity to the 1.2 billion people who do not currently have electricity access will depend on microgrids, individual home lighting systems, and other alternatives to central grid connections (Sustainable Energy for All 2012). This is strong validation of the notion that a properly-functioning microgrid has the ability to serve as a long-term solution for currently un-electrified communities.

Benefits of rural microgrids

Rural microgrids deliver benefits by replacing low-quality energy sources already being used with higher-quality energy fuels and technologies providing the same energy services that communities already have access to, and by enabling new services altogether. Benefits include improved health, safety, productivity and education (United Nations Development Programme, 2008b). Electric light is a vital replacement to kerosene-based lighting, and, when supplemented with other services enabled by electricity access, can improve productivity on the local scale, and improve quality of life for women and children (Cabraal et al., 2005).

On the national scale, per capita electricity service is highly correlated with improvements to the Human Development Index (HDI) showing extremely strong marginal diminishing benefits. In other words, just a few kWh beyond zero can vastly improve HDI (United Nations Development Programme, 2008a).

Health Benefits

The litany of detrimental health effects from kerosene use includes structural fires and severe burns, respiratory disease, potential links to tuberculosis and cataracts, and child poisoning from unintentional ingestion of kerosene. Low light levels from kerosene lighting faced by medical practitioners create a host of challenges such as risks to infant delivery for midwives in rural areas and infections due to the difficulty of maintaining sanitation (Mills, 2012). The provision of electric light alone drastically reduced health and safety effects such as difficulty breathing, itchy eyes, and burn injuries in the Philippines (Thatcher, 2012). The United Nations' literature on the connection between energy and the Millennium Development Goals (MDGs) calls specific attention to the disproportionate harmful effects of energy poverty on women and children (United Nations Development Programme, 2008).

There are also unexpected benefits of electricity beyond these familiar ones. In the Sundarbans region of India, presented later in this study, an archipelago situated at the Ganges river delta, poisonous snake bites and fatal run-ins with tigers were known to occur. With the introduction of domestic and public electric light, villagers could see poisonous snakes in their bedrooms or avoid stepping on one in a dark road. Coupled with refrigeration for anti-venoms and other medication, the microgrid operators on these islands claim that injuries and fatalities from these threats decreased sharply after the introduction of electric light (Chaudhuri, 2013).

Social Benefits and Income-Generation Opportunities

Studies have shown a variety of social benefits and income-generation opportunities associated with microgrids. A detailed case study in a rural town in Kenya reveals significant improvements to worker productivity, revenues and sale prices in small- and micro-enterprises (SMEs) such as cafes, carpentry workshops and tailoring enterprises (Kirubi et al., 2008). The same study reveals improvements to education services by reducing time spent collecting water at schools through water pumping, improved lighting at home and in schools for study, and being able to offer a wider range of vocational classes that depend on electric tools such as carpentry, welding and information technology. In Bhutan, rural hydroelectric microgrids enable households to cook with electric rice cookers, saving time and avoiding expenditures on more expensive cooking fuels like wood, charcoal or kerosene (Quetchenbach et al., 2013).

Sovacool and Drupady's collection (Sovacool & Drupady, 2012) of case studies on small-scale renewable energy development in Asia catalogs numerous social and productivity benefits of electrification:

- In Laos, communities that have received grid electricity told the authors that grid electricity "changed their daily life in several ways, by providing extended daylight hours, enabling access to refrigeration and electric ironing, facilitating the sales of perishable food items in their restaurant, allowing electric water pumping, running electric rice mills, and making available entertainment through TV and radio". One of the most significant benefits from solar home systems was "extended daylight hours…which helped them to do basket weaving at night or allow children to study after sunset". (Sovacool & Drupady, 2012) While the Laos Rural Electrification Project did not include microgrid development, the intermediate level of energy services offered by microgrids would be expected to deliver benefits that fall somewhere between those cited by individuals receiving grid electricity and those receiving solar home systems.
- The Bangladesh case study qualifies the limit of the benefits of electricity. The authors cite an impact evaluation report by the Bangla-

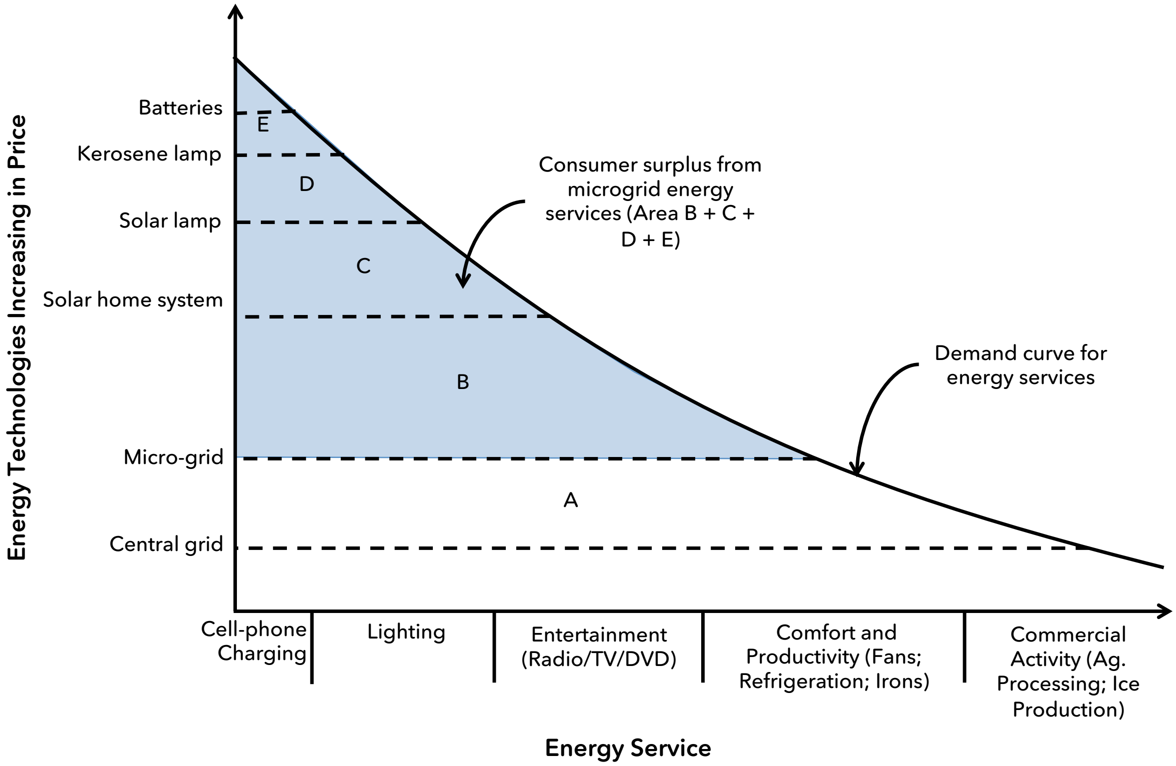


Figure 9: Price of Energy Services Provided by Energy Fuels and Technologies

desh Rural Electricity Board that concludes that access to electricity did not significantly eliminate poverty. However, the report does note that "living standards" were elevated amongst electrified households.

- Unlike Bangladesh, the Nepal case study cites reports that reveal significant increases to income from electrification among other benefits. A World Bank report with 2,500 survey respondents including micro-hydro customers and control groups from five regions of the country found that incomes in communities with micro-hydro microgrids rose by 11% relative to those without (Banerjee et al., 2000). The same report found that users consume 54% less kerosene than non-micro hydro customers. A UNDP report surveyed 1,503 households in 10 districts who were served by 20 microgrids and found an increase in household income of 52% from 1996 to 2005 (United Nations Development Programme, 2008). It also found significant reductions in the mortality rate of children under five (from 9.4% to 5.3%) and maternal mortality rates (from 5.3% to 4.3%), which may be attributed to reduced indoor smoke as a result of electricity displacing kerosene for lighting. The surveyed households also credited electric light with improved educational outcomes, supported by the higher literacy rates found in these communities.

Economic Benefits

Microgrids also deliver benefits through cost savings relative to lower quality energy fuels and technologies. In Haiti, for example, rural households spend an average of USD 10 per month on kerosene and candles, and an additional USD 4 per month on cell-phone battery charging (EarthSpark International, 2009). In Bangladesh, rural families use approximately half a liter of kerosene every night for lighting, which amounts to USD 11 per month (Sovacool and Drupady, 2012). These high costs are reflective of the importance of lighting and phone charging services, and the exorbitant prices of each. Those prices work out to approximately 20 – 45 USD/kWh for kerosene lighting on a CFL and LED equivalent basis, respectively and USD 60 –115 USD/kWh for cell-phone charging depending on the size of the phone battery. Microgrids, when combined with efficient end-use technologies – deliver these services at far lower prices, as shown in **Figure 9**. Tariffs for microgrids can result in unit prices under 1 USD/kWh.

The implication of these cost differences is delivery of consumer surplus. Because customers have no choice but to pay such high prices for lighting and cell-phone charging energy services, large amounts of consumer surplus are delivered when they provision these services via microgrids instead of kerosene and candles. The size of that surplus is the shaded triangle created by area B + C + D + E in **Figure 9**. However, microgrids do not necessarily completely offset the use of kerosene. Surveys fielded in Nepal reveal that while 84.8% of households without electricity use kerosene for lighting, 72.6% of households connected to micro-hydro microgrids also use kerosene for lighting (Sovacool and Drupady, 2012). Another study revealed that micro-hydro microgrid customers decreased their consumption of kerosene by about 19 liters per year in Nepal (United Nations Development Programme, 2008b). Additionally, diesel-renewable energy hybrid models are becoming a more common replacement for 100% diesel microgrids. Hybrid models significantly reduce diesel consumption and also turn out to be cheaper, more reliable, and less environmentally destructive over its lifetime.

Microgrids also deliver consumer surplus when conceptualized as a backstop against the central grid. Typically, the central grid is capable of delivering energy services at even lower prices than microgrids. The resulting consumer surplus from the central grid is therefore area A + B + C + D + E in **Figure 9**. However, the delivery of that surplus is contingent on a functioning grid; every time the grid fails to function, consumers are left only with lower quality fuels and technologies to deliver energy services, and the surplus is temporarily lost. Microgrids, therefore can act as back-stops or "caps" on the amount of surplus that can be lost in the case of a grid outage.

A Husk Power Systems employee loads rice husk to fuel a microgrid biomass gasifier generation system.

Seven microgrid developers were included in this research, located in India, Malaysian Borneo and Haiti, representing a range of options - from business model to geography, the policies they contend with, the financing sources available to them, and the microgrids they have built. Given the large number of microgrids within each developer portfolio, and the dearth of centralized data that the developers were willing to share, a case study methodology was chosen. This section details the aggregated data available from the developers on their full portfolios, presents the case study methodology utilized to collect and analyze data from the field visits, and provides detailed information on the 17 microgrid sites that were visited. **Table 2** presents a brief description of each developer.

Collectively, these developers have installed 787 microgrids with an installed capacity of 14.6 MW and over 58,000 customers. **Figure 10** shows the total number of microgrids built by each developer, and **Figure 11** shows the total number of microgrids by generation type.

Some developers, like WBREDA, have been building microgrids since the mid-1990s, while others, like HPS, have been building microgrids only since 2008. **Figure 12** shows the cumulative capacity of microgrids in kW built since 1996 and the cumulative investment in nominal USD for developers where such data is available. The microgrids developed by EDH are excluded from the plot as there was insufficient data on the construction year and cost. For investment, we have estimated some values for GE, CREDA, and WBREDA based on their other projects.

Table 2: Developer Descriptions

Developer	Acronym	Short Description
Chhattisgarh Renewable Energy Development Agency	CREDA	Chhattisgarh, India – Government agency installing and operating mainly solar PV microgrids through contractors.
DESI Power	DESI	Bihar, India –Private developer installing biomass gasifier-powered microgrids in communities with anchor business tenants.
Electricité d'Haiti	EDH	Haiti – EDH is the national utility of Haiti. The microgrids it develops are municipally-owned and operated. All of them are powered by diesel generators.
Green Empowerment/ Tonibung/ Partners of Community Organizations/ PACOS	GE/T/P or GE	Borneo, Malaysia – Green Empowerment and Tonibung are non-profits working together to finance and develop micro-hydro microgrids while integrating community empowerment goals into rural electrification. PACOS is the community empowerment NGO partner.
Husk Power Systems	HPS	Bihar, India – For-profit company installing biomass gasification systems with multiple business models.
Orissa Renewable Energy Development Agency	OREDA	Orissa, India – Government-funded photovoltaic, lighting-only microgrids for the most remote villages in the state.
West Bengal Renewable Energy Development Agency	WBREDA	West Bengal, India – Government funded photovoltaic microgrids interacting with central grid expansion.

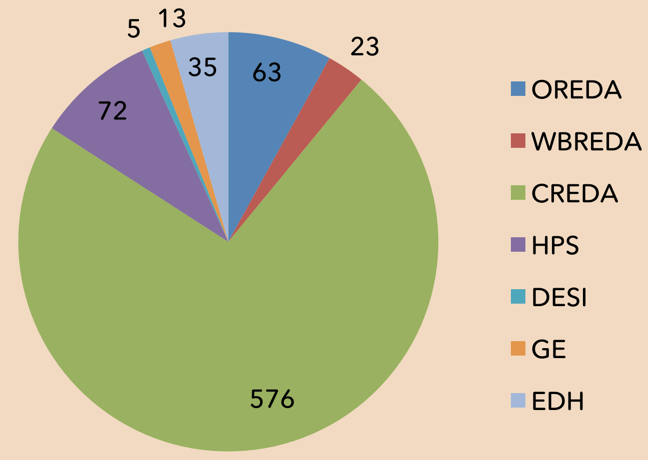


Figure 10: Total microgrids, by developer

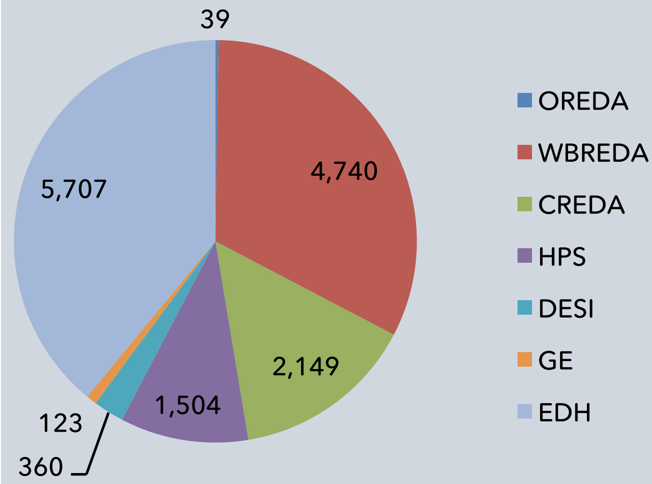


Figure 13: Installed capacity (kW) in 2012, by developer

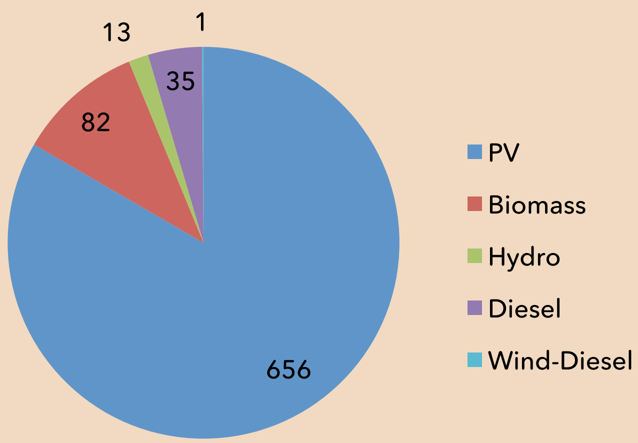


Figure 11: Total microgrids, by generation type

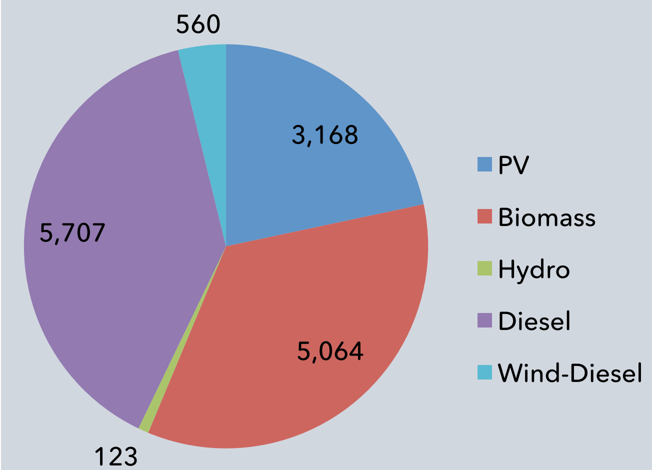


Figure 14: Installed capacity (kW), by generation type

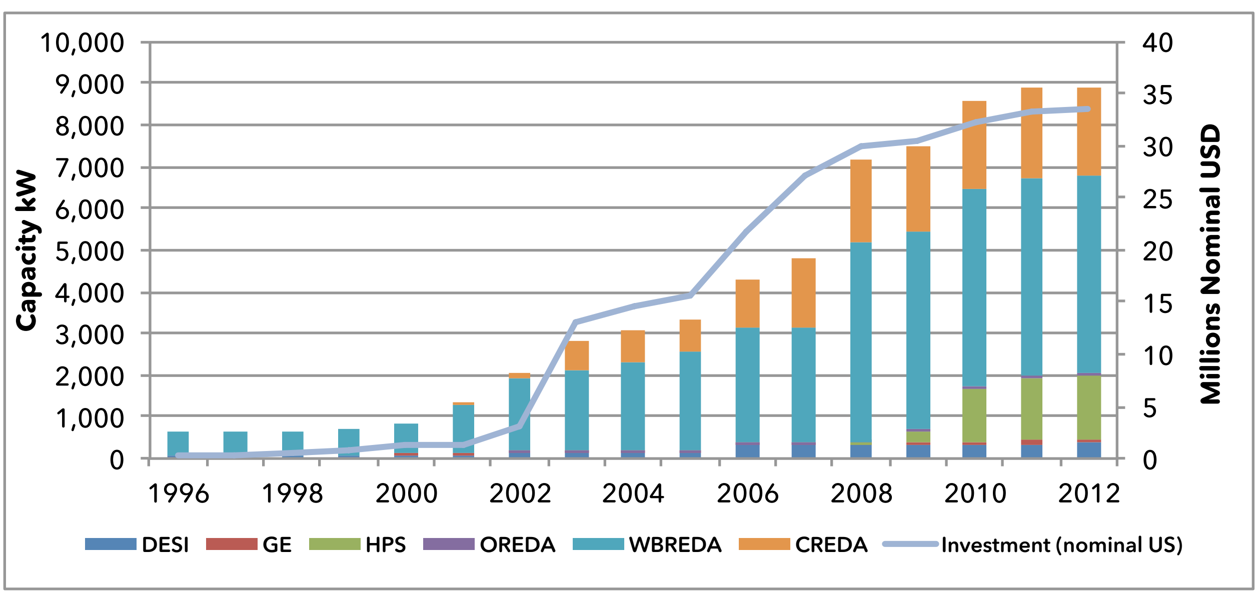


Figure 12: Cumulative microgrid capacity built per year, by developer, 1996 - 2012

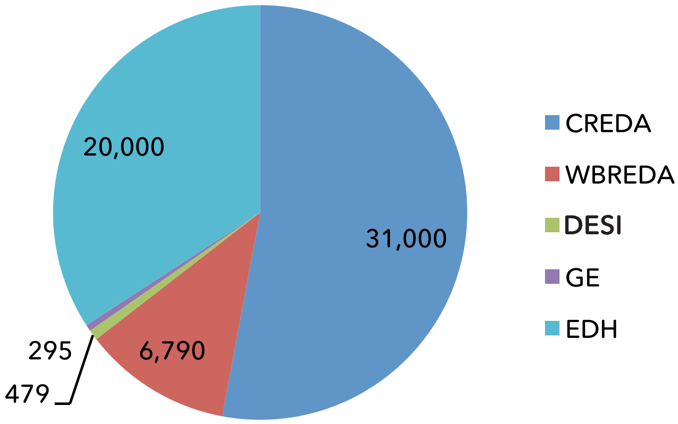


Figure 15: Number of customers, by developer

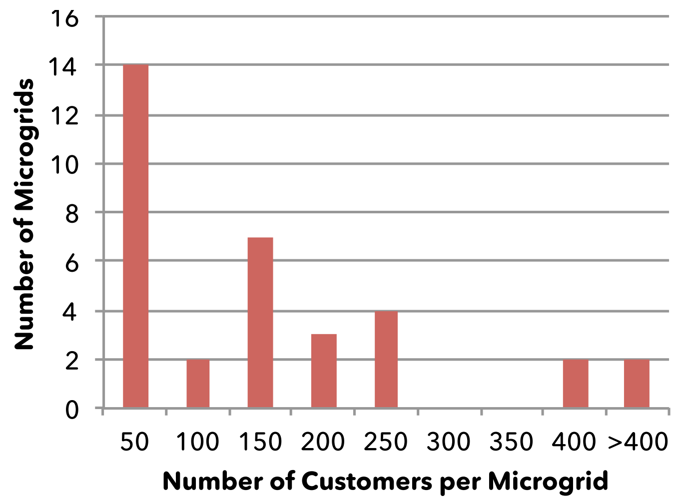


Figure 16: Histogram of number of customers per microgrid

Accurate data for installed capacity for the full developer microgrid portfolios were available for all developers except for OREDA. The figure of 39 kW of installed capacity for OREDA includes each of the seventeen 2 kW PV microgrids developed in the District of Nuapada under their program supported by the United Nations Development Programme (UNDP). They have also developed 46 other microgrids independently, but we were unable to obtain data on their sizes from the Agency. **Figure 13** presents the installed capacity for the developer portfolios by developer and **Figure 14**, by generation type.

Accurate counts of number of customers were not available for OREDA or for HPS. **Figure 15** shows the number of customers for each developer for which full or estimated data was available. The EDH and WBREDA figures are estimates. Full data tables for each developer are presented in the case study sections in Chapter 6 include the number of customers in each microgrid, when available.

Of the 787 total microgrids included in this report, an accurate count of the number of customers on each microgrid was available for only 34. **Figure 16** is a histogram showing the number of customers on each of these 34 microgrids for which data is available.

Case Study Method

The authors conducted case studies based on site visits and detailed interviews with microgrid developers and operators. This method was chosen because the literature on rural electrification and microgrids contained sufficient *generalized* advice on best practices and lacked *particular*s – particulars on how other developers were approaching microgrids and particulars on successes and challenges given their *specific* community situations and objectives. The case study approach was chosen over a broader survey approach because general recommendations and information regarding microgrids were plentiful in existing microgrid literature, but detailed information and guidance from practitioners was lacking. Case studies were most suitable to highlight the nuances and variety in approaches.

The case study approach was also chosen as a means of adding specifics to the literature on microgrid best practices that could address the perceived limitations of existing, generalized best practices. Microgrids sometimes failed in practice even though developers had access to general best practice recommendations. Case studies can shed light on factors of interest to developers that might have been neglected in the existing literature. Furthermore, developers may not communicate with each other and share detailed, useful lessons learned before they begin operations. Case studies can effectively package such lessons learned, bringing the experience and knowledge gleaned by one developer to another who may share those specific circumstances but lacks the experience.

While we intend for our approach to contribute to the literature and success of microgrids on the ground, we must first recognize the limitations of case studies as an analysis tool. Rather than focusing on controlled "variables", the case study approach does not have controlled variables and instead has layers of complexity (Becker, 1992). The complexity and lack of control variables make it difficult to truly define or isolate all the reasons for better or worse microgrid performance. The seven detailed case studies comprise a small sample size that is insufficient for determining causality. The study did not capture a wide breadth and cannot claim to represent all *types* of microgrids (for example, we visited mostly renewable-powered microgrids), but instead focused on the *depth* of research. More specifically, picking a smaller number of case studies allowed us to pursue each developer in great depth; hours were spent interviewing each developer and operator. Also, in-person site visits allowed first-hand experience with operations, multiple points of view for each case study, and confirmation of the veracity of developers operating accounts. In addition, our studies are limited temporally as we could visit each site only once. Even though situations are endlessly changing and comparing an evolution over time would provide a richer analysis, the interviews took place at a distinct time and place and are limited by time boundaries (Becker, 1992).

We utilized existing literature to establish identities and categories, constructed our analysis based on previously established principles on best practices, and finally analyzed the factors that contribute to the current operational status of each particular microgrid. By looking at existing frameworks and recommendations through the nuanced lens of specific microgrids, we hope to make our case studies part of a "complex nesting of studies within frames of reference that themselves resulted from still other lines of studies" (Becker, 1992). The research and case studies should provide finer distinctions of previous studies and help inform the professional practice of microgrid development and operations.

Data on reasons for microgrid failure and success simply do not exist in the appropriate depth and detail for a large number of cases, so at the very least, our report begins a process of providing an in-depth analysis on a few cases.

Cases were selected based on a combination of capturing the greatest relevant diversity in developing country rural microgrids, finding developers willing to participate, and geographical constraints. This diversity included a wide variety of developer objectives, ownership models, community cohesiveness, generation technologies, government interactions, age, and performance. The diversity selected corresponded to the diversity in organization-types, funding sources, and business models found through background research. The in-person visits and detailed case studies do not cover all the continents (Africa is not represented at all in our research[2]) or nearly all the different cultures or external factors to be representative of all microgrid situations, yet the case studies did capture a variety of social, economic, and cultural circumstances. While limited in breadth and geography, the case studies selected still demonstrate the variety of approaches and associated lessons learned and many of these are applicable across the globe.

Case Study and Field Visit Profiles

The microgrids visited were small, community-based systems with between 2 and 150 kW installed capacity and fewer than 500 customers (often less than 100 customers). The case studies include microgrids powered by PV, micro-hydro, diesel, and biomass as generation sources. While the site visits were limited by geographic feasibility and could never capture the full range of approaches or issues facing microgrids, a wide and representative range of microgrids possible were selected. We expect the business models and concerns in the following case studies to be highly relevant to rural microgrid development and management in other developing countries.

The seven in-depth case studies involved interviews with six developers at their headquarters and in-person visits to and interviews with 17 separate village microgrid sites as well as with their operators in India, Malaysian Borneo, and Haiti. The locations of the site visits are pinpointed in **Figure 17, 18 and 19**. The site visits were selected to capture a wide variety of ownership structures, business models, generation sources, and financing mechanisms within the limitations of geographic feasibility and the developers' willingness to participate.

2 Due to limitations on funding and time, the authors were unable to establish relationships with microgrid developers in African countries to conduct case studies there.

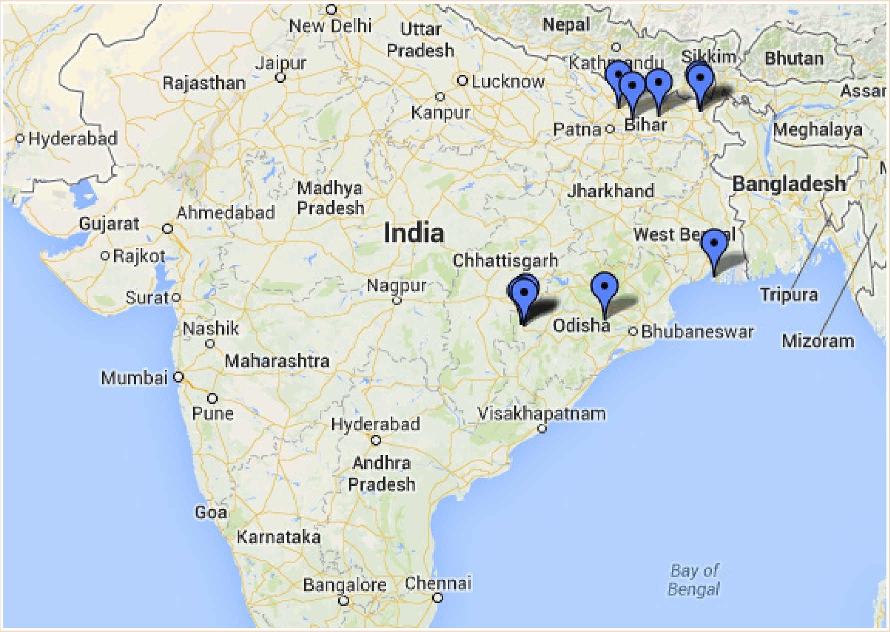


Figure 17: Map of Microgrid Developer and Site Visits in India. Microgrids visited in India include those owned by Desi Power, Husk Power Systems, OREDA, and WBREDA

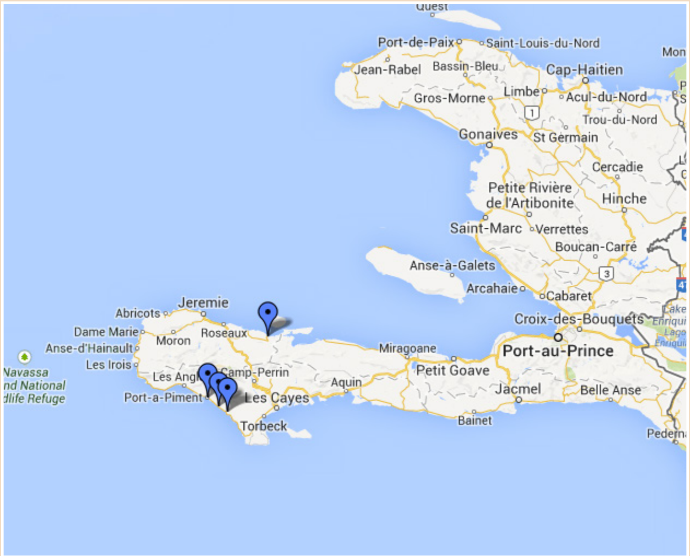


Figure 18: Map of Green Empowerment/Tonibung/PACOS microgrids visited in Sabah, Malaysia (L); Figure 19: Map of Electricité d'Haiti microgrids visited in Haiti (R)

Detailed interviews with standardized questionnaires were conducted with microgrid developers in the main office and with microgrid operators and other employees or village energy committee members at individual village microgrid sites. The UC Berkeley Human Subjects Review Board approved all aspects of the protocol. Each interview took between 1.5 - 3 hours, consisted of open-ended questions, and often involved a guide to translate the questions and answers between English and the local dialect. We also photographed the sites, equipment and operators. Interviews were conducted between April 2012 and April 2013, and were recorded for later analysis. Descriptions of the microgrid site visits are detailed in **Table 3**. In-person interviews and site visits were supplemented with a literature review, phone or email interviews, and developer data (e.g. operational or financial data).

Table 3: Description of microgrid site visits

Developer	Town	State	Country	Generation Source	Capacity (kW)	Year Installed	Capital Cost (Nominal Currency)	Description of Capital Contributions	Hours	Status	Date Visited
DESI	Bara	Bihar	India	Biomass	32	2012	3,200,000 Rs	80% Minda; 20% DESI	6pm-midnight	Functional	1/9/2013
DESI	Baharbari	Bihar	India	Biomass, diesel	35	2002	3,500,000 Rs	100% DESI	6pm-midnight	Functional	1/9/2013
DESI	Bhebra	Bihar	India	Biomass	43	2006	4,300,000 Rs	100% DESI	6pm-midnight	Functional	1/9/2013
DESI	Gaiyari	Bihar	India	Biomass	150	2006	15,000,000 Rs	100% DESI	6pm-midnight	Functional	1/9/2013
GE/T/P	Buayan	Sabah	Malaysia	Hydro	14	2009		GEF SGP; DANIDA	24 Hours (except for dry season, then nighttime only)	Functional	1/20/2013
GE/T/P	Terian	Sabah	Malaysia	Hydro	5	2005	100,000 RM	Green Empowerment; Seacology; Borneo Project	24 Hours (except for dry season, then nighttime only)	Non-functional (landslide)	1/21/2013
EDH	Coteaux	Sud	Haiti	Diesel	125	1994	N/A	100% EDH	7-10pm, Su, M, W, F, Sa	Not functioning properly	Multiple visits, 2012
EDH	Pestel	Grande Anse	Haiti	Diesel	85	1986	N/A	100% EDH	N/A	Not functioning properly	Multiple visits, 2012

EDH	Port-a-Piment	Sud	Haiti	Diesel	200	2009	N/A	100% EDH	6-10pm Su; 7-10pm Tu, Th, Sa	Not functioning properly	Multiple visits, 2012
EDH	Roche-a-Bateaux	Sud	Haiti	Diesel	100	2008	N/A	100% EDH	7-10pm, 5 days/wk	Not functioning properly	Multiple visits, 2012
HPS	Bhadhi	Bihar	India	Biomass	50	2010	2,000,000 Rs	61% Husk; 39% MNRE	5pm - 11pm winter / 6pm - 12am summer	Functional	1/10/2013
HPS	Samstipur	Bihar	India	Biomass	32	2012	2,000,000 Rs	61% Owner; 39% MNRE	5pm - 11pm winter / 6pm - 12am summer	Functional	1/10/2013
OREDA	Anupgarh	Orissa	India	PV	2	2002	1,500,000 Rs	50% OREDA via UNDP; 50% MNRE	6pm - 10pm; streetlights all night	Not functioning properly	1/14/2013
OREDA	Matiapadhar	Orissa	India	PV	2	2002	1,500,000 Rs	50% OREDA via UNDP; 50% MNRE	6pm - 9pm or 10pm; streetlights operate all night	Not functioning properly	1/14/2013
OREDA	Palsipani	Orissa	India	PV	2	2002	1,500,000 Rs	50% OREDA via UNDP; 50% MNRE	6:30pm or 7pm - 9pm; auto shut-off after 2 hrs	Not functioning properly	1/14/2013
OREDA	Tuluka	Orissa	India	PV	4.5	2010	1,800,000 Rs	50% OREDA; 50% MNRE	6:00 PM - 12:00 AM	Not functioning properly	1/14/2013
WBREDA	Koyalapada	West Bengal	India	PV	120	2005	24,000,000 Rs	50% WBREDA; 50% MNRE	6pm-midnight	Functional	1/7/2013

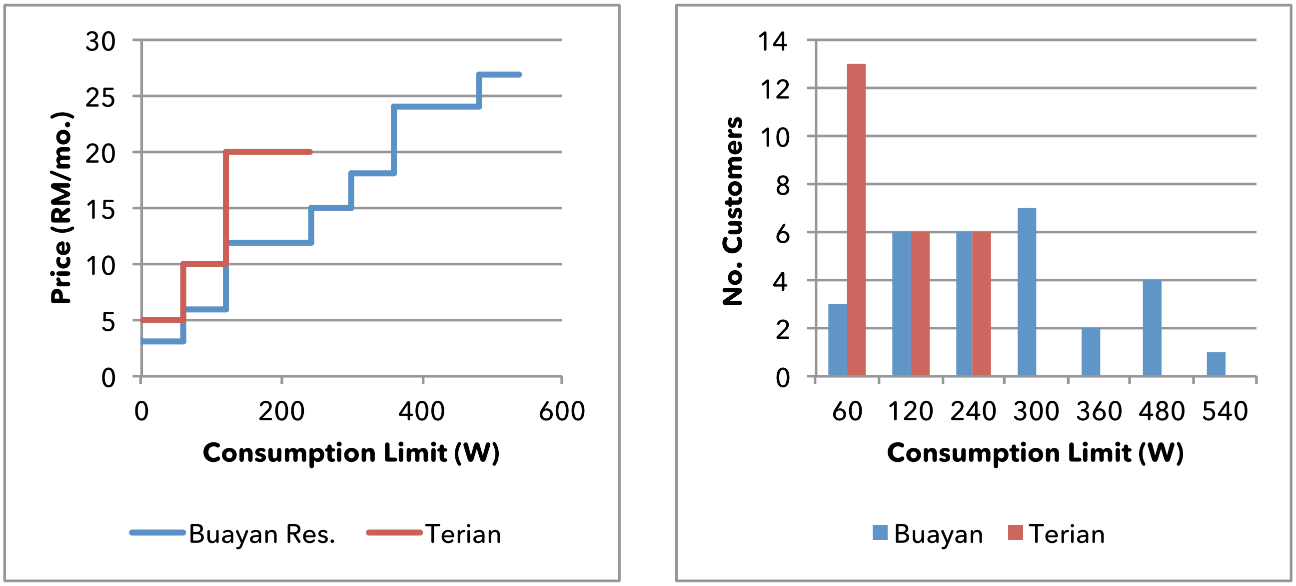


Figure 20: Price structure for GE/T/P tariffs in Malaysian Ringgit (RM) per month (L);
Figure 21: Number of customers at each tariff level (R)

Tariffs varied greatly from one developer to the next, and our field visits revealed that tariffs were rarely consistent from one microgrid to the next within the same developer portfolio. **Figure 20** and **Figure 21** show the tariff structures for the two GE/T/P microgrids that were visited and the number of customers on the grid at each tariff level. **Figure 22** and **Figure 23** show the same information for the two HPS microgrids that were visited.

Microgrids vary widely in the consumption limits that delineate the tariff levels. HPS's consumption limits increase in increments of 15W for the first

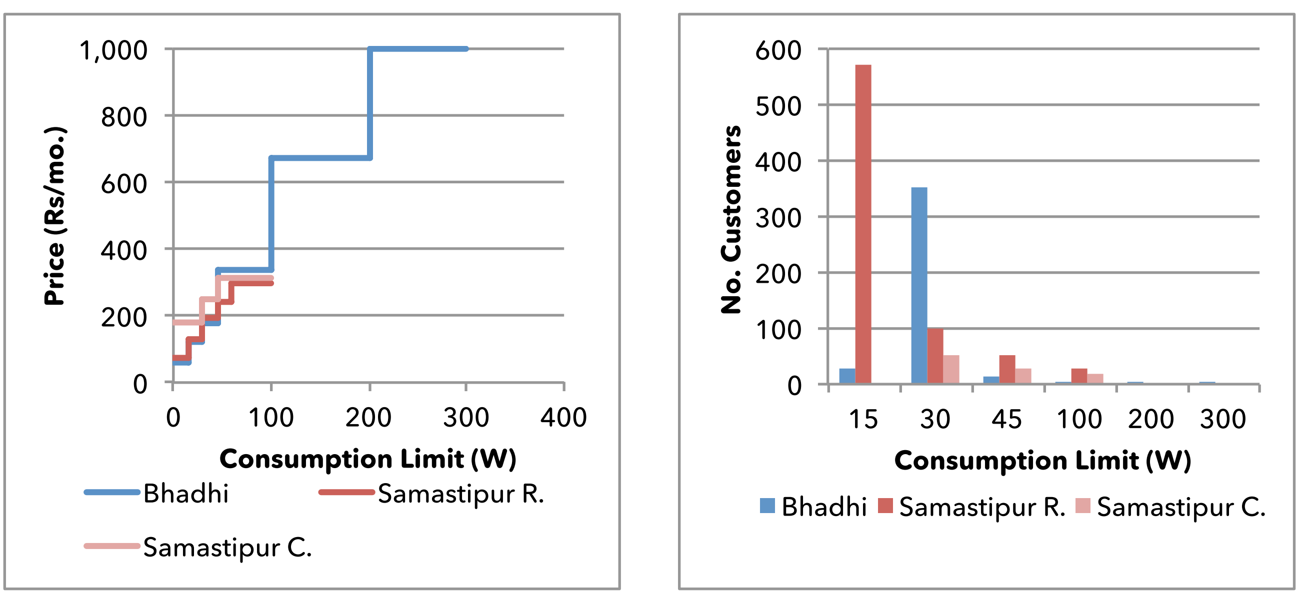
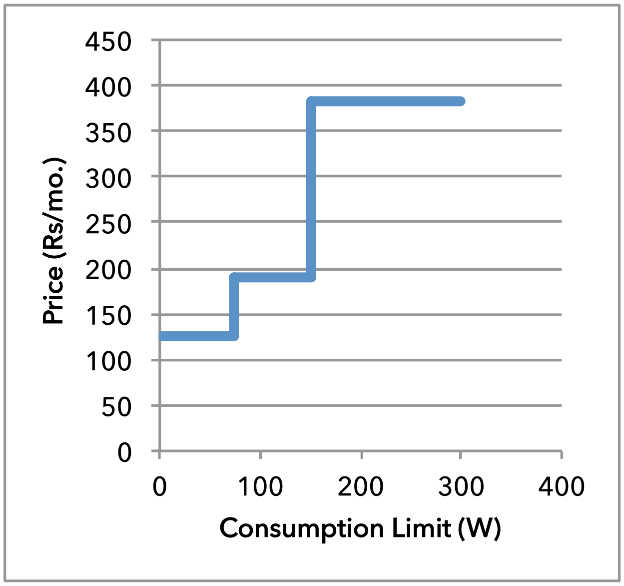


Figure 22: Price structure for HPS tariffs in Rupees (Rs) per month (L);
Figure 23: Number of customers at each tariff level (R). Samastipur charges a different tariff for commercial customers.



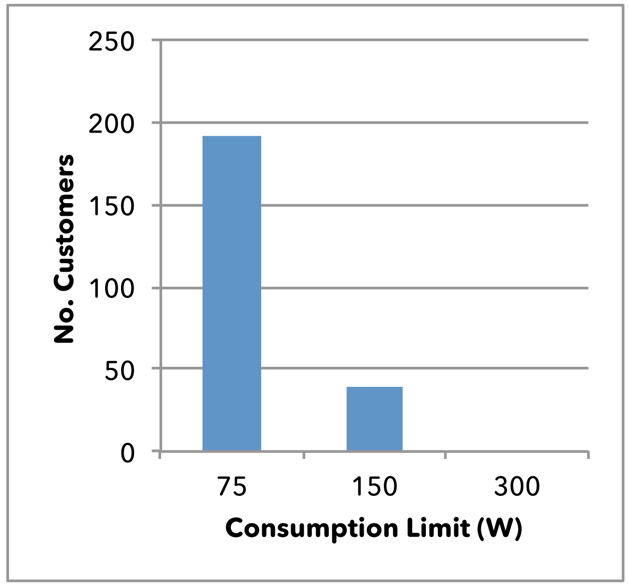


Figure 24: Price structure for WBREDA Koyalapara tariff in Rupees (Rs) per month (L);
Figure 25: Number of customers at each tariff level (R).

few levels of the tariff, while GE/T/P's increase in increments of 60W to 120W. WBREDA's Koyalapara microgrid's tariff structure and number of customers at each level is shown in **Figure 24** and **Figure 25**. Many other microgrids have only one tariff level. Tariffs for these microgrids are shown in **Table 4**.

Table 4: Tariffs for microgrids visited with one tariff level

Developer	Town	Capacity (kW)	Total Residential Customers	Total Commercial Customers	Watts or Number of Points	Price (Nominal Currency)
CREDA	All			0	2 x 11W	5 Rs/mo.
DESI	Bara	32	370	7	11 W	3 Rs/day
DESI	Baharbari	35	75	1	11 W	3 Rs/day
DESI	Bhebra	43	0	17		
DESI	Gaiyari	150	0	9		
EDH	Coteaux	125	250		3 pts.	50 HTG/mo.
EDH	Pestel	85	250	0	1 pt.	100 HTG/mo.
EDH	Port-a-Piment	200	170	0	3 pts.	150 HTG/mo.
EDH	Roche-a-Bateaux	100	158	0	3 pts.	150 HTG/mo.
OREDA	Anupgarh	2	35	0	18 W	10 Rs/mo.
OREDA	Matiapadhar	2	35	0	22 W	10 Rs/mo.
OREDA	Palsipani	2	45	0	18 W	10 Rs/mo.
OREDA	Tuluka	4.5	115	0	18 W	20 Rs/mo.

Distribution lines above a village served with electricity by a WBREDA solar PV microgrid.

A small number of existing guides and reports on rural electrification and microgrids delineate "best practices" in microgrid planning, operations and maintenance. This report assesses the degree to which these practices are relevant for the seven developers and seventeen microgrids included in the scope of the study.

Figure 26: Macro areas for best practices

Toward this end, we have divided the recommendations from the literature into three broad clusters shown in **Figure 26**. "Strategic Planning" groups a set of practices that reduce uncertainty and risk for the developer, including market and supply chain assessment, technological choices, and government policy. Under "Operations" we have clustered technical, commercial, and financial practices that pertain to the microgrid enterprise. Finally, "Social Context" gathers activities relating to community involvement and service.

Much of the literature recognizes the variety of approaches to and objectives of microgrid electrification and does not attempt to claim a "one method fits all" approach. As such, this chapter presents a summary of overall recommendations from the literature review. A comprehensive analysis and critique of these recommendations from literature will follow in Chapters 5 to 7.

Strategic Planning

Microgrid literature emphasizes the importance of considering a diverse set of factors that affect the technical design of the microgrid system as well as the repercussions of a chosen design on its operational structure. Specifically, the consensus "best practice" with respect to design is that developers should not design the system based on "pure technological considerations, but instead adapt to the specific social and economic characteristics of the rural community" (Alliance for Rural Electrification, 2011). With respect to operations, the consensus "best practice" is to be thoughtful about the effect of a chosen design on the price of electricity to the end user, the lifetime of the system, and the quality of energy services delivered (Alliance for Rural Electrification, 2011).

In 2000, the Joint UNDP/World Bank Energy Sector Management Assistance Program (ESMAP) published its "Mini-Grid Design Manual" to promulgate best practices particularly in technical design such as conductor sizing and pole options. In addition to these technical aspects, the report extensively addresses the inputs to system design and operational modes – namely demand projections and site assessment – with attention to local cultural and political contexts. In doing so, the manual is pragmatic and a reminder of the importance of the human element of microgrid planning, which planners can only discover through on-the-ground site visits and stakeholder consultation. Specifically, the manual advises an initial assessment of interest, population density, willingness to pay, and how these factors influence the selection of a responsible management entity and appropriate generation source before even committing to install a microgrid at the site.

These real-world planning considerations are crucial reminders that,

> "in the enthusiasm to get access to electricity in areas far from the grid, there is often an eagerness to immediately get down to the job-gathering and setting poles; stringing conductor; buying fuses, house-wiring, and lighting fixtures, etc. However, before purchasing the necessary materials and setting up a system, the proper design must be established. But even before this, it is critical that the necessary elements for a successful project are in place. While ensuring this may not guarantee success, omitting to consider them is a sure recipe for failure" (ESMAP, 2000).

The ESMAP guide advises that further planning efforts should also include matching the expected uses (e.g. lighting, entertainment, business uses) with the sizing of the grid (ESMAP, 2000). If not done properly, "Unnecessarily oversizing a mini-grid increases the cost that the community must cover. Under-sizing it will lead to consumer frustration and dissatisfaction with service quality, a dissatisfaction that can easily lead to the loss of consumers and the inability of the remaining consumers to cover costs" (ESMAP, 2000). In a similar vein, the Alliance for Rural Electrification (ARE) recommends that "Over-sizing some components… can be a good idea to anticipate a future demand growth and facilitate the mini-grid's expansion" (Alliance for Rural Electrification, 2011).

There are a variety of methods available to determine projected demand, such as surveys of existing energy services, site visits, surveys of electricity use in the nearest neighboring village with electricity access, assessing population growth trends, analyzing load growth in electrified areas. Regardless of the method, both guides emphasize that demand prediction is an important part of planning.

Operations

Commercial and Financial: Tariffs, Penalties, and Subsidies

The success of a microgrid is often dependent on cooperation among consumers with respect to their individual levels of consumption and timely payment of their electricity bills. Penalties are frequently incorporated into microgrid rules to discourage customers from consuming more power than they are permitted and from making late (or no) payments. Tariff levels – and the collection of tariff payments – are especially important factors for determining microgrid success in models that depend on revenue from users to cover operational costs. Unfortunately, the literature on best practices for tariffs often neglects to recognize the varied business models in the space, and how these models influence tariff design based on their objectives and cost recovery requirements. Subsidies are inextricably linked to tariff levels and payment and play an important role in determining microgrid success. Intuitively, it is expected that subsidies – both for capital or ongoing expenses – can drive tariff levels down and reduces the portion of the operator's revenue requirement to be collected from consumers.

Regardless of whether a microgrid operator seeks cost recovery, tariff levels imply a trade-off between the financial needs of the system and the customers' ability and willingness to pay. As ARE notes, "The concept of affordability plays of course a crucial role," and in the Design Principles set forth by Sovacool, it is noted that successful programs "should first consider affordability" (Sovacool, 2012). The ESMAP guide makes the point concisely: "In addition to generating the desired revenues to cover project cost, the tariff schedule should also contribute to making electricity more affordable" (ESMAP, 2000).

In cases where microgrid operations depend heavily on tariff collection, ARE finds that "setting appropriate tariffs and subsidies (i.e., obtaining the right energy price) is probably the most important factor to ensure project sustainability." The justification is that the tariff-subsidy calculation must balance customer affordability with operator self-sufficiency. The ARE report suggests that the fixed monthly fee is usually more suitable to the cost structure of microgrids, which consist of mostly fixed costs.

In contrast, the ESMAP guide does not make a definite judgment on what type of tariff design should be used, but offers extensive advice on what to consider in setting both energy- and power-based tariffs. It does note that the energy-based tariff "may be regarded as a more equitable approach, because a consumer is charged according to the energy actually consumed. Those who use less electricity pay less." While this is true, the guide notes the increased cost and technical difficulty in implementing an energy tariff as a result of using electricity meters. In contrast, a power-based tariff need not necessarily require any hardware – simply an agreement between the customer and operator that the customer will use only a certain amount of power. The challenges to such a tariff are discussed further in the demand-side management section below.

Towards affordability, the ESMAP guide also recommends that operators practice the following:

- Provide a "lifeline" tariff sufficient for simple lighting so that even the poorest members of a community can have access to electricity.

- Increase the number of customers on a microgrid to spread fixed costs over as large a customer base as possible.
- Be flexible with customer payment rules. Customers being served by microgrids typically have irregular incomes which are not spread out evenly over the year. Rather, income is often earned in lump-sums coinciding with seasonal harvests. Operators could accept bulk payments for several months at a time under the monthly payment model or could accept pre-payment to accommodate these income streams.

The best practice with respect to subsidies from different sources converges on the choice between capital and ongoing subsidies. The ARE report criticizes projects that depend on up-front investment in installation to ensure longevity and states that "one of the important lessons… was that donations or large capital cost subsidies without a sustainable business plan can destroy local renewable energy markets…[and] people don't take care of things that they get for free" (Alliance for Rural Electrification, 2011). Similarly, Sovacool finds that "effectual programs encourage community ownership and…they reject the 'donor gift' model" (Sovacool, 2012). The Ashden India Sustainable Energy Collective is actively advocating for improved subsidies and tariff reform to address such concerns. Specifically, while the Collective acknowledges that capital support is necessary, they see alternatives such as performance-linked grants, avoided cost tariffs or value-added tariffs being superior to flat capital subsidies (Ashden India Sustainable Energy Collective, 2012). Such tariffs are effectively ongoing operational expense subsidies, and can be disbursed directly to consumers if they are given "energy coupons" from the government. Alternatively, the government pays a "feed-in tariff" to the project developer based on the metered number of kilowatt-hours produced (Ashden India Sustainable Energy Collective, 2012).

Tariff design is insufficient on its own to deal with non-payment and theft. These issues are a result of difficulties in payment collection rather than in the design of the tariff itself. It is not uncommon for practitioners to incorporate customer disconnection for non-payment and zero-tolerance for theft in their business models. The ARE report states that "failing to respect the payment methodology can jeopardize the sustainable operation of a system, regardless of the model used" (Alliance for Rural Electrification, 2011). The ESMAP guide recommends that "it must be clear that if the consumer no longer has the wherewithal to pay, that household will be disconnected." It also recommends that each customer enter into a written agreement wherein disconnection for non-payment is well defined. Regarding theft, the guide advises a zero-tolerance policy (ESMAP, 2000).

Technical

Demand-Side Management

As has been discussed, microgrid systems are typically constrained by the total amount of power available. Systems with battery storage are also constrained by energy, and high operating costs in diesel microgrids also constrain the total amount of energy available. Contending with these limitations, system operators often rely on demand side management to ensure system reliability.

A recent review of Demand-Side Management (DSM) practices in microgrids identifies several strategies and technologies (Harper, 2013).

DSM strategies include:

- Efficient appliances and lights
- Limiting business hours
- Restricting residential use
- Price incentives
- Community involvement, consumer education and village committees.

DSM technologies include:

- Load limiters (including miniature circuit breakers, fuses and intelligent load limiters that discourage users from using energy-intensive appliances during brownouts)
- Distributed intelligent load control (automatically optimizing load reduction with a "smart" controller)
- Conventional meters
- Pre-paid meters
- Advanced metering systems with centralized communication.

As the review notes, some of the above-listed strategies and technologies are designed primarily for the sake of load management. Others, such as pre-paid meters, provide opportunities for demand-side management as a secondary function.

Best practices from the literature are summarized below:

- *Efficient appliances:* Perhaps the greatest amount of energy and, at times, highest share of load on many microgrids comes from lighting. Due to their low cost, inefficient incandescent light bulbs are commonly used by customers. Switching to efficient light bulbs enables more customers to be served and makes power available for other energy services without augmenting installed capacity. Efficient light bulbs (fluorescent or LED) should be provided to customers who cannot afford them towards achieving these benefits (ESMAP, 2000). Energy-efficient and low-power models of appliances such as water heaters, rice cookers and refrigerators are typically more expensive than inefficient models. They are more expensive due to the use of higher quality components, but could be less expensive with a higher market demand as a result of economies of scale. While it would be ideal for customers to use such appliances, they tend to be too expensive for low-income residential microgrid customers, but commercial enterprises might be able to afford them (Harper, 2013).
- *Limiting business hours:* This strategy can improve load factors by setting rules that make high residential consumption and high commercial consumption non-coincident (Harper, 2013). The ESMAP guide suggests "encouraging other uses of electricity at times outside peak lighting hours in the early evening" (ESMAP, 2000).
- *Restricting residential appliance use:* Many microgrids place restrictions on how much power customers can consume individually. In practice, this can be done through a variety of means:
    - *Customer agreements:* Such agreements may be verbal or written. ESMAP recommends using written agreements, but does not explicitly recommend including a statement on appliance/usage compliance. The guide acknowledges that while such agreements are "the cheapest approach, it will probably only work for some small systems where there is a good understanding between all members of a community" (ESMAP, 2000). Harper cites several microgrids where certain appliances were banned through verbal agreements, but customers used those appliances anyway (Harper, 2013).
    - *Home-wiring restrictions:* Limit customer use to lighting by only installing light sockets and no plug outlets. Such an intervention provides a barrier to customers using other loads, but there are cases where households have worked around this barrier by installing outlets for using appliances (Harper, 2013).
    - *Over-use penalties:* A penalty for over-consumption adds "teeth" to customer agreements that set power limits or forbid certain devices. The reports reviewed mentioned penalties but carried very little information regarding actual application of overuse penalties.
    - *Load limiters:* Load limiting devices have been associated with microgrids nearly since their inception and come in the form of several types of devices. They can be fuses, miniature circuit breakers (MCBs), positive temperature coefficient thermistors (PTCs) or electronic circuit breakers. As mentioned in the "tariffs" section, load limiters can be used to effectively replace electricity meters for power-based tariffs. The ESMAP guide advises two considerations in choosing a load limiter: 1. Likelihood of fraud and theft, and 2. Cost vs. accuracy. The best practice for installation is to restrict access to the device so as to prevent tampering, and install the device outside of the home (ESMAP, 2000).

Maintenance & Safety

Maintenance is vital not just for operations on a daily basis, but also to prevent potentially expensive or difficult problems in the future. The literature stresses the importance of developing and implementing a maintenance plan. As the ARE guide makes clear, "operation and maintenance have to be planned carefully in any business development project and integrated into the project structure itself, as well as in the financing scheme, to be sure that the system will continue to run smoothly on a long-term basis. There is no project sustainability without a carefully established business plan integrating the question of the operation, maintenance and management (O&M&M) financing" (Alliance for Rural Electrification, 2011).

Unfortunately, the type and schedule of a maintenance plan cannot be standardized across microgrids because maintenance needs vary by generation technology, community dynamics, financial resources, the local environment and the types of energy services provided by the grid. There is also variability in how maintenance tasks can be carried out; these depend on external factors such as the availability of spare parts, availability of trained maintenance providers, and ability to train local microgrid customers to perform maintenance tasks.

Sovacool emphasizes the role of customer support in successful rural electrification programs as a general lesson learned (Sovacool, 2012). However, while best practices with respect to maintenance are not completely unified, they are also not mutually exclusive. One main point is the importance of a widespread or national maintenance infrastructure, including vendors and manufacturers of spare parts, along with well-established "service centers" with trained maintenance providers. The Nepalese national microgrid program incorporates such an infrastructure and recent program evaluations partially credit this maintenance infrastructure with the program's success (Sovacool and Drupady, 2012).

Another main point on maintenance best practices places a greater emphasis on maintenance within the community itself rather than on an external national infrastructure. The ESMAP guide details the maintenance and operations activities that a microgrid operator should undertake, including starting and shutting down the plant according to the established schedule, determining when periodic maintenance should be undertaken, trouble-shooting problems, and keeping log books and records to complement those activities. The local operator will be able to undertake these tasks only with sufficient investment in operator training. The guide details what types of observations should be recorded in a logbook, including hours of operation, kWh readings at the beginning and end of each day, and voltage and current readings at regular intervals. The guide also recommends regular inspections and consistent maintenance through activities such as trimming branches and removing illegal connections (ESMAP, 2000).

Such local maintenance work will ensure that the system operates according to the schedule expected by the community, that equipment functions for its expected lifetime, and that the community is safe from electrical hazards.

On safety, the ESMAP guide recommends implementing comprehensive safety measures because "electricity can be dangerous, particularly for villagers to whom it is largely unfamiliar. Every effort should be made to minimize the risk to those using electricity" (ESMAP, 2000). The guide offers several specific ideas for communicating safety concerns to customers, such as enlisting teachers from schools and providing illustrated brochures and posters.

Social Context

Community Management and Involvement

Many different recommendations exist on how communities should be involved, but most reports point to the involvement of the community as essential for success of a project regardless of what business model is chosen. The ESMAP guide suggests that any project promoted from outside the community is destined to be short-lived and states that, "it must be clear that some mechanism for organizational continuity exists and that the elements are there for a long term commitment to the project. In the absence of a reliable and capable individual and community organization, it may be best to forego a project; otherwise, this effort will likely be costly, time consuming, and frustrating and in the end stagnate and collapse after the outside promoter has departed the scene" (ESMAP, 2000). It goes on to state that there absolutely must be a long-term committed organization to manage the project over the twenty to twenty-five year lifetime, or the high upfront investment will end up being useless.

Both reports identify different models as requiring more or less community involvement. For example, the ARE report suggests that private microgrid operators do not need much community involvement in operations, but still need to involve stakeholders in every step of the planning process by holding local consultations and working within existing organizational structures. This will ensure that the community is interested, familiar with the benefits of electricity and contributes their local knowledge to the design of the grid in order to set up the system for long term customer satisfaction (Alliance for Rural Electrification, 2011).

In the case of community ownership and community-based management of the microgrid, there is recognition of the vested interest of the community (as the managers are also the consumers), but also a recognition of the challenges to the community ownership socio-business structure. Challenges include lack of technical and business skills, "tragedy of the commons" usage patterns, and difficulty in limiting individual consumption, corruption, and conflicts (Alliance for Rural Electrification, 2011). In recognition of both the advantages and challenges of community-owned microgrids, ARE explains that "community-run minigrids have myriad positive impacts on the community in terms of self-governance and local buy-in into the electrification system. However, a long preparation period including technical training and capacity building is imperative to compensate for the lack of skills and potential social conflicts" (Alliance for Rural Electrification, 2011). Beyond the training time, nurturing, and capacity building, the community could benefit from structured contracts and technical solutions, such as meters, to address some of the challenges of a community-based model.

Enable Income Generating Activities

There appears to be agreement in the literature that electrification should be coupled with development of commercial activities. This can be traced to two perspectives: Reports on microgrids state that enabling income-generating activities increases the ability for customers to pay tariffs. Other reports, including economic development-focused literature often imply that the enabling of microenterprises is a major objective of electrification projects. The ARE report justifies such development as an integral component of microgrid operations because "the economic viability of mini-grids often depends on the presence of an industry because households do not usually provide an adequate revenue base to pay for mini-grid investments" (Alliance for Rural Electrification, 2011). It continues to discuss how stable, low priced electricity has the potential to unlock a variety of economic activities in a village and these income-generating activities both make consumers attach a monetary value to the microgrid and provide a reliable source of revenue for the microgrid operator.

Furthermore, the ability for microgrids to support carpentry, irrigation, telecom, or other industries expands the local economy, which can in turn foster stable household revenues for the microgrid. The ARE report also presents a case where the conclusion is for the program to be "as commercially oriented as possible" (Alliance for Rural Electrification, 2011).

The ESMAP report views income-generating activities as an explicit objective of microgrids, justified on the basis that such activities "generate additional income and thereby…reduce the costs that residential consumers would have to cover" (ESMAP, 2000). Sovacool finds that successful rural electrification programs "match energy services with generating income," citing the micro-hydro microgrid scheme in Nepal that "coupled its promotion of micro hydro dams with the agricultural processing needs of communities" (Sovacool, 2012).

Operating remote microgrids in less developed countries is a challenging undertaking that requires proficiency in the domains of engineering, finance, management, policy, and two-way community engagement. Our case studies indicate that no single developer has discovered the perfect formula for a successful microgrid, but they each have learned many lessons across domains. They have each had successes where their model has triumphed and challenges they have had to overcome. This chapter presents those successes and challenges alongside the lessons they gleaned over the years.

Chhattisgarh Renewable Energy Development Agency (CREDA), India

Successes

Scalability and wide reach: Significant forest cover and a low rate of electrification in the Indian state of Chhattisgarh necessitated the development of off-grid electrification solutions in the form of both solar PV microgrids and solar home lighting systems. CREDA, the state's designated government agency for the development of renewable energy solutions has installed and operated more than 500 solar microgrids, by far the most in India. This success has been possible due to an effective and well-run government organization, as well as the financial support and commitment of the state government of Chhattisgarh.

Public-private partnership: CREDA's business model relies on private contractors to install the microgrids, and also to provide ongoing O&M services. Often, the contractors that installed the microgrids were different from the ones providing O&M services. But, recent contracts have included five year maintenance terms along with the installation of solar microgrids. Enlisting the private sector to provide installation and O&M services has also enabled CREDA to expand its operations across the state.

Effective monitoring and verification: For a public-private partnership to work successfully for the provision of basic services, effective monitoring and verification of private services is essential. CREDA has a relatively well-defined and -executed monitoring and verification program to track the monthly generation from each of its microgrids, a significant task given the remoteness of the communities. Further, consumers communicate their complaints first to the operator, then to the service provider, and eventually to CREDA officials; but they also have an option to call CREDA directly in case the microgrid stops working.

Equity and coverage: A low fixed fee of approximately Rs 300 per connection (USD 5) and a very low fixed monthly fee of approximately Rs 5 (USD 0.08) have made electricity connections from CREDA solar microgrids relatively affordable and thus, enabled relatively wide coverage. According to CREDA, coverage of 80-90% of the households in a community is common. The low fees are a result of substantial financial support from the Chhattisgarh government and the MNRE, both for initial capital costs and ongoing O&M costs.

Challenges

Limited electricity service levels: CREDA's solar microgrids are designed to provide lighting loads only. Each household is provided with two 11W CFLs and a plug point for charging a cell phone. These microgrids are not designed to provide energy for any commercial activities or additional residential loads. However, after the initial installations, some communities quickly come to expect additional electricity to power other household appliances such as TVs and fans. The addition of these loads strains the microgrid supply and necessitates operators to exercise limits on loads. Ineffective demand-side management leads to some microgrids having a shorter daily supply of energy than the designed duration, while some stop working entirely due to demand exceeding supply. However, CREDA views its solar microgrids as a stopgap solution before central grid extension, and designs its microgrids to provide lighting loads only.

Poor payment collection: Local CREDA microgrid operators are responsible for the collection of payments from the community. As part of the community themselves, operators are often unable to enforce payments from certain community members due to the social dynamics of the community. Although penalties for non-payment in the form of disconnection exist, these are often not exercised. CREDA and the service providers do not rely on the relatively small community tariffs for supporting their O&M activities, and try to enforce payments mainly as a matter of principle than for financial sustainability of the microgrids.

Central grid extension: The village grid extension program of India has led to the central grid being extended to many of the communities served by CREDA's solar microgrids. Communities welcome and desire the central grid extension given its relatively unlimited power supply compared to the solar microgrid. However, extension of the central grid lines do not ensure a reliable power supply due to the large power and energy shortages in India, and rural areas are often left without electricity, especially during the evening peak hours. As mentioned earlier, CREDA views solar microgrids as a temporary solution. In the event of central grid being extended to a community, CREDA can move its microgrids to another community that has no access to electricity.

Personnel security issues: Many of CREDA's microgrids are located in areas where rebel groups are active. This poses security issues for CREDA as well as third-party service provider personnel.

Lessons Learned

Strong state backing for long-term sustainability and equity: Often times, standalone microgrids have known to fall into disrepair when communities fail to pay tariffs and the financial sustainability of the systems is compromised. However, in CREDA's case, the state government of Chhattisgarh provides significant financial support to its solar microgrid program. India's Ministry of New and Renewable Energy (MNRE) provides both capital subsidies and supports ongoing O&M. This has enabled CREDA to not rely on community payments to ensure long-term sustainability of its microgrids. Given that CREDA's stated revenue stream for financial viability is not community tariff collection, it is important to note that the state government backing has been sufficient for the sustainability and affordability of basic electricity services for the mostly poor households served by the microgrids to date.

Consumers' need for additional residential and commercial electricity services: CREDA's solar microgrids are designed only for lighting loads, and their operation is often jeopardized by any additional loads that are often desired by the consumers. Further, these microgrids are unable to provide enough electricity for commercial electricity services such as running flour or rice mills, or oil presses. Commercial and other services that reduce the work burden on women and enhance economic activities can significantly increase the quality of life in a community. However, larger microgrids would entail a much larger financial commitment of government finances. To increase electricity services through its microgrids and limit government spending, CREDA will need to raise consumer tariffs and enforce payments from consumers to ensure financial sustainability. It should be noted that CREDA does install solar water pumps, and uses other technologies such as biomass gasifiers and micro-hydro where feasible to cater to larger loads in remote areas.

Effective monitoring and verification key for quality operation: CREDA's outsourcing of the installation and O&M services of solar microgrids has been successful mainly due to its monitoring and verification practices, which ensures accountability from the installers and service providers. CREDA's enforcement of equipment and installation standards ensures reasonable quality of its microgrids, and its reporting mechanisms ensures that contractors provide timely maintenance of its systems. This model has also enabled CREDA to scale its services across the state.

DESI Power, India

Successes

Tariff collection: DESI Power claims very high rates of tariff payment. This is attributed to multiple factors: 1) it serves a relatively small number of customers, most of whom are commercial, on each of its microgrids; 2) it sells power on a metered energy basis; and 3) the company is highly diligent about tariff collection, sending out collectors on a daily basis to be available for residential customers to make their payments, and sending them out once or twice a week to commercial customers.

Market Selection and Development: DESI Power invests significant time prior to installation to develop markets and ensure a reliable "anchor" commercial customer. One DESI employee focuses solely on "market development." Prior to their second installation, they surveyed 100 villages in order to determine the most suitable markets. DESI's careful selection process and market development efforts have also likely contributed to the successful tariff collection at their microgrid sites.

DESI Power staff members describing the operations of a biomass gasifier plant in Bihar, India

Poor Competition: In Araria, Bihar, the central grid operates so poorly (often only two hours per day) that business customers cannot depend on it. The impression of the central grid held by potential customers in the remote towns where DESI operates its microgrids is negative, and they are enthusiastic about becoming microgrid customers. The company has installed microgrids in sites where the central grid has already arrived, signifying confidence in providing more reliable service than the central grid.

Operational Discipline: DESI undergoes a thorough due diligence process prior to installation. Their attention carries through in their operations. DESI has a small number of microgrids and monitors them carefully by making frequent site visits. During those visits they assess biomass feedstock supplies, address problems with the gasifier and generator unit, investigate customer theft, and check operator logs. Some distribution lines are installed underground to prevent hazards to customers and increase resilience to natural hazards.

Social and Economic Outcomes: In DESI's markets, electricity expands economic opportunities for villagers by enabling processing of agricultural products. Prior to the installation of the microgrid in Baharbari, farmers sold raw rice paddy – a low-value, unprocessed commodity. With the introduction of an electric-drive rice huller, they can now sell hulled rice and earn more money. DESI also employs women to operate their grids and conducts women empowerment and business development activities to complement the arrival of electricity.

Challenges

Lack of Scalability: While DESI has successfully operated its six microgrids, it has scaled up slowly. The reason for the slow scale up is uncertain. It could be excessive due diligence, a lack of interest, or a goal of setting an example for others to replicate rather than electrifying thousands of people themselves.

Residential Customer Overuse: DESI Power estimates that as much as 2-3 kWh/day are stolen by residential customers at certain sites. Residential consumption is difficult to monitor because most of it occurs in the evening, making it easy to conceal theft, and there are dozens to a few hundred customers, depending on the site. The customers are experienced about theft, and are careful to not leave evidence. While the operator does have a community level meter that allows him/her to see that more electricity is being used than is being paid for, they do not have the installed technological capability to prevent or monitor overuse at the individual customer level.

Flawed Contracts: DESI Power was contracted to serve a Vodaphone cell phone tower in Gaiyari with electricity for 4 hours per day. The cell phone tower was being powered by a stand-alone diesel generator for 12 hours a day. The cell phone company delivered diesel daily to the local, independent tower operator. The operator established the power purchase contract with DESI Power, but did not reveal this to Vodaphone, which continued to deliver enough diesel to power a 12 hour/day load. The operator sold the excess diesel fuel and kept the earnings. Vodaphone eventually discovered this scheme and forced the operator to sever the contract with DESI. This seems to have been a missed opportunity to work directly with Vodaphone to secure a contract.

The government needs to provide an enabling environment: DESI has expressed frustration with the government's haphazard approach to central grid expansion. Some places receive only two hours of central grid electricity per day, and in other villages, the DESI Power Director observes "there is a pole, there is a wire. There is everything but electricity." DESI would like to create a microgrid using central grid infrastructure, which would enable speedy project development and access to many customers. However, they cannot do so without the government's cooperation.

Lessons Learned

Specific policies, investment funds and special mechanisms are needed for load development. According to DESI Power, the establishment of a microgrid is not a significant challenge. They can find investors, grant-based funding, and even government capital subsidies with little effort. Rather, the challenge is on the load side, as the market for electricity is very undeveloped and demand is low. In most areas, especially "village" markets, electricity is not linked to productive activities in the minds of villagers – only to lighting. DESI Power's experience is that no plant can financially sustain itself on household loads only, which primarily consist of lighting, cell phone charging and a few TVs or other appliances. As such, prior to investing, they seek to develop loads like irrigation pumps, value-add agricultural services, and refrigeration. This "customer creation" is essential to operational sustainability, as a small number of such loads can provide a significant and reliable revenue stream. DESI Power complements its investment in equipment with a unique staff position that is dedicated to assisting commercial customers to develop their businesses and increase electrical load.

Incorporate technological solutions to deter theft. DESI incurs significant costs collecting daily payments from residential customers, and has struggled to monitor overuse. They are aware that their systems could benefit from load limiters or automated payment collection devices, but implementation has been rife with challenges. An appropriate solution has yet to be found at a reasonable cost, but they have concluded that it is technological, and not a function of their operations.

Remove barriers to tariff payment. The operational design of DESI Power's tariff collection resolves two challenges with tariff collection: 1) customers are not self-motivated to make payments, and 2) due to various circumstances, customers are sometimes unable to make a payment when the opportunity is presented to them. Tariff collection that is managed by simply having an office where customers are expected to travel to make their payment resolves the second issue, but not the first. Tariff collection that is managed by sending a collector once or twice a month to customers resolves the first issue, but not the second. By sending tariff collectors frequently to households, DESI Power manages to obtain high rates of payment, but at a high transactional cost.

Green Empowerment/Tonibung/ Partners of Community Organization /PACOS (GE/T/P), Malaysia

Successes

Community building: The most notable aspect of GE/T/P's projects is the dedication to community empowerment through the project. From the start, GE/T recognized that community ownership was key to the long-term success of the micro-hydro facility. Without a private investor or a government agency behind the project, community ownership

Microgrid distribution lines at a GE/T/P site in Sabah, Malaysia

was their only option. As such, the developers invested significant time, effort, and funds into community organizing. While technical engineering was GE/T's forte, they prudently deferred to organizations like PACOS that specialize in community organization, to help with the behavior change aspect of the project. Together, the NGOs (Green Empowerment, Tonibung, and PACOS) use the micro-hydro projects as an entry point into a village to advocate for other issues related to the community. Most of this advocacy is in response to the encroachment of palm oil plantations into these communities. Without empowerment, leadership, and coordination, these communities would be vulnerable to external forces that threaten their existence. Because the microgrid is a positive, mutually beneficial project requiring community coordination, PACOS has found that it functions as an effective focal point around which the village can convene and work toward these ends.

Conservation: There is a significant conservation element to the micro-hydro projects as well, including a watershed conservation incentive. Heavy logging upstream compromises the efficiency of the micro-hydro system. In some cases, the projects encourage ecotourism.

Community maintenance efforts: Every system suffers from down time, and in GE/T/P's case it is between 10-70% depending on factors such as geography, community maintenance efforts, and cooperation of usage in the dry season. Generally, volunteers operated the GE/T/P systems on a daily basis, and community funds were used for repairs when possible.

Challenges

Major repairs: There is no external monetary support for ongoing operations. Collected tariffs can cover a small payroll for operators and minor maintenance (e.g. lubricants, fuses) but the villages sometimes need external support for expensive repairs. The responsibility falls on the community to take care of the system, and there is high variability between systems with respect to how well each community has been able minimize service interruptions in the wake of major maintenance issues. For example, a landslide in Terian in

2012 meant the whole system had been non-operational for several months. The village was likely incapable of fixing it by themselves due to financial and technical constraints.

Community adaptation to seasonal variability: Micro-hydro suffers from seasonal variability. As our visit was during the dry season, we did not have electricity in Buayan on either night of the three-day visit. For the community, seasonal variations dictate that either only one-third of the village will have power, or the entire community needs to limit the load in every household so that everyone could at least have basic lighting. If neither of these terms are agreed upon by the entire community, there will be significant amounts of down time.

Demand-side management: Aside from seasonal variation, other factors contribute to demand-side management challenges. As villagers from Terian and Buayan spend more time in cities, their expectations around what loads they should be able to power with electricity increase. At the same time, household income is reportedly increasing in these villages, enabling them to purchase the devices that are available in the cities. This puts upward pressure on the household load limits and on the system as a whole, resulting in brownouts and downtime. While community empowerment has been shown to be possible through the micro-grid projects, it is still proving difficult for communities to be fully cooperative around their usage.

Inefficiencies due to shared management responsibilities: Most management activities at each micro-grid are shared among several people. This often leads to sub-optimal performance, as individuals do not have complete task ownership or incentives to complete their tasks. In Buayan, the job of payment collection is transferred or shared among several people, which leads to irregular record-keeping of payment collection.

Lessons Learned

Invest thoughtfully in community training. Being dedicated to the community ownership model, GE/T/P learned that community dynamics were the biggest factor in determining the longevity and performance of a microgrid. In response to this requirement, they prudently invest many resources in equipping the village with the tools they need for community coordination of operations. While this seems straightforward, it is not always the case that developers fostering the community ownership model will follow through with the appropriate level of community training. The municipal microgrids in Haiti and community microgrids developed by OREDA highlight this oversight.

Devise thoughtful rules and enforcement mechanisms pertaining to customer usage. The successful operation of the microgrid depends entirely on community cooperation and coordination. Clear rules, identification of people to enforce them, and mutual understanding within the community need to be specified. For example, in Saliman, when the village headman ignored his load limit, other villagers followed suit and reliability waned. In Lumpagas, the headman exercises significant control and will disconnect systems immediately at the first sign of improper usage. Despite having a small, 1.5 kW system, the community rarely suffers down time from over-usage.

Cooperate with other NGOs. GE/T/P is a unique developer because it is essentially a consortium of three disparate NGOs. Each NGO has its own strength and contributes vitally to the success of the portfolio.

Communities have solutions. GE/T/P's experience reveals that communities have innovative ways of managing their resources and solving problems. By their own admission, these novel solutions would not have been deemed feasible or conceived of by GE/T/P staff. For example, at the Bario village in Sarawak, the civil works preparation faced difficulties in moving a large boulder. GE/T was at a loss for what to do, but the community came up with a solution using fire, brush, and ice water to crack pieces off the boulder and eventually remove it.

Share experiences through technology and hands-on assistance among villages. Sharing experiences of managing the system and conducting operations and maintenance with each other both in-person and using multimedia (video, telephone, etc.) can improve practices. This inter-village cooperation is integrated into all projects, where people from different villages volunteer to help with new construction. At the Renewable Energy People's Assembly, they formed a Sabah Micro Hydro Network with regular meetings to help each other. This collaboration and sharing of experiences improves the internal management of the microgrid and improves the village's awareness and ability to react to destructive external forces.

Community commitment is the key to long-term success. At least 10,000 hours of work by the community is required for each project. Residents and GE/T/P employees alike credit this up-front community work for creating a degree of savviness and familiarity with the microgrid system. While maintenance and problems arising from over-usage are common, their familiarity with the system nevertheless sensitizes the community to the reality that problems will occur if they do not respect load limits or if maintenance is not performed.

Incentivize labor continuity to insure consistent maintenance and operations. Continuity of labor occurs through either a single person committed to staying in the village and performing their duties, or through systematized skills transfer within the village. The micro-hydro committee leader in Buayan believed that the person who is managing the accounts should be in the village on a regular basis. A compensation and continuing education scheme was implemented to incentivize that person to stay and continue their duties. In Long Lawen (a village in Sarawak with a GE/T/P microgrid), the operator trained younger villagers on performing his duties, and passed on the daily operations to them. This enabled him to focus on his other village duties and reduced the dependency of grid operations on a single person.

Government recognition provides protection and channels for recourse. GE/T/P microgrids are at risk due to the ambiguous legal status of microgrids as a result of the state and national governments not formally recognizing their right to operate. The communities own the microgrids, but the microgrids are not registered in any way with the government - a conscious choice to avoid being subject to regulations and taxes. However, this lack of recognition does not allow for recourse in the event of damage caused by other entities. In Buayan, for example, the government took down microgrid components such as utility poles and distribution lines when they expanded the road to the village. Therefore, microgrids would benefit from a special arrangement of legal recognition without financial penalties from the government.

Electricité d'Haiti (EDH), Haiti

Successes

Customer payment: Customers tend to make payments when the microgrids are working. For most microgrid customers, there is no expectation or prospect of a central grid connection, so cus-

The generator house and step-up transformers at the Coteaux microgrid in Haiti tomers are content to pay for electricity from the microgrid as long as it is providing power.

Challenges

Poor cost recovery: Microgrid tariffs are not set to cost recovery levels, and generators are oversized for the loads they serve by a factor of two to three (see Chapter 6 for further detail); consuming fuel at very low efficiency and driving up operational costs. In tandem, these factors greatly restrict the cost recovery that can be attained by the microgrid operators. As a result, small, occasional maintenance problems tend to go untreated because even small amounts of money are unavailable for purchasing replacement parts such as fuses, lubricating oil, gaskets, and transformers.

Political favoritism can determine microgrid service: The director of the Bureau des Provinces at EDH acknowledges that the decision of whether a microgrid can be serviced by EDH sometimes depends on the political connections of the mayor requesting the repairs or fuel. This approach to microgrid performance is inequitable and an unfortunate by-product of a poorly designed microgrid rural electrification scheme.

Lessons Learned

Poor service leads to non-payment. A nearly virtuous cycle exists where service is delivered with reasonable reliability. Customers are willing to pay for electricity, but the cycle grinds to a halt every few months because the tariffs are not high enough, and the operator cannot afford to buy fuel or replace parts. As a result, customers pay less as service becomes more erratic, leading to a downward spiral until the microgrid ceases to operate for months at a time.

Avoid oversizing generators. Field visits and interviews reveal that EDH does not conduct a detailed load assessment to size the microgrid generators. Unfortunately, due to the inaccessibility of project documents, it is not clear how exactly EDH sizes them. Data collected over a one-year period show that the generators at Port-a-Piment and Coteaux are consistently run at very low set-points. Operating costs could be reduced significantly by using appropriately sized generators.

Husk Power Systems (HPS), India

Successes

Customer satisfaction: Customers seem to be generally satisfied by the performance, availability and service levels of the HPS systems. HPS attributes its customers' satisfaction with the high quality of service they provide, and the fact that the alternatives to their microgrids are undesirable**.** Kerosene and diesel are both very expensive and the central grid, if it exists in the village, is extremely unreliable.

Reliable service: Compared to other microgrids visited, HPS plants have very little down time. HPS addresses risks to service systematically, from fuel supply to regular maintenance. HPS undertakes thorough research before construction and enters into detailed agreements with local rice mills to prevent running out of feedstock.

Scalability: At 82 systems installed as of January 2013, HPS has more systems than most other microgrid developers. Their scalability is attributed to their usage of standardized models for their generator system, distribution system and for operations. HPS also accesses government subsidies, which reduces the amount of capital necessary for constructing a single grid. Their capital requirements are relatively low because they use biomass gasifiers, which are less expensive than solar PV.

Experimentation and innovation: HPS prides itself on its degree of experimentation, research and development. HPS is motivated to find a model that scales both to further their social mission of widespread electrification and to achieve profitability. Over the last five years, it has tried different business models, demand management schemes, and constantly refine the details of operations. HPS has also developed multiple versions of its pre-pay meters and implemented remote monitoring systems for several of its power plants.

Attractiveness to investors: HPS has managed to attract a wide variety of funding sources including government subsidies, venture philanthropy investment and grants. They hope to monetize Certified Emissions Reductions (CER) credits under the Clean Development Mechanism (CDM) in the near future. HPS may not be highly profitable, but their attempt at profitability appeals to a wider variety of funding sources than government or NGO

A biomass gasifier plant at a HPS microgrid site in Bihar, India

developers. The profit component of their mission has also garnered substantial media attention, which also feeds into the amount of financing they have received.

Challenges

Replicability concerns: HPS has a positive gross margin, which is a feat in itself, but it is not as high as it had hoped (HPS's targeted 50% gross margin is in reality closer to 20%). HPS CEO Gyanesh Pandey points out that there are very few other developers who have tried to replicate their model to date, which may indicate a lack of confidence in addressing rural electrification using the HPS business model.

Limited entrepreneur finance access: Village entrepreneurs seeking to own and operate HPS microgrids often face an investment barrier because it is difficult for them to qualify for bank loans. Furthermore, the local entrepreneurs, while knowledgeable, are not well-positioned to navigate the bureaucracy around obtaining a government subsidy. HPS has found that it must direct some of its efforts into enabling funding mechanisms for entrepreneurs to finance plants under its "build-maintain" (BM) franchise model. This has been a drain on their resources and they would like to see a more accessible process put into place by the government and banks for village entrepreneurs to be able to access financing for HPS plant franchises.

High maintenance requirements: While biomass gasifiers have low capital costs, they require a large amount of feedstock, proper storage practices, and significantly more labor than other types of systems. Operationally, gasifiers are vulnerable to a multitude of problems. On a daily basis, tar build-up or wet husk can prevent operations. Other common issues with the systems include spark plug failure, battery discharge, and bottle coil (an unintentional current to the spark plug). Aside from issues on the supply side, they must contend with distribution system problems as well – from ground faults to pole replacements. Nevertheless, HPS has learned how to minimize down time due to the technical issues through a well-trained workforce and customer sensitization.

Feedstock dependency: Biomass gasifiers require an enormous amount of rice husk for operations: approximately 50kg per hour for 6 hours each day. This dependency on rice husk has led to a collusion of rice mills with HPS employees to increase prices, and some difficulty in obtaining enough rice husk. A further challenge is keeping the husk dry during the rainy season.

Demand management: Theft and over-usage are still significant problems for HPS. Some customers bypass their meters; others use incandescent light bulbs, which are banned from HPS systems, in sites where HPS has not installed load-limiting technologies. HPS can monitor over-usage by comparing the plant output meter with the sum of the paid customer usage levels, but this is a laborious, manual process that does not identify specific offenders. Most villages HPS operates in are not tribal, and therefore do not have a high level of community cohesiveness, requiring technical or "enforcement from above" solutions to keep the microgrids running properly.

Lessons Learned

The franchise model enables rapid scale-up. As discussed in further detail in Chapter 6, HPS utilizes two business models – Build-Own-Operate-Maintain (BOOM) and Build-Own-Maintain (BOM) – that entail HPS ownership of the microgrid, and one that is owned and operated by an independent entrepreneur – Build-Maintain (BM). HPS has found that scaling up with a BOOM plant model is not feasible because it is difficult to simultaneously manage and finance hundreds of plants. While HPS has developed only a handful of BM plants so far, the experience of the entrepreneurs has shown that they can be highly profitable. HPS management emphasizes that village entrepreneurs should not be underestimated in their ability to run a highly successful business. Thus far, BM plants operate more reliably and are more profitable than BOOM or BOM plants because the entrepreneur can focus on a single plant and directly benefit from its success. However, BOOM plants, while perhaps not quite as well-performing as BM plants, were essential for HPS to experiment and learn how to "get the formula right."

Diesel can pave the way for biomass. In places with an existing and operating diesel microgrid, HPS can simply set up a system and villagers will automatically choose to connect to it because it is less expensive and more reliable. In villages without an existing microgrid, HPS has found that they must collect a deposit from a threshold number of villagers to ensure that they are committed to the construction of the gasifier as well as the continued use of and payment for the electricity.

Village cohesiveness is rare. Non-tribal communities are not cohesive, and the idea of cooperating to help keep a shared resource running is not natural to them. HPS has partially resolved this problem by involving community members in the system by giving them jobs. This is viewed by the community as self-empowerment, and provides them with an incentive to cooperate.

Bypass elected leaders. HPS has learned to deal with the community directly rather than a single leader or elected person in a village. The leaders and officials HPS has interacted with have sought to extract something for themselves out of the agreement. This lesson applies to the initial assessment work, commissioning and operations.

Bonuses rarely work. Unlike urban communities, HPS finds that employees in rural communities are difficult to motivate with bonuses. Many of them are content with their fixed salary and will not push themselves to perform in order to increase their salary. For example, HPS sought to increase its collection rate by incentivizing payment collectors with a bonus contingent on payment amount and rate. They found an insignificant increase in performance and an insignificant increase in effort by payment collectors. This is consistent with the literature on "backward-bending" labor supply curves.

Manage supply chains tightly and with enforceable contracts. HPS has encountered several difficulties in their supply chain due to what was identified as "greed and deceit." Examples include:

- A wealthy land-owner who agreed to lease land to HPS for a power plant and later tried to negotiate higher payments,
- Poor employee performance by individuals who were also leasing land to HPS, and
- Collusion between HPS employees and rice husk suppliers to raise prices.

In response, HPS advises to regularly perform audits on each of its major expense categories – employee wages, fuel, land leases, and maintenance. In most villages, HPS has had to be forceful with their contracts and ensuring people abide by agreements. On several occasions, they have invoked threats of lawsuits.

Low-income microgrid customers have unique metering requirements. Microgrid meters must track energy usage or duration of energy usage in addition to limiting power (W), energy (kWh) or time limits. While HPS is fervent about the role of this type of sophisticated technology on its microgrids, it concedes that no amount of technological innovation could fully obviate the need for human interaction. A trustworthy payment collector or auditor must make visits to check on houses to ensure that sophisticated meters are not being spoofed or bypassed.

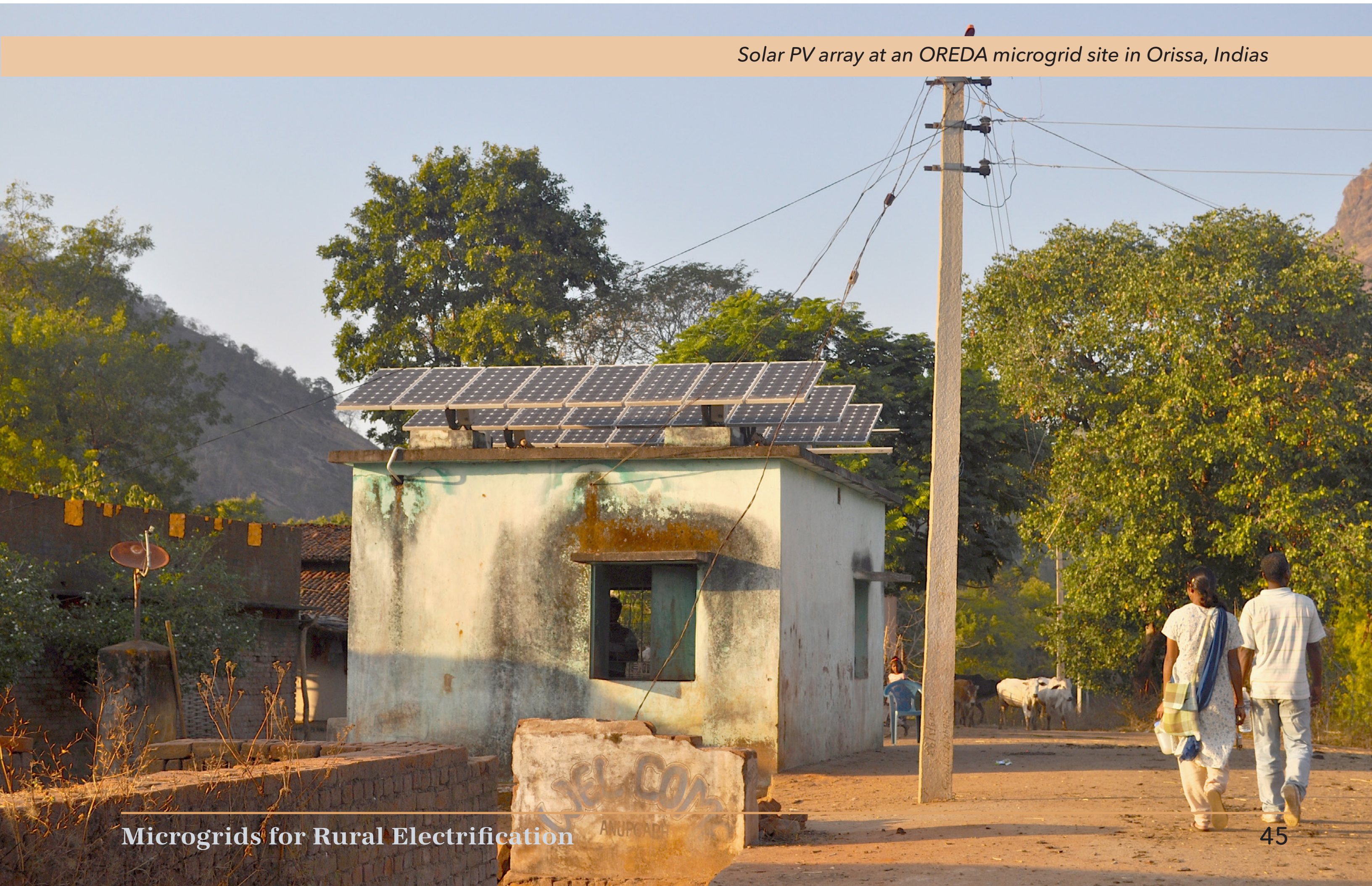
"Rural electrification is not grassroots." According to the CEO of HPS, microgrids "unfortunately cannot be spearheaded by people who are suffering. They must be initiated by people who are more fortunate." He attributes this to the complexity of microgrid development and operations. There is a persistent notion in the aid and NGO community that microgrids can be self-organized. While HPS's success as a private developer does not disprove this notion, it does lend credibility to the notion that positive outcomes can result from private intervention, whereas there is little evidence of successful microgrid development and operation when it is fully entrusted to a community.

Orissa Renewable Energy Development Agency (OREDA), India

Successes

Wide reach: OREDA has had an impressive track record of scaling up their electrification efforts and reaching over a thousand villages with distributed solar home systems. PV microgrid systems that were installed over 10 years ago still exist and provide electricity to many people, some of the time.

Solar PV array at an OREDA microgrid site in Orissa, Indias



State and agency cooperation: The state's cooperation with OREDA, and the clear division of the villages OREDA electrifies and the villages to which the main grid extends, allow for certainty about the longevity potential and need for microgrids in each community.

Inclusion of the poorest: A high percentage of the people within OREDA microgrid villages are connected to the system and payments are affordable (or more often non-existent). The average income in most of the villages encountered in field visits was only 1,000 – 1,500 Rs/month (16 - 24 USD/month), significantly lower than communities served by other developers.

Energy dervices reliability: OREDA's goal was to at least provide lighting for basic activities, such as reading and chores for a few hours each night. While some systems in their 11th year of operation are not functioning as reliably as they once did, OREDA successfully installed systems that could provide the intended energy service for everyone in the village for at least the first several years.

Challenges

Poor maintenance: OREDA's installation and maintenance model functions poorly in practice, which causes significant consumer losses, as households revert back to kerosene for lighting. Historically, maintenance contracts were awarded through public tender for a ten-year period, but OREDA has been disappointed with the performance of the chosen maintenance contractor, Tata BP Solar. The contractor is asked to visit each system every three months, and ensure it is working properly. In practice, many systems remain in a non-functional or barely-functional state for years. In 2012, new contracts were awarded for five-year terms to a different vendor. In Palsipani, they have had only 30 minutes of electricity per day for the last 18 months until four days prior to our field visit. The maintenance contractor, Tata BP, replaced eight out of 20 batteries at that time. The timing of the maintenance visit and poor practice of partial battery replacement could have been a rushed attempt to save face in advance of our field visit. In Tuluka, solar panels were coated in dust during our field visit and villagers did not realize they could be washed. It is suspected that this lapse in maintenance caused them to have electricity only two or three hours per day since mid-2012, whereas the system was designed to provide power for five hours a day.

There is also confusion over how villages "call in" maintenance requests – OREDA managers indicate that a Village Electrification Committee (VEC) can either call or visit the vendor or OREDA offices (either district or headquarters), but the VECs seem to have been under the impression that it was necessary to write a letter to OREDA headquarters to request that OREDA contact the maintenance provider. It is apparent that OREDA should clarify the service request procedure with VECs.

Absence of on-site distillation requires transporting large volumes of distilled water through rural, logistically challenging places. Distillation tables at villages would enable an easy, reliable source of distilled water for the batteries at remote sites.

Lack of community cooperation: Community collaboration and cooperation is a significant downfall for OREDA's microgrids. While the Village Electrification Committee was intended to be the institution that managed operational and maintenance activities, the VECs in practice have proven ineffective against challenges like village disputes, theft, improper maintenance, and overuse, which regularly compromise performance of the system. In Matiapadhar, a village dispute has resulted in only the two village leaders being served with electricity. The dispute has left the community members disenfranchised and unable to resolve the distribution system and battery problems that have left them without electricity for three years. In Anupgarh, the system had not been functioning for the six months prior to our field visit. Someone in the village stole some of the panels when service started to decline, and the village has now mostly reverted back to kerosene. In Tuluka, overuse is rampant – fans and incandescent light bulbs are the norm.

Rebel factions: Many of the installed systems could not be maintained by contractors because Maoist rebels in certain villages threaten violence against government officials or government-affiliated workers who enter.

Poor payment collection: The three villages which had systems installed in 2002 under the UNDP-OREDA program are scheduled to have the ownership transferred to the community in 2013, but each village is certain that the system will fall into disrepair because they have not collected payments diligently and have very little, if anything, saved up for the transfer.

Lessons Learned

Community ownership without an effective institution leads to a tragedy of the commons. OREDA's deputy director said with disappointment during an interview that "community ownership means no one's ownership". OREDA has found that communities let their microgrids fall into disrepair because it is a common good, and the burden of maintenance for the whole village falls on only a few members of the community. For its future rural electrification strategy, OREDA decided to electrify more communities with individual solar home systems rather than microgrids. This decision is in part motivated by their observation that individual households take ownership over their systems and maintain them better than they would a shared system.

Electrification should provide opportunities. OREDA has found that villagers do not value lighting alone enough to pay for lighting-only microgrid service. They also do not want to dedicate the time needed to collectively maintain the system that could never support income-generating opportunities. OREDA realizes that it needs to design future systems to enable income-generating activities or provide entertainment (such as TVs) in order to stimulate willingness to pay. Yet OREDA struggles with a limited budget in which it had to choose between providing a very low-capacity system to many, or a high-capacity system to a few. OREDA has chosen to install smaller systems in the nearly 2,000 villages in the state (which either have no light or use kerosene) over providing bigger systems to fewer villages that could support appliances, entertainment, or income generating activities.

Maintenance contractors must be audited and penalized for poor performance. As a state government agency overseeing 63 systems, OREDA enlisted maintenance contractors to regularly check on and maintain the systems. Yet without strict monitoring and enforcement, the contractors have done a poor job maintaining some of these systems, and has failed to respond to requests for urgent service from communities.

Facilitate communication among beneficiaries, developers and maintenance providers. Communication between the village and OREDA must be streamlined because messages about system performance are often ignored. There is a disconnect between the initiative the village might take regarding system failures or under-performance, the mode of communication, the OREDA action, and the maintenance contractors' response. Village training and institution development should include a process to communicate with OREDA and the contractors.

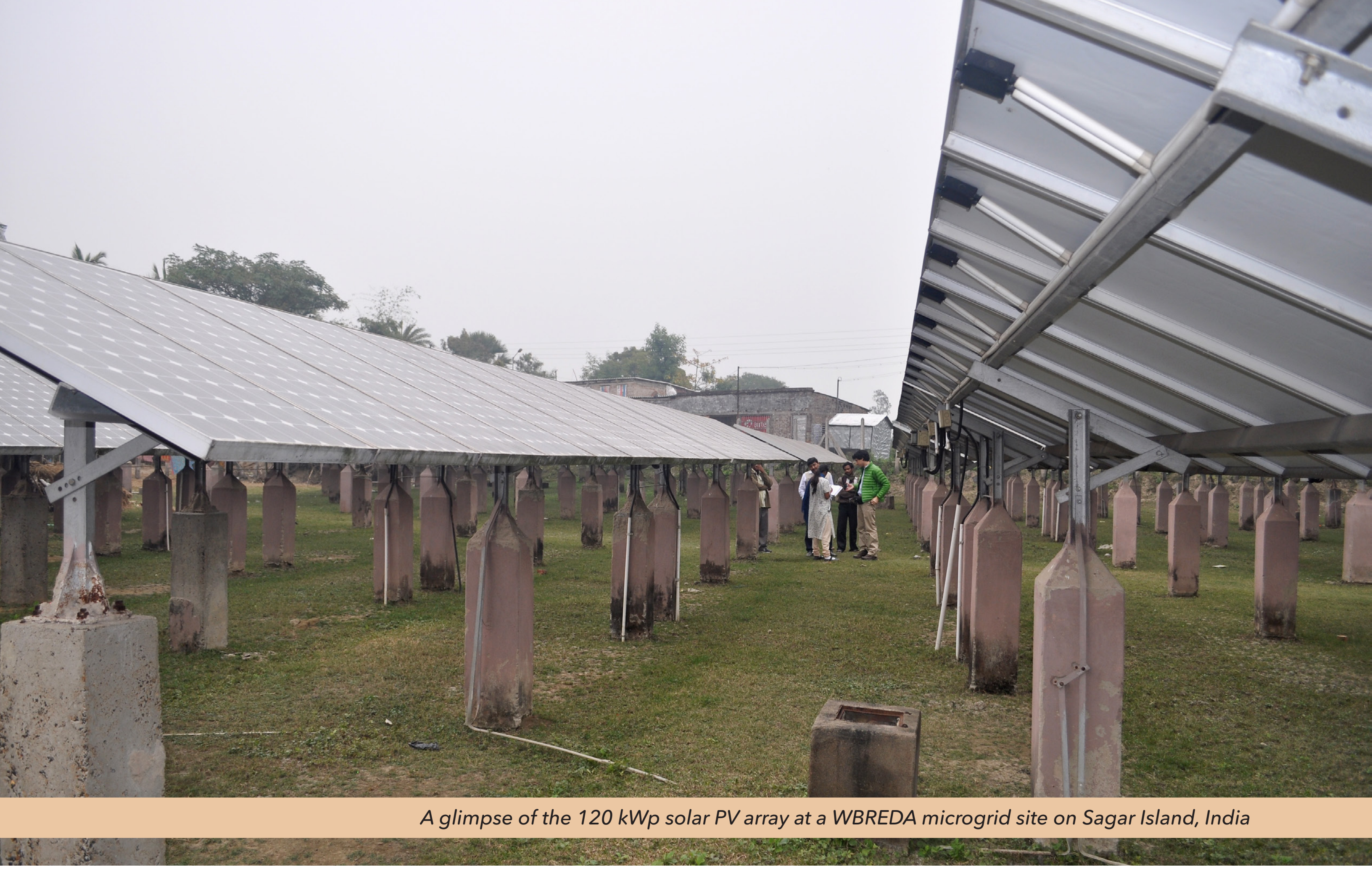
Village cohesiveness varies. There is a correlation between strong village leadership and how well the grid functions. Remote tribal villages with strong leaders (even if poorer) coordinate villages much better than more educated, less cohesive villages that are closer to commercial areas where they can buy electronic gadgets and overload the systems. The lesson learned from this is that developers should note and respond to the cohesiveness of the community. For most villages, they might consider investing resources into more extensive institutional development.

West Bengal Renewable Energy Development Agency (WBREDA), India

Successes

Community involvement in microgrid development: In the early years of WBREDA's microgrid development, community involvement was an integral component. All villages contributed land to host the power plants, and cooperatives were created to fulfill key development roles, such as creating distribution system paths, selecting customers, and communicating expectations between the customers and WBREDA. Many communities successfully maintained their cooperative maintenance model for five years or more before switching schemes.

Maintenance. Maintenance and operational tasks are carried out by employees of a private contractor that keeps one lineman and one operator at each microgrid site. WBREDA appears to hold its maintenance contractors to high standards, and the presence of solar distillation chambers for water and on-site staff appears to ensure reliable maintenance. The batteries at Koyalapara were last replaced 2 years before our visit, and some fraction is topped off with the distilled water produced on-site daily. On-site water distillation capabilities reduce transportation costs as well as dependence on outside sources of distilled water.



A glimpse of the 120 kWp solar PV array at a WBREDA microgrid site on Sagar Island, India

Frequent competition between maintenance contractors for the one-year WBREDA service accounts likely increases the quality of service.

Proper maintenance appears to be key to the consistent high quality of service of the WBREDA microgrids. For as the community depends on the microgrid as their primary electricity source, proper maintenance perpetuates a virtuous cycle that earns the loyalty of the customers: Customers experience a level of service that is consistent with their expectations and the stated microgrid schedules. In exchange, they are comfortable paying a fixed monthly fee for their service. Steady payments in turn ensure that WBREDA can continue to renew maintenance contracts.

Penalty enforcement. The goal of customer disconnection for non-payment and excessive power consumption over load limits is to deter such behavior, which can jeopardize the microgrid's performance. According to the Koyalapara microgrid operators, the local microgrid institution (known as the "beneficiary committee") enforces both types of penalties. While the microgrids are able to sustain decent levels of performance, the penalties seem to be more effective at curtailing non-payment than at preventing the exceeding of load limits. In other towns, the tariff collectors employed by WBREDA report non-payment to WBREDA officials. The officials can give orders to the tariff collectors to disconnect the defaulting customer. Current estimates of non-payment are 15-20%.

Health and social benefits: The microgrid has delivered a variety of social and safety improvements. For example, lighting increases economic opportunity for women, such as stitching and tailoring at night. Many villagers cite the "most important development" as allowing them to avoid snakes in or around their houses at night, which has reduced the number of snakebite cases on Sagar Island. Additionally, community refrigerators can store anti-venom or general vaccines. Other productive end uses for electricity include integrating water pumps into the microgrids to deliver drinking water from aquifers.

Economic Benefits: Electricity has enabled the establishment a number of new enterprises among the communities being served. For example, in the village of Mousini, people used to travel 40 kilometers to make a photocopy at the nearest city. One entrepreneur bought a photocopier and operated it for two hours a day in Mousini. He ran a successful business by charging three Rs ($0.05 USD) per copy. Another entrepreneur started a smaller mobile phone charging business by trickle charging a battery during operating hours and charging customers three Rs per charge.

Challenges

Community involvement in microgrid operations: Over the years, the WBREDA microgrid business model and ownership structure evolved to accommodate changing political realities, village dynamics, and incorporate valuable lessons learned. The first microgrids were developed on Sagar Island under a pioneering rural electric cooperative concept developed by Dr. Gon Chaudhuri. The Sagar Island cooperative served as an umbrella for all microgrids developed or to-be-developed in the future on Sagar Island. Later on, other islands – Gosaba, Chhoto Mullakhali, Partha Pratina, and Mousuni – established cooperatives as well.

While hard data on rates of payment and operational uptime is lacking, WBREDA officials claim that this model worked well for the first few years in each region. According to WBREDA, the cooperative model in Sagar collapsed when Sagar Island cooperative officials sought a financial interest in tariff collection to be shared amongst themselves. In response, WBREDA hired its own tariff collectors to circumvent the cooperative. By 2001, the cooperative "existed in name only."

Three examples of cooperative failures are as follows:

- On Gosaba Island, there were regular cooperative elections from 1996 until 2011. By 2011, the elections devolved into a political contest. With the functions of the cooperative subject to political infighting, WBREDA circumvented the cooperative on Gosaba Island as well.
- On Pathar Pratima, the cooperative failed to function very shortly after the microgrids became operational. WBREDA stepped in almost immediately to act as the operator.
- In Mousuni, the cooperative functioned well for nine years, until a change in the Panchayat leadership. The new Panchayat government prevented the cooperative from performing its duties because the cooperative was led by the leadership of the former government.

Microgrids cease operations due to grid extension: Well before the arrival of the central grid, microgrid customers are aware of its pending construction. There is little question in their mind over whether to continue being served by the microgrid or to switch over to central grid service. They understand that the central grid will deliver electricity at a lower cost, and there will be no limit to their consumption - even if the electricity is unreliable. In rural areas, central grid power is sold to residential customers at a highly subsidized rate – just 2.5 Rs/kWh (0.04 USD/kWh) – compared to 6.5 Rs/kWh (0.11 USD/kWh) in Kolkata. Before the central grid arrived in towns served by WBREDA microgrids, customers demonstrated a willingness to pay of 8 – 10 Rs/kWh (0.13 – 0.16 USD/kWh) for electricity from the microgrids.

Four installed microgrids are no longer in service due to consumer migration to central grid extension. Non-payment is also on the rise in several other microgrid systems because customers are putting pressure on their local politicians to attract central grid electrification.

Lessons Learned

Inter-agency coordination must be improved. Poor coordination and conflicting policy directives between WBREDA, the MNRE and the Ministry of Power results in obsolete microgrids. Even after the arrival of the central grid in a community, microgrids and the central grid can co-exist and complement each other.

The goals of the RGGVY (Rajiv Gandhi Grameen Vidyutikaran Yojana) scheme, administered through the MNRE and WBREDA, conflict directly with the national government's goals for 100% central grid electrification, administered through the Ministry of Power (MOP) and State Electricity Boards. State-level politicians have every incentive to take funds from MNRE through RGGVY and also from the Ministry of Power, which results in overlapping electrification expenditures. The RGGVY-funded distributed energy projects end up being overtaken by the central grid rather than being integrated. Both MNRE and MOP must agree on a coordinated strategy such that funding is not allocated to electrify an area with one system that will render the other obsolete. A clear problem contributing to poor coordination is that renewable energy systems are not considered by the national government to provide "electrification". The only acceptable system that can provide "electrification" as defined by the national government is the central grid. As such, MOP and the State Electricity Boards must enter every area to achieve the goals of the national policy. This definition also permits State Electricity Boards to provide an *operational* subsidy to rural customers to reduce the retail price of electricity down to 3 Rs/kWh (0.05 USD/kWh) for central grids. The MNRE does not offer an operational subsidy – just a capital subsidy for renewable energy system development. As a result, renewable energy systems (including microgrids) cannot compete on a cost basis with the central grid.

In the places where WBREDA microgrids have been overtaken by the central grid, power shortages are common. WBREDA acknowledges that such shortages will eventually be reduced, as the Ministry of Power is always trying to improve service. WBREDA believes that at some point, there will be uninterrupted central grid power even in the rural areas. The government has declared that by the end of the 12th Five Year Plan (2017), all villages will be powered by the central grid. In the meantime, better coordination could allow microgrid assets to be integrated with the central grid such that the microgrid could be "islanded" to power the community when the central grid is not functioning.

The ideal situation would involve government entities coordinating with each other, avoiding overlapping electrification efforts, and subsidies designed to incentivize prudent system selection in remote areas. For example, if only a capital subsidy were offered for central grid extension or a microgrid system, a village will opt for the more appropriate (and better-performing) microgrid system because the operational cost will be much less than the operational cost of the central grid, which translates to a lower retail price. Unfortunately, government subsidies are not aligned with sustaining renewable energy microgrids. As a result, customers thus far have opted for the lower-priced central grid even though it has lower quality service.

Systems must be incrementally expandable or improve demand-side management. Due to increased economic activity leading to higher incomes, increased demand is an inevitable result of microgrid electrification. Microgrids, especially those intended for more than lighting, must be sufficiently flexible to accommodate additional generation over time. Microgrid owners must also ensure that financing will be available to pay for additional generation. In WBREDA's case, tariffs are designed only to cover ongoing operating costs. As a result, WBREDA must look to alternative non-commercial forms of financing to add generating capacity.

Community involvement is helpful to development but can be detrimental to operations. During the initial period of development, community involvement was an important factor in WBREDA's ability to establish the microgrids. Without the assistance of local leadership and broad involvement, WBREDA might not have been welcome. In the absence of such involvement, a local politician could falsely claim to be working to bring central grid electrification to his region. The strong local support for the microgrids prevented these political games, and actually overcame such an objection when a local politician claimed to be in the process of bringing a nuclear power plant to the Sundarbans nearly 15 years ago.

Even during the transition from discussions to microgrid commissioning, the communities in the Sundarbans played an important role through the cooperative institution. With the intervention of the cooperative, communities provided land, helped set out paths for distribution lines, and acted as a conduit for communications between the customers and WBREDA. As WBREDA acknowledged, it was the cooperatives that were in a much better position to perform the social engineering necessary for the acceptance of particular rules.

Unfortunately, the track record on community involvement in operations is mixed. The cooperatives failed over time due to financial demands or political squabbles. However, local beneficiary committees appear to be durable in more limited operational roles, such as enforcing penalties.

The following section contains seven detailed case studies based on in-person interviews with the developer, and between one to four operator interviews and microgrid site visits for each developer. In each case study, we provide a description of the developer and sites visited, the business model, financing sources, microgrid costs, penalties, service coverage, levels of service, and load management schemes. Costs given in foreign currencies have been converted to US dollars using April 2013 exchange rates.

Chhattisgarh Renewable Energy Development Agency (CREDA), India

Description

The Chhattisgarh Renewable Energy Development Agency (CREDA), a state government agency of the Indian state of Chhattisgarh, is responsible for implementing renewable energy programs defined and sponsored by the central government's Ministry of New and Renewable Energy (MNRE). The state of Chhattisgarh is densely forested with a predominantly tribal population and until recently, a low rate of electrification. Since its formation in 2001, CREDA has been tasked to electrify communities through microgrids and solar home lighting systems, and to provide clean cooking options through improved biomass cookstoves and household biogas systems. To date, CREDA has installed and operated over 500 solar PV microgrids under the Remote Village Electrification Program, and tens of biomass gasifier-based microgrids under the Village Energy Security Program. According to CREDA, the solar PV microgrids serve approximately 30,000 households. **Table 5** lists all the solar microgrids installed in 2010-2012.

Business Model

CREDA's business model entails that the community owns the microgrid, private developers and service providers build and operate the system, and CREDA manages and monitors the entire ecosystem of microgrids. The village energy committee (VEC), made up of members of the local community, is responsible for the community's involvement during the installation of the plant in terms of identifying the needs of the community and the provision of labor and land. Post-installation, they are also responsible for the day-to-day operations of the plant.

The selection of the private contractors for installation, operations and maintenance (O&M) is usually done through a bidding process. In their latest contracts, installers are also required to provide five years of O&M services. The operator is usually chosen from the community.

The large number of installed microgrids makes CREDA one of the most successful government agencies in India. Several reasons lie behind the agency's success, including a strong monitoring and verification program, a technically competent staff and a professionally managed institution. But most importantly, the significant financial support from the state government of Chhattisgarh, in addition to the usual central government subsidies, has enabled CREDA's projects to not depend on electricity service payments from the community in order to be financially viable. Although non-payment of dues is prevalent in these projects, service providers continue to get paid on time through CREDA's central tranche, which ensures relatively small interruptions in service.

Financing

Most of the solar microgrids installed by CREDA have been developed under the Remote Village Electrification (RVE) program of the Ministry of New and Renewable Energy (MNRE). Under the RVE program, the MNRE provided capital subsidies of approximately Rs 250 per Wp (~USD 4 per Wp), which covered a little less than 50% of the total expenditure. The rest of the cost has been borne by CREDA through the Chhattisgarh state government subsidies. These additional costs include the ongoing subsidies for O&M of the plants. CREDA has instituted a separate fund of Rs 8 crores (USD 1.3 million) for O&M, to be used in case there are interruptions in the allocation of state government subsidies.

Microgrid Costs

The most recent capital costs for CREDA's solar microgrid generation systems with battery stor-

Table 5: CREDA microgrid development, 2010-2012

Village	District	Capacity (kW)	Year Installed	Total Residential Customers
Bedmi-1	Sarguja	5	2010-11	201
Bedmi-2	Sarguja	2	2010-11	
Putki	Sarguja	4	2010-11	60
Navadihkurd	Sarguja	4	2010-11	57
KarwaN	Sarguja	5	2010-11	48
Navadih	Sarguja	4	2010-11	62
Pandawari	Sarguja	2	2010-11	33
Basnara	Sarguja	5	2010-11	69
Taharagi	Sarguja	3	2010-11	45
Jelha	Sarguja	4	2010-11	62
Karoti	Sarguja	6	2010-11	111
Chonga	Sarguja	6	2010-11	97
Ramgarh	Sarguja	4	2010-11	65
Umjhar	Sarguja	6	2010-11	115
Rasoti	Sarguja	6	2010-11	92
Khohir	Sarguja	4	2010-11	62
Risgaon	Dhamtari	10	2010-11	143
Amabahar	Dhamtari	10	2010-11	138
Baghel	Koriya	3	2011-12	41
Hanspur	Koriya	2	2011-12	28
Dhanhar	Koriya	2	2011-12	21
Lawahori	Koriya	3	2011-12	44
Jamuniya	Koriya	3	2011-12	46
Devgarhkhoh	Koriya	2	2011-12	32
Padewa	Koriya	3	2011-12	46
Madpa	Dantewada	1	2011-12	12
Edka	Narayanpur	2	2011-12	24
Benur	Narayanpur	2	2011-12	24
Dhodoi	Narayanpur	2	2011-12	24
Halamimunj meta	Narayanpur	2	2011-12	24
Farasgaon	Narayanpur	2	2011-12	24

age are approximately Rs 4 lakh per kW (USD 6.5 per Wp). In addition, the power distribution network costs approximately Rs 10,000 (USD 160) per household. Assuming 15 households per kWp and an additional Rs 50,000 per kW of O&M costs, CREDA assumes a total cost of Rs 6 lakhs per kW (USD 9,800 per kW) for their solar micro-grids. CREDA pays the capital expenses to private contractors through a bidding/tender process. For O&M services, CREDA pays the service provider Rs 45 (USD 0.73) per household per year, as well as any additional expenditure for battery replacement or distribution network maintenance.

Tariffs and Payment

CREDA has set a fixed connection fee of Rs 300 (USD 4.88) per household and a relatively low fixed monthly fee of Rs 5 per household. Since the monthly tariff is on a per household basis, the tariff for a kWh of reliable supply of electricity is approximately Rs 1-2 kWh (0.02 – 0.03 USD/kWh), assuming 2 CFLs of 11W operating for 6 hours a day.

Penalties

In case of non-payment of dues, the defaulting customer gets notified by the village energy committee, and then eventually is disconnected after two to three months of continual default. While these rules exist, in reality, they are seldom exercised. Further, neither CREDA nor the service provider depends on the relatively small consumer payments for O&M expenses, which are covered almost entirely by state government support.

Coverage

According to CREDA, the coverage of their microgrids is 80-90% of all households in most villages, which is high. A relatively low fixed connection fee of Rs 300 (USD 5) per household and a very low monthly fee of Rs 5 (USD 0.08) per household have enabled most households to afford the electricity service.

CREDA has installed solar PV microgrids predominantly under the RVE scheme of MNRE. The subsidies under this scheme are for the provision of lighting loads only, and microgrids are designed accordingly.

Load Management Schemes

CREDA's solar PV microgrids are designed for lighting loads only (two 11W CFLs for 6 hours). Any additional loads can quickly exceed the capacity of the plant to provide its designed energy output. Hence, it is critical for CREDA to ensure that no customer uses more loads or devices than the allocated lighting loads. This responsibility of load management is given to the Village Energy Committee (VEC). CREDA believes that local community leaders can be more effective in enforcement than an outside agency.

However, households do end up buying additional electrical appliances, and consume more than their allocation. Exceeding the designed load and energy supply limits is the most common reason for failure of the solar PV microgrids. At that time, the VEC either tries to enforce the load limit for each household, or petitions CREDA for an additional plant in their community. It is up to CREDA's discretion whether to provide an additional plant or not, given that the policy support is for solar PV microgrids to provide lighting only. CREDA also provides CFLs to operators for replacing incandescent light bulbs.

Performance

CREDA solar PV microgrids are designed to provide electricity for lighting loads for 6 hours a day. According to CREDA, over 80% of the solar PV microgrids plants are presently operating. However, this needs to be ascertained given the rural central grid electrification efforts under the RGGVY, the central government's rural grid extension program. Notwithstanding the unreliability of the central grid supply, microgrid consumers tend to prefer a central grid connection since they believe it will not impose a limit on their consumption.

The relatively high up-times of these microgrids can be attributed to CREDA's commitment to the ongoing operations and maintenance of the projects. The financial backing of the state government is key to keeping the projects running without depending on the payments from consumers.

DESI Power, India

Description

Decentralized Energy Systems of India, or DESI Power, is a non-profit company that designs and builds biomass gasification microgrid systems, primarily in Bihar, India. The company has installed biomass gasifiers in five villages (four in Bihar, one in Madhya Pradesh). System size varies between 30 - 150 kW. Feedstock is locally produced agri-residue, twigs, and rice husk.

DESI greatly emphasizes the empowering aspects of electrification. They explicitly set out to create opportunities for women and the lowest income villagers through community-owned agricultural processing facilities, local plant operator jobs and by purchasing local feedstock.

Business Model

DESI Power explicitly states that it is a "triple bot-

Table 6: DESI Power microgrid development

Town	State	Generation Source	Capacity (kW)	Year Installed	Capital Cost (Nominal Rs)	Description of Capital Contribuitons
Bara	Bihar	Biomass gasifier	32	2012	3,200,000	80% Minda; 20% DESI
Baharbari	Bihar	Biomass gasifier and dual fuel engine	35	2002	3,500,000	100% DESI
Bhebra	Bihar	Biomass gasifier	43	2006	4,300,000	100% DESI
Gaiyari	Bihar	Biomass gasifier	150	2006	15,000,000	100% DESI
Orja	M Pradesh	Biomass gasifier	N/A	1996	N/A	100% DESI

Table 7: DESI Power microgrid customers

Town	State	Total Residential Customers	Total Commercial Customers	Status
Bara	Bihar	370	7	Functional
Baharbari	Bihar	75	1	Functional
Bhebra	Bihar	0	17	Functional
Gaiyari	Bihar	0	9	Functional
Orja	M Pradesh	N/A	N/A	Functional

tom line" business that delivers economic, social and ecological returns. Its decision to invest in a project is based not only on financial returns, but also on the number of jobs created, improvements to health, and emissions reductions. Their customer base usually includes one reliable "anchor" customer to ensure there is enough demand and a reliable source of revenue.

To achieve these returns, DESI has experimented with several different business models to fit what it has identified as different microgrid "markets." These markets are classified as village, industrial and semi-urban. The company has developed at least one microgrid for each of these markets:

- The "village" model is defined by a two-step process. The first step of the process focuses on the development of commercial activities in the town. In Baharbari, where this model was deployed in 2002, DESI partnered with a village cooperative called BOVS to develop commercial activities. The development included the installation of commercial equipment for irrigation, hulling, milling, battery charging and a small workshop. The equipment is owned by BOVS and was financed through a loan provided to them by DESI. The intent of this first step is to increase villager income because they could not pay for electricity when DESI first developed the microgrid. In 2006, four years after introducing the commercial services, DESI began to connect households for lighting-only services.

- The "industrial" model sells electricity to customers with large peak loads that demand consistently reliable power. Electricity is sold on a metered basis to customers, who pay an energy-based tariff. While power purchase contracts are not used, the model presupposes that the customers have no other alternative for reasonably priced, reliable power. In Gaiyari, DESI serves a big rice mill, carpentry workshops, and banks.
- The "semi-urban" model is a hybrid of the "village" and "industrial" models. It caters to small commercial customers that purchase electricity on a metered, energy-based tariff, but also provides users with energy services. In Bhebra, DESI serves a cinema house, computer shop, and petrol pump. It also owns irrigation pumps there and sells the irrigated water to farmers on a services basis.

DESI Power's model sometimes involves serving residential customers in non-village microgrids by serving an intermediary business instead of serving residential customers directly. In Bara, a semi-urban area, there are three such independent businesses – "evening lighting suppliers" – that purchase power from DESI on a metered basis, and sell electricity to residential customers. There are a total of about 370 customers with one to two light bulbs each. The total load for the evening lighting is about 7 kW. The other customers served directly by DESI in Bara are two mills (7.5kW each) and two carpentry shops (3.5 kW each).

DESI Power's investment model is flexible. It operates two separate entities – a non-profit company called DESI Power, and a for-profit company called DESI Power Kosi. DESI Power is used to prove out its three business models. DESI Power Kosi launched its first microgrid in 2012 through a joint venture that owns the Bara microgrid with an independent investor, Minda. Minda invested 80% of the 3.2 million Rs. (or approximately USD 60,000) in capital costs for Bara, and DESI Power Kosi invested 20%.

Financing

Although DESI considers itself flexible and opportunistic with funding resources, all but one of DESI's microgrids have been financed entirely by DESI Power. The organization has been funded through international grants and individual funds. In 2004, DESI Power won a World Bank Development Marketplace Prize valued at approximately USD 180,000 for its Village EmPower Partnership Model, which it used to build three systems. The above-mentioned Bara plant received 80% of its financing from a private investor partner – Minda Power.

DESI has taken a small subsidy from MNRE to convert its engines to run on biogas. The subsidy covers 90% of the conversion cost. DESI has not used the MNRE capital cost subsidy for building microgrids because they lack trust in government subsidies and believe doing so would subject them to tighter regulation.

Microgrid Costs

DESI was unable to share detailed cost information. DESI estimates plant capital costs at approximately USD 1,800/kW on average, and did not provide any operating cost information.

Tariffs and Payments

DESI has a variety of tariff structures and collection methods depending on the type of customer and the specified usage. Energy tariffs are exclusively used for commercial customers and vary between 5-12 Rs/kWh (0.08 – 0.20 USD/kWh). In Gaiyari, the rice mill pays 12 Rs/kWh. All other customers in Gaiyari pay 8 Rs/kWh (USD 0.13/kWh). In Baharbari, BOVS, the commercial village cooperative, pays 7-8 Rs/kWh. DESI employees read meters and collect payments once or twice a week for commercial customers. All payment collections are done in person.

The menu of available options available to residential customers varies depending on the site. Some customers can only use lighting, and others use fans, televisions, and refrigerators. Residential customers served by the evening lighting suppliers can select the capacity level in terms of the number connection points. In Bara, customers can choose between one to five 11W "points." The evening lighting suppliers charge customers in Bara a set rate of three Rupees per 11W "point" per day and collect payments daily.

DESI Power also charges for energy services in Baharbari and Bara. It sells irrigation water at 60 Rs/hour (USD 1/hour), and also charge for de-husking, grinding and battery charging as energy services.

Penalties

Commercial customers are penalized for non-payment with disconnection. Theft is rare because there are so few customers and it is easy to monitor connections.

Residential customers sometimes bypass their meters, which is difficult for DESI Power to detect. The Baharbari plant operator estimates that two to three kWh are stolen each day. Disconnection is a penalty for residential theft, but is often unenforced because of the difficulty in detecting the offending households.

Coverage

While empowering the disadvantaged and the poor is a priority for DESI, they will not install a microgrid in a village without viable commercial or industrial customers. If they can find an anchor customer near an un-electrified community, they will push to connect households. In Baharbari, where they do serve residential loads directly (70-80 households total), about 70-80% of the village is connected. The Bara microgrid serves 370 households out of 1,000 households in the vicinity through the evening lighting suppliers.

Having operated for well over ten years, DESI Power is scaling up slowly with only five plants total. DESI is systematic about choosing locations, stimulating the local economy, and serving un-electrified customers. But overall or within each community, DESI does not attempt to serve the greatest number of customers possible.

Load Management Schemes

Load management is a "problem area" for residential customers. Households in Baharbari were connected with miniature circuit breakers in 2006, but these were not working during the site visit. DESI Power is hoping to start integrating more technological innovations, and plans to roll out a "wireless control system and meter" to monitor residential customers in the near future.

Performance

DESI Power systems claims that they are motivated to provide very high quality service and customer satisfaction because their success is dependent on delivering reliable services. Their business is predicated on being able to provide better service than the central grid (which often exists concurrently with the DESI microgrid) and at a lower price than individual diesel generators. If they become less reliable or more costly than either of those options, they will lose business.

In order to recover costs the plants must run for 10-12 hours/day. However, operational problems were encountered during our site visits. In Bara, the gasifier was broken, but they had a diesel generator to provide backup power. The Gaiyari microgrid had been shut down for the previous 15 days because of an underground cable problem, and a solution was not yet identified.

Green Empowerment/Tonibung/PACOS (GE/T/P), Malaysia

Description

Green Empowerment, along with partner organizations such as Tonibung and Partners of Community Organizations Trust (PACOS), has installed a number of micro hydroelectric powered microgrids in villages located in the Malaysian Borneo rainforest. The most unique aspect of these particular microgrids is the emphasis on community organization and leadership around the microgrid, which in turn allows the community to organize and protect themselves against interests such as the palm oil and logging industries that threaten the village's very existence. In this sense, the microgrid is not an end unto itself, but a means to achieve community empowerment and cohesion.

Tonibung, or Friends of the Village Development, is based in Sabah, Malaysia, and focuses on rural electrification through micro-hydro as well as empowering rural indigenous communities. Green Empowerment, based in Portland, Oregon, partners with local organizations such as Tonibung, to implement renewable energy, water access, environmental protection, and health improvement programs around the world. Partners of Community Organizations (PACOS) Trust strengthens community organizations in indigenous communities in Sabah, Malaysia. Green Empowerment, Tonibung, and PACOS (GE/T/P) work together in Malaysian Borneo on installing, and funding micro-hydro projects to empower indigenous communities.

We visited two villages: Terian and Buayan. Terian's micro hydro facility was installed in 2005 and Buayan's was installed in 2009.

Business Model

Green Empowerment and Tonibung collectively develop and raise capital for microgrid installation and training. The organizations act as conduits for donor funds to the community microgrid, being the entities that apply for funding and execute agreements with donors. PACOS has supported the leadership building and community organization around the microgrid. The community initiates the micro-hydro project installation by contacting any of the organizations to express interest. Usually, the communities find out about the microgrids through word of mouth or interactions with other villages that are already connected to microgrids.

GE/T/P then transfers ownership of the microgrid to the community and expects it to be entirely run by the community soon after the project is completed and fully operational for a year. A self-organized village micro-hydro committee, consisting of a secretary, chairperson, treasurer and between one to seven operators, acts as the institution responsible for management and operations. Each committee develops its own customer contracts and operational rules. Those rules are informed by the feedback of the village and interactions with committees in other villages with existing microgrids.

Table 8: GE/T/P microgrid development

Town	State	Generation Source	Capacity (kW)	Year Installed	Description of Capital Contribuitons
Bario Asal, Arul Layun	Sarawak	Micro-Hydro	45	2009	GEF SGP/Seacology
Babalitan	Sabah	Micro-Hydro	5	2012	Ranhill Powertron
Bantul	Sabah	Micro-Hydro	5	2005	GEF SGP
Buayan	Sabah	Micro-Hydro	14	2009	GEF SGP/DANIDA (Danish International Development Agency)
Inakaak	Sabah	Micro-Hydro	3	2010	GEF SGP
Long Lawen	Sarawak	Micro-Hydro	15	2000	Green Empowerment/ Seacology/Energreen/ Borneo Project
Lumpagas	Sabah	Micro-Hydro	1.5	2009	Digi
Mudung Abun	Sarawak	Micro-Hydro	20	2011	GEF SGP/Finnish Embassy/Seacology
Saliman	Sabah	Micro-Hydro	3	2010	CIMB
Sungai Rellang	Selangor	Hydro/PV Hybrid	1.5	2012	GEF SGP
Terian	Sabah	Micro-Hydro	5	2005	Green Empowerment/ Seacology/Borneo Project
Tanjung Rambai	Selangor	Micro-Hydro	5	2011	GEF SGP/Shell/Selangor Government

Table 9: GE/T/P microgrid customer table

Town	State	Total Customers	Status
Bario Asal, Arul Layun	Sarawak	55	Functional
Babalitan	Sabah	27	Functional
Bantul	Sabah	18	Functional
Buayan	Sabah	22	Functional
Inakaak	Sabah	18	Functional
Long Lawen	Sarawak	40	Functional
Lumpagas	Sabah	15	Functional
Mudung Abun	Sarawak	30	Functional
Saliman	Sabah	18	Functional
Sungai Rellang	Selangor	9	Functional
Terian	Sabah	22	Non-functional (landslide)
Tanjung Rambai	Selangor	21	Functional

It is expected that communities provide in-kind labor, where each family has to contribute in some significant way. The community as a whole usually contributes 10,000 hours to the project and in between 20 – 30% of the total cost of the facility through material, labor, or other in-kind services. The project is not registered with the government in any way because, as claimed by GE/T/P, they would be subject to government regulations and taxes.

Financing

Tonibung has coordinated the development of 15 microgrids since 2000. Green Empowerment has collaborated with Tonibung in applying for financing for three of those 15 microgrids. For the 15 microgrids, the majority of funding (70 – 80%) has come from international donor agencies or NGOs such as UNDP, Global Environment Facility, DANIDA, the Borneo Project, and Seacology. The remaining funding comes from the community itself in the form of in-kind contributions.

Tonibung finds that transaction costs are too high for their small organizations to try to qualify for a Certified Emissions Reduction (CER) credit under the Clean Development Mechanism (CDM). Tonibung is beginning to utilize Corporate Social Responsibility (CSR) funds from companies such as Air Asia, CIMB Bank, Shell, and Digi (a telecom company). GE/T/P will depend on Corporate Social Responsibility (CSR) program grants or revolving funds in the future as international donor agencies reduce their funding to Malaysia over the next few years.

Each community maintains an account for system repairs, funded by customer tariff payments. Except in four cases (three landslides and one controller retrofit), the communities have been able to pay for all repairs.

Microgrid Costs

Capital costs are approximately USD 8,000/kW (including labor, community development activities, and equipment), but the capital equipment alone is USD 2,600/kW. The average cost per project is USD 50,000, and project sizes vary between 1.5 kW and 45 kW, with most projects in the 3 - 5 kW range.

All ongoing operations are done as volunteer work, or for very low compensation by the community. Micro-hydro has no fuel costs associated with the system, only occasional maintenance costs; therefore operational costs are kept to a minimum.

Tariffs and Payment

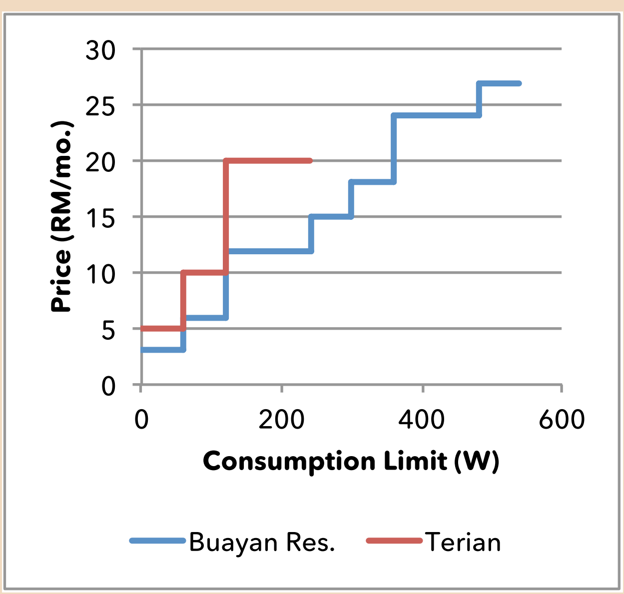
Each community determines its own collection schedule, tariffs, and enforcement regime. **Figure 27** below illustrates the tariff levels for the Terian and Buayan microgrids. At both Terian and Buayan, most members give their monthly contribution to the community fund at the community meeting after church service on Sundays. In Buayan, there is a fairly flexible payment schedule where customers can pay three months at once (post- or pre-pay). Two of the operators are in charge of collecting the payments at the weekly meetings, but due to inconsistent record keeping, it is difficult to determine how successful they are actually collecting payments.

As shown in **Figure 27** and **Figure 28**, village members may choose from many service levels, and also have the option of upgrading or downgrading after over time.

There are no traditional business customers in the villages, but there are larger customers such as community centers, a church hall, kindergartens, and e-centers connected to the microgrid with higher demand levels. Communities also accommodated special events with higher loads such as weddings with amplifiers and additional lighting, with customized temporary connections..

Penalties

Penalties for non-payment and theft are determined by each community, but community leaders report that penalties are difficult to enforce in a tightly knit community. Nevertheless, penalty structures exist in most villages. For example, in Terian, customers are fined for non-payment by an increasing, cumulative amount for each month of non-payment: one Malaysian Ringgit (USD 0.31) for the first month, plus two Ringgit (USD 0.62) for the second month, plus three Ringgit (USD 0.93) for the third month, for a total of six Ringgit (USD 1.84) after three months of non-payment. Terian's policy also dictates that they will physically disconnect a customer after two to three months of non-payment or theft. Despite multiple violations, this has only been enforced one time and occurred in 2011.



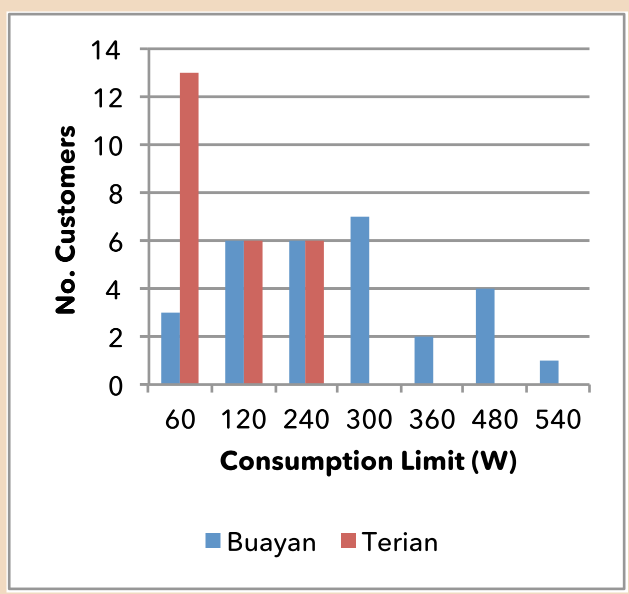


Figure 27: Price structure for GE/T/P tariffs in Malaysian Ringgit (RM) per month (L);
Figure 28: Number of customers at each tariff level (R).

Coverage

Those who want to be connected to the microgrid can contribute through labor rather than upfront fees. In both villages that were visited, only slightly more than half the village was connected (Terian, 26 of 48 households were connected and in Buayan, 22 of 40 households were connected), but those who were not connected were usually too far away or uninterested in the service, for reasons such as already having solar home systems funded by the UNDP and other aid agencies.

Most of the other villages that GE/T/P have worked with in the region have a higher percentage of the village connected to a microgrid because they either live in group longhouses or build their homes closer together. Half of the villages with microgrids reach a 100% coverage rate and most fall above 70% of households connected.

The communities visited seemed to have relatively high standards of living and access to many more electrical appliances than the villages visited in India, indicating a high quality of service and options of service levels - at least during the wet season.

Load Management Schemes

Load management is particularly challenging due to the micro-hydro turbine's seasonal variation in output. At the time of installation, GE/T/P runs educational programs that underscore the communal aspect of the system, and explains the limitations of the system and the load management schemes available. GE/T/P installs miniature circuit breakers (MCBs) in each household as standard procedure to control demand, but these are sometimes seen as a nuisance by villagers and are either removed or bypassed.

During low river flow times, only a portion of the village is electrified in the evening. During our two-day visit to Buayan, we only had electricity for two to three hours. Based on anecdotal input, it did not appear that a higher capacity system meant that a greater number of connected customers would have electricity a higher percentage of time as one might intuit, because customers adapt their usage to the peak capacity on the system.

GE/T/P's experience is that load management is most successfully done in a place that has a strong and respected leader. For example, in the village of Saliman, the village headman was the first to violate the load management system, and bypassed his MCB. This resulted in continued difficulties in getting other community members to only use the service up to their approved levels. On the other hand, in a village called Bantul, the village leader immediately disconnects households that utilize more than their respective service levels. In this way, he has been able to manage the demand and load of the community with even a very small system.

Demand side management appears to be challenging to carry out properly during the low-flow times of year because the village as a whole has acquired devices that use close to the maximum potential of the system during the wet season. In Terian, the agreed upon "procedure" is for all households to only operate lights during the dry season. But as households become accustomed to a variety of electrical devices, it is difficult to minimize usage of non-lighting devices in order for all households to have access to at least lighting during the low-flow times of year.

Buayan has a three-phase system (uncommon for GE/T/P microgrids), meaning there are three microgrid "clusters." During low capacity times, the operator "rotates" service every 36 hours or so and enables one to two "clusters" to have power at a time. Other single-phase grids cannot rotate clusters or disconnect portions of the village and must manage demand more closely to prevent overloading the system.

Performance

Most of the down time has been due to seasonality of water flows and the need for significant repairs, such as those caused by landslides. The micro-hydro system is vulnerable to upstream sedimentation, landslides, foreign objects caught in the turbine, and low river flow. The operational cost recovery requirement is being met, which helps maintain a virtuous cycle of service as maintenance is paid for, leading to further reliability and customer willingness to pay. Overall, the GE/T/P microgrids have proven to be both schedule and energy service reliable, and continue to be functional several years after installation.

Electricité d'Haiti (EDH), Haiti

Description

Similar to many other developing countries prior to power sector reforms, the Haitian power sector is highly centralized, both institutionally and physically. The government-owned utility, Electricité d'Haiti (EDH) owns 72% of generation capacity as well as 100% of transmission and distribution assets, and is the sole entity legally authorized to sell electricity to end-use customers. Indicators of the health of the electricity sector in Haiti are particularly dismal: the current electricity tariff is a staggering 0.35 USD/kWh, the rate of theft is over 30% of all electricity being produced, and technical losses stand at 18% of all electricity produced (Bureau of Mines and Energy et al., 2006). Revenues are estimated to cover only 20% of electricity produced (The Sentinel, 2013), and one of Haiti's Independent Power Producers ceased operations for three months in 2013 due to payments owed from EDH totaling USD 12 million (Haiti Libre, 2013). The theft and loss rates, together with the inefficiency of the government monopoly, make the USD 0.35 price understandable, but do not stop it from blocking economic growth in Haiti.

There are a small number of Independent Power Producers that account for the ownership of 28% of Haiti's 260 MW of total generation assets. Industrial businesses employ self-generation because they cannot depend on the reliability of the EDH system, and, if connected, their electrical load would compromise the already tenuous stability of Haiti's grids.

In addition to owning much of the centralized grid assets and being responsible for operations, EDH is mandated to provide rural communes with access to electricity through microgrid systems. There is a department within EDH devoted to this cause, but no formal program or policy that sets clear responsibilities for this department exists. As of 2013, 35 communes had been electrified by EDH with microgrids since the first ones were built in the mid-1980s. There is an unfortunate dearth of data on these systems. According to EDH, the detailed project documents for these microgrids are stored in an archive that is not publicly accessible. Requests for access to these documents outside of the archive have gone unfulfilled. As such, detailed information about a few projects has been obtained only through site visits.

Table 10: EDH microgrid development

Town	Department	Capacity (kW)
Ennery	Artibonite	100
Gros Morne	Artibonite	250
Marmelade	Artibonite	300
Dondon	Nord	150
Pilate	Nord	100
Plaisance	Nord	60
Capotille	Nord-Est	100
Mont Organisé	Nord-Est	175
Ste Suzanne	Nord-Est	80
Anse à Foleur	Nord- Ouest	150
Bassin Bleu	Nord- Ouest	350
Bombardopolis	Nord- Ouest	200
Chansolme	Nord- Ouest	350
Jean Rabel	Nord- Ouest	500
Mole St Nicolas	Nord- Ouest	N/A
Casale	Centrale-Ouest	175
Pointe à Raquettes	Centrale-Ouest	60
Anse d'Hainault	Grand'Anse	150
Dame Marie	Grand'Anse	225
Marfranc	Grand'Anse	300
Pestel	Grand'Anse	85
Anse à Veau	Nippes	100
Baradères	Nippes	100
Grand Boucan	Nippes	100
L'Asile	Nippes	240
Petit Trou de Nippes	Nippes	150
Pte Rivière de Nippes	Nippes	150
Coteaux	Sud	125
Port à Piment	Sud	200
Roche à Bateau	Sud	100
Tiburon	Sud	150
Anse à Pitre	Sud-Est	150
Arnaud	Sud-Est	150
Belle Anse	Sud-Est	100
Côte de Fer	Sud-Est	200
Thiotte	Sud-Est	132

All of the microgrid systems are powered by diesel generators, and their installed capacity varies from 60 - 500 kW. Nameplate capacity for each system is listed in **Table 10**. The distribution systems are built to relatively high standards, with most using wooden utility poles, heavy gauge conductors, and a medium-voltage primary distribution system coupled with a low-voltage secondary distribution system.

Business Model

Although no written procedure for developing municipal microgrids in Haiti seems to exist, there is a formalized process for project development that has become accepted by EDH over the years. The mayor of the municipality must first write a letter to EDH specifying the community's need for the system. A copy of the letter should also be sent to the Ministry of Public Works and the Ministry of Planning. EDH will respond to the letter by sending a technical team to perform a site assessment and a load survey, compiling these efforts into a report. The report specifies the size of the system, the number of customers and an estimated budget. The report is then sent to the mayor, who, in turn, sends it to the Ministry of Planning along with a request for the ministry to fund the project. The ministry then either sole-sources the procurement and installation work to EDH, or issues a public tender for private contractors to submit bids for the work.

Upon completion of the work, the municipality itself owns the entire microgrid system, including the generator. However, the land upon which the generator house is built must be ordained by the mayor as an area for "public utilities," and is registered as such with the General Tax Directorate (GDI), which is the government entity responsible for lend tenure records. At this point, the mayor must consign the land to EDH. EDH's rationale for owning the land is that it reduces the risk of a mayor selling the land at some point in the future.

The systems are operated by the municipality itself (i.e. the mayor's office), by an independent committee appointed by the mayor, or by an independent, chartered non-profit organization. Regardless of operational responsibility, the microgrid operator typically needs to recover operating costs, as there is no explicit subsidy mechanism for operational expenditures. Operational cost recovery alone is sufficient, as the owner (i.e. the municipality) does not require either capital cost recovery or a return on capital, and neither does EDH.

According to EDH, they are responsible for providing ongoing maintenance – capital replacement, installation, and various repairs – as well as fuel to run the microgrid during major "fêtes" or parties that happen a few times a year.

Financing

According to interviews with mayors and Deputies (members of the lower house of Parliament, the House of Deputies), microgrid systems have been financed by combining the following sources: community fundraising makes nominal contribution; the Deputy or Senator (member of the upper house of Parliament) contributes a portion of his "discretionary funds"; and the Government of Haiti pays for the balance. It is unclear what the proportions are. Interviews with the director of the Bureau des Provinces at EDH contradict these interviews. According to EDH, funds for project development and implementation are provided primarily by the Ministry of Planning, and EDH provides a significant amount of in-kind labor. Due to the inability to obtain the original project records from EDH, it remains unclear as to how the systems were actually financed.

System Costs

There are no available data on capital expenditures, and neither mayors nor Deputies know what the total expenditures were on these systems. EDH was unwilling to share capital expenditure data without referring to the project documents themselves, located in a restricted-access archive.

For the systems that were visited, monthly operating costs range between USD 725 - 1,500. The majority of operating costs are diesel fuel purchases. Some microgrids pay small salaries to management personnel, such as a secretary who collects payments and makes purchases, or operations staff, such as a generator house guardian or janitor. Maintenance expenditures are small, but insufficient, as the generators occasionally fall into disrepair and remain non-functional for weeks or months even as a result of minor maintenance requirements such as replacing generator house fuses or engine oil filters.

Tariffs and Payment

The municipality has full authority to set microgrid tariff levels. The microgrids that were includ-

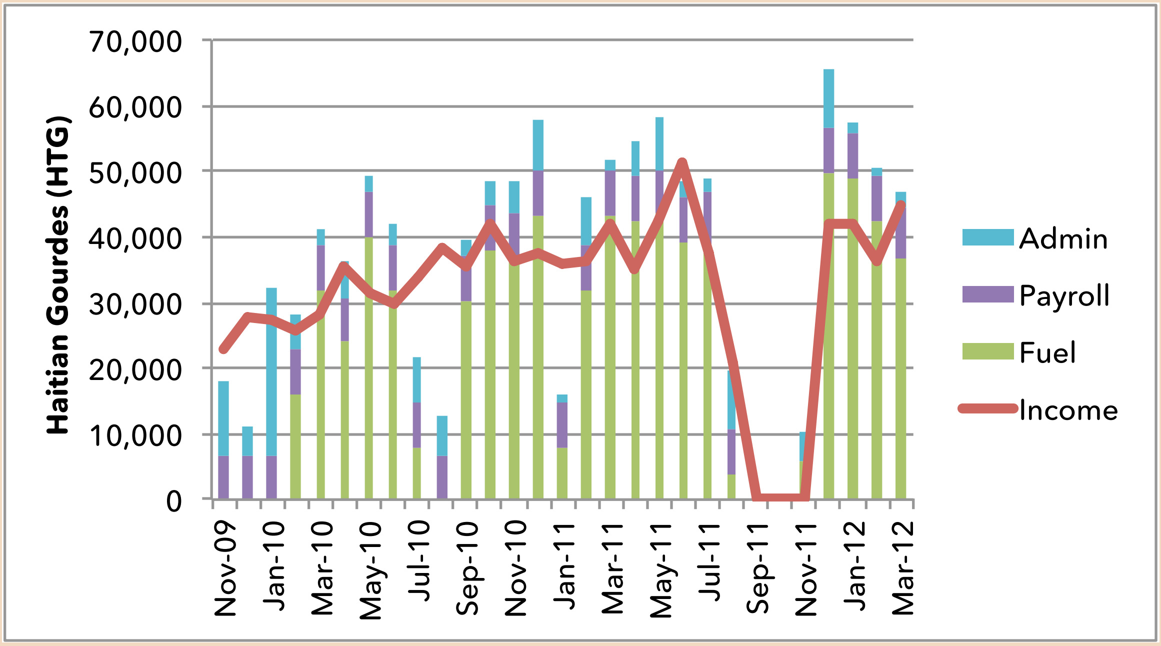


Figure 29: Monthly expenses and accounts receivable in the Port-a-Piment microgrid.

ed in field visits all charge customers based on the number of light bulbs or appliances are in a given home. The per-bulb payments range from 50 - 150 HTG per month (~1.25 - 3.75 USD per month). Customers go to a central office to make their payments once a month.

Monthly revenues from three microgrids that were visited are variable, depending on the quality of the electricity service and the state of accounts receivable. The operators allow customers up to three months to make payment, which results in grid revenues being erratic across months rather than smooth and consistent. When the grid is functioning consistently, operators claim that payment rates are high and are paid within the 3-month window.

Figure 29 shows the monthly expenses and accounts receivable for the Port-a-Piment microgrid from November 2009 to March 2012. As is apparent, accounts receivable sums are typically below expenses, indicating that tariffs are set to levels that are below cost recovery.

Table 11 compares several microgrid characteristics across three of the four microgrids that were included in the site visits.

Penalties

Each of the microgrid operators uses penalties to discourage late payments and theft. Customers are allowed to make payments within three months. If payment has not been made within three months, they are disconnected. Re-connection will be made if the customers pay their outstanding charges and, in some cases, an additional fee. The Port-a-Piment grid operator indicated that disconnection is strongly enforced. The other microgrid operators indicated that they are not as stringent on enforcement as their neighbors in Port-a-Piment.

Coverage

The microgrids target communities confined to the "downtown" area of a particular commune. These areas, referred to as the "centre villes," are much denser than the rural neighborhoods in a commune. The centre villes are also much more accessible by road, and typically have internal paved roads even if there is no paved road connecting one commune to the next. Those living in the centre villes tend to have slightly higher incomes than those in more rural areas.

When power is available, households are limited only by what appliances they can afford with

Table 11: Haiti microgrid comparison

	Coteaux	Port-a-Piment	Roche-a-Bateau
Operating since	1994	2009	2008
No. Customers	250	210	100
Nominal Schedule	7-10pm, Su, M, W, F, Sa	6-10pm Su; 7-10pm Tu, Th, Sa	7-10pm, 5 days/wk
Grid management entity	Volunteers affiliated with Mayor's office and paid EDH technician	Electricitè de Port-a-Piment (EDP)	Paid municipal staff in Mayor's office
Tariff	50 HTG/bulb (USD 1.22)	150 HTG (USD 3.66) plus 50 HTG/bulb (USD 1.22)	150 HTG (USD 3.66) plus 50 HTG/bulb (USD 1.22)
Disconnection penalty rule	3 months missed payments	3 months missed payments	3 months missed payments
Re-connection fee	Arrears	Arrears + 150 HTG (USD 3.66) penalty	Arrears + 250 HTG (USD 6.10) penalty
Typical Monthly Revenue	25,000 HTG (USD 610)	35,381 (USD 861)	24,000 HTG (USD 585)
Typical Monthly Costs	60,000 HTG (USD 1,463)	40,385 (USD 985)	30,750 HTG (USD 750)
Typical Monthly Shortfall	35,000 HTG (USD 853)	5,084 HTG (USD 124)	6,750 HTG (USD 165)
Typical Monthly Shortfall	5,084 HTG (USD 124)	35,000 HTG (USD 853)	6,750 HTG (USD 165)

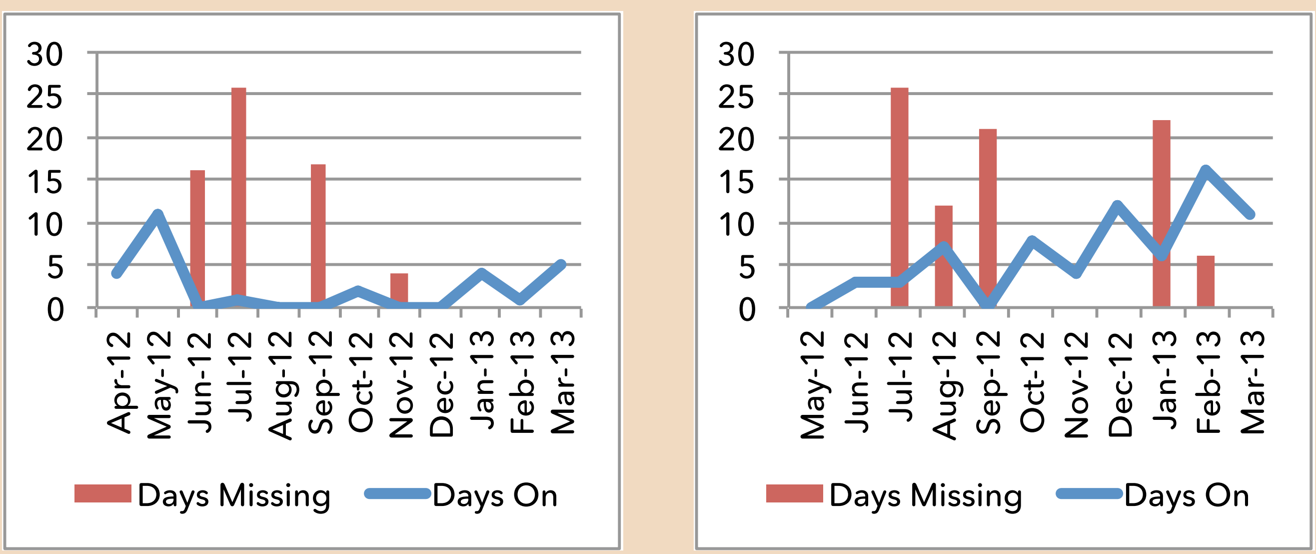


Figure 30: Number of Microgrid Operating Days Per Month in Port-a-Piment (L);
Figure 31: Number of Microgrid Operating Days Per Month in Coteaux (R).

respect to the energy services they have access to. That is, there is no power limit placed on customers.

Load Management Schemes

Based on the microgrids included in the field visit, the microgrid diesel generators are generally oversized relative to their loads. As a result, there is an essentially unlimited amount of power for any particular customer. Line overloading is highly unlikely as the distribution system is designed to meet EDH guidelines on grid-connected distribution systems.

Because of oversizing, there is no load limit, and no mandates on allowable loads.

Performance

The performance of the commune microgrids in Haiti is notoriously poor. Data loggers recording one-minute current data were placed on the Coteaux and Port-a-Piment microgrids in April 2012. **Figure 30** and **Figure 31** show the number of days in each month from April 2012 to April 2013 where the microgrid provided power to each town. Unfortunately, the data loggers sometimes went through extended periods during which their batteries died. Those periods are indicated in the figures by the number of "days missing" in a particular month. Removing periods during which the microgrids were operating for less than 15 minutes, the microgrid in Coteaux was operational for 66 days during the times that the data logger was active, and for only 28 days in Port-a-Piment – or 28% of days and 10% of days, respectively. When the microgrids are operational, they typically operate for fewer hours than what is scheduled. The average duration for microgrid operations is just 119 minutes in Coteaux and 116 minutes in Port-a-Piment. Coteaux microgrid operating duration is less than the mean 43% of the time, while Port-a-Piment's microgrid operates for less than the mean duration 64% of the time. A normalized histogram of microgrid operating duration is provided in **Figure 32**.

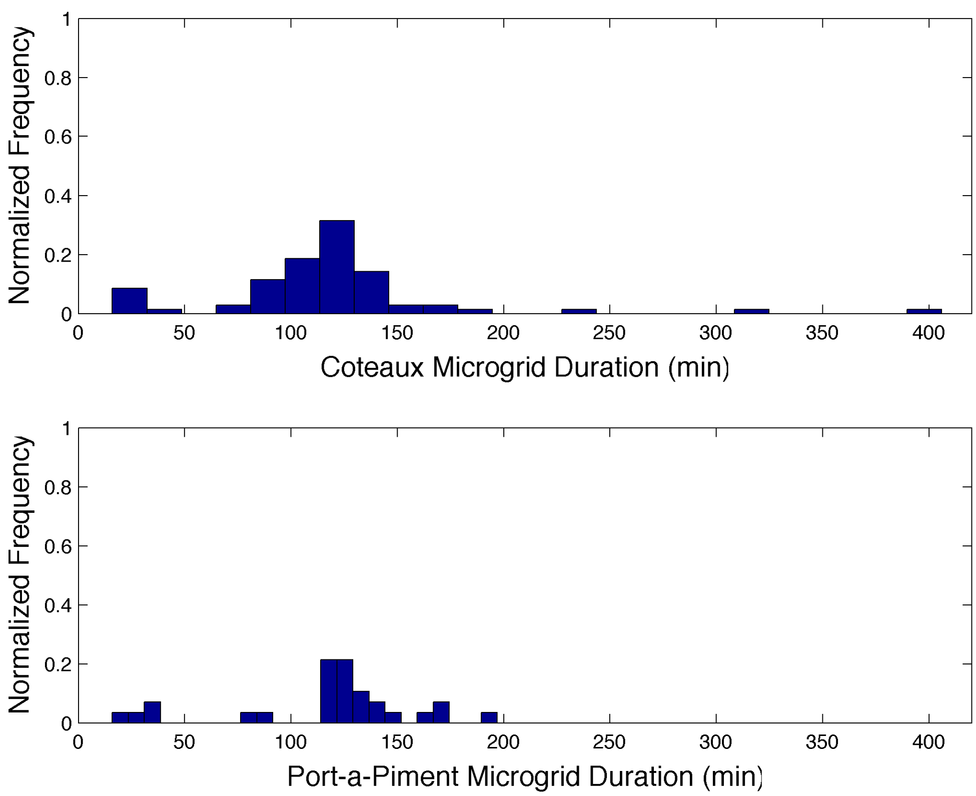


Figure 32: Distribution of Microgrid Operating Duration.

*Table 12: HPS microgrid development**

Town	Date Installed	Capital Cost (Nominal Rs)	Description of Capital Contribuitons	Status
Barwa	10/2010	2,000,000	39% MNRE Subsidy	Functional
Bhatawa	09/2010	1,700,000	28% MNRE Subsidy	Functional
Bajhiya	08/2010	2,000,000	39% MNRE Subsidy	Functional
Bariya Sthan	12/2010	2,000,000	39% MNRE Subsidy	Functional
Belahi Plant	01/2011	2,000,000	39% MNRE Subsidy	Functional
Bhadhi	08/2010	2,000,000	39% MNRE Subsidy	Functional
Bhuidharwa	01/2010	1,700,000	28% MNRE Subsidy	Functional
Chirwihaya	10/2010	2,000,000	39% MNRE Subsidy	Functional
Dahwa Plant	10/2010	2,000,000	39% MNRE Subsidy	Functional
Daunaha	03/2009	1,700,000	28% MNRE Subsidy	Functional
Devipur	04/2010	2,000,000	39% MNRE Subsidy	Functional
Dhoomnagar	09/2010	2,000,000	39% MNRE Subsidy	Functional
Dhuniapatti	06/2010	1,700,000	28% MNRE Subsidy	Functional
Ghorahwa	09/2010	2,000,000	39% MNRE Subsidy	Functional
Inarwa	03/2010	1,700,000	28% MNRE Subsidy	Functional
Jamunapur Pharsahani	12/2010	2,000,000	39% MNRE Subsidy	Functional
Khotwaha	03/2010	1,700,000	28% MNRE Subsidy	Functional
Koirepatti	09/2009	1,700,000	28% MNRE Subsidy	Functional
Laukaha Pakriya	12/2010	2,000,000	39% MNRE Subsidy	Functional
Machargawa	04/2010	2,000,000	39% MNRE Subsidy	Functional
Madhubani	01/2009	1,700,000	28% MNRE Subsidy	Functional
Malahi Bazaar Plant	05/2010	2,000,000	39% MNRE Subsidy	Functional
Malahitola	03/2009	1,700,000	28% MNRE Subsidy	Functional
Mangalpur	10/2009	1,700,000	28% MNRE Subsidy	Functional
Manjharia	03/2010	1,700,000	28% MNRE Subsidy	Functional
Marchahwa	06/2010	2,000,000	100% Husk	Functional
Mathiya Baithaniya	09/2010	2,000,000	39% MNRE Subsidy	Functional
Mujhouliya	05/2009	1,700,000	28% MNRE Subsidy	Functional
Muradih	01/2010	1,700,000	28% MNRE Subsidy	Functional
Murgahwa	09/2010	2,000,000	39% MNRE Subsidy	Functional
Nautan Plant	01/2010	1,700,000	28% MNRE Subsidy	Functional
Panghara Bartara	01/2011	2,000,000	100% Husk	Closed
Piprasi	10/2010	2,000,000	39% MNRE Subsidy	Functional
Pokhariya	07/2010	2,000,000	39% MNRE Subsidy	Functional
Ranglalahi Plant	12/2010	2,000,000	39% MNRE Subsidy	Functional
Runi Saidpur	01/2011	2,000,000	39% MNRE Subsidy	Functional
Ruphi	01/2008	2,000,000	100% Husk	Functional
Samastipur	06/2012	2,000,000	39% MNRE Subsidy; 61% Private Developer	Functional
Sangrampur Plant	08/2010	2,000,000	39% MNRE Subsidy	Functional
Sarisawa	06/2009	1,700,000	28% MNRE Subsidy	Functional
Shivrajpur	04/2010	2,000,000	39% MNRE Subsidy	Functional
Shyampur Baithaniya	08/2010	2,000,000	39% MNRE Subsidy	Functional
Sisma	01/2011	2,000,000	100% Husk	Closed
Surajpur	01/2011	2,000,000	39% MNRE Subsidy	Functional
Thakraha	03/2010	1,700,000	28% MNRE Subsidy	Functional
Thumma	01/2011	2,000,000	39% MNRE Subsidy	Functional
Tunihawa	06/2010	1,700,000	28% MNRE Subsidy	Functional
Turki Minapur	01/2011	2,000,000	39% MNRE Subsidy	Functional

** not an exhaustive list*

Not surprisingly, these microgrids fall into the "vicious cycle" described throughout this report. The cycle manifests itself as follows: the number of days where the generator provides power each month is very low. This is because the microgrid operators cannot purchase fuel because they do not recover costs. Eventually, the grid enters an extended non-operational period, which is due either to inability to purchase fuel or a needed repair. The grid only re-enters a "virtuous cycle" through the use of external support, usually via EDH providing the microgrid with free fuel for several days or a month.

Husk Power Systems, India

Description

Husk Power Systems (HPS) microgrids are powered by biomass gasifiers that use agricultural waste, particularly rice husk, as fuel. HPS has built a somewhat standardized grid design around a 32 kW biomass gasifier unit, which integrates proprietary technological improvements, such as decreasing tar formation.

We visited two different types of plants. The first, located in Bhadhi, is built, owned, operated and maintained by HPS. The second, in Samastipur, was built and is maintained by HPS, but is owned and operated by a village entrepreneur.

Financing

HPS, as an organization and developer, has received many different types of financing, combining grants, loans, and equity investment. They have received funding from over 25 different sources over the past five years. These include a federal government subsidy of 480,000 Rs/plant (USD 7,800) for first 20 plants, and for the following 60 plants, 780,000 Rs/plant (USD 12,700) from the Indian Ministry of New and Renewable Energy (MNRE); a USD 2,000,000 grant from the Shell Foundation; USD 1,000,000 in equity and USD 250,000 in debt from the International Finance Corporation (IFC); and Series A investment from venture philanthropists such as Acumen, Bamboo Finance, LGT Venture Philanthropy, Draper Fisher Jurvetson, and Cisco. HPS has also leveraged the Credit Guarantee Trust for Small and Medium Enterprises (CGTSME), an Indian government program to support HPS entrepreneurs with loans of up to USD 200,000 at 12.25% interest with no collateral required and 80% of defaults covered by a trust.

HPS has built over 50 plants to date, each requiring approximately 2,000,000 Rs (USD 32,500) in capital costs. The franchise model plants (referred to as "Build-Maintain" or "BM" plants) are financed by the entrepreneur, with the assistance of the CGTSME loan program.

Table 13: Average annual operating costs for six Husk Power Systems plants, 2012

Expense Category	Annual Average Expense (Rs)	Annual Average Expense (USD)
Machine Maintenance	100,000	1,800
Wages Cost	200,000	3,600
Fuel cost (rice husk or alternative fuels)	239,000	4,300
Total Expenses	539,000	9,700

Microgrid Costs

The standard HPS 32 kW biomass gasification plant costs 2,000,000 Rs. Plant costs may vary due to a particular location's requirements for civil commissioning and the materials involved.

The major ongoing expenses are maintenance, wages and fuel. The average annual expenses among six (BOOM) plants for these categories are shown in **Table 13** for the year 2012.

It is notable that the expenses, as percent contributions to total expense, tend to be fairly consistent from month to month. **Figure 33** shows the distribution of each expense as a monthly contribution to total cost in each grid across 2012.

Business Model

HPS's 82 operating plants fall under three different structures:

1) BOOM - Build-Own-Operate-Maintain. As the owner-operator, HPS is fully responsible for the maintenance of the system over its lifetime but also earns a return on capital. There are 51 BOOM plants in the HPS portfolio. The BOOM model is the structure un-

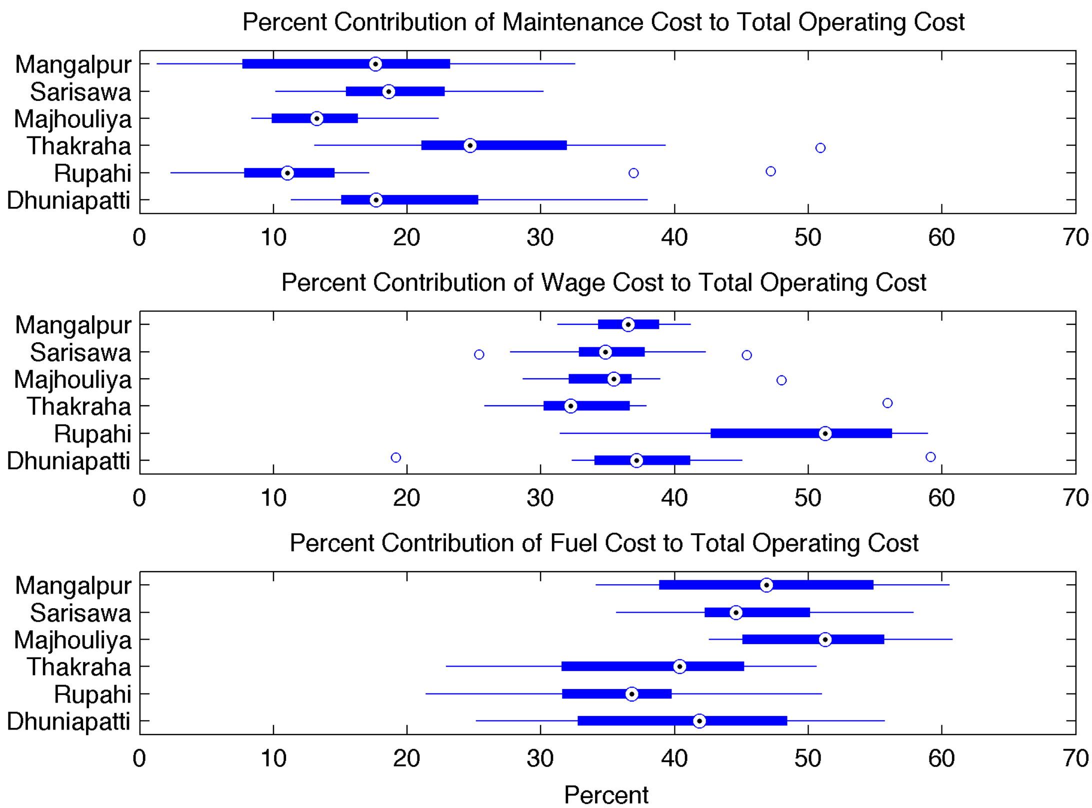


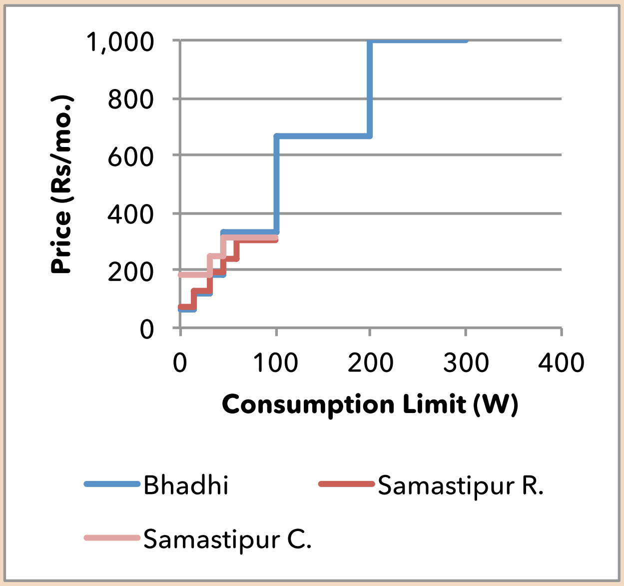
Figure 33: Monthly Percent Contribution of Operating Costs to Total Costs for Six Husk Power System Plants, 2012.

der which HPS first chose to develop micro-grids. However, HPS has recently begun to move away from this model due to overhead costs being high and with difficulties in managing a large number of plants. Because the on-the-ground operators are HPS employees, HPS has found difficulties in providing those local operators with the right incentive to follow rules, collect tariffs consistently and operate the plant reliably.

2) BOM – Build-Own-Maintain. The second model that HPS experimented with is the BOM model, under which it contracts the daily operations to an independent, local entrepreneur. As the owner, HPS still keeps profits and conducts maintenance. The operator has incentive to collect payments, and, because customers are more motivated to pay when the grid is reliable, an incentive to operate according to schedule and to enforce load management rules. There are 21 BOM plants in the HPS portfolio, but HPS is moving away from this model as well.

3) BM – Build-Maintain. The BM model removes HPS from all aspects of ownership and operation except for maintenance. Under this model, a local entrepreneur uses his own investment capital to purchase a plant from HPS. As the owner-operator, the local entrepreneur has a full profit incentive to operate his plant efficiently, collect tariffs, enforce load management rules and operate according to schedule. With the purchase of the plant, HPS builds and maintains the system over its lifetime. Currently ten BM plants are in operation, and HPS intends to massively scale their portfolio under this model.

HPS has found that its demand for customers is easily met. Merely setting up a BOOM plant in one village creates a demand for the same services in the next village. For the BM model, they reach village entrepreneurs by advertising in the local newspaper and can get 300-400 applicants. Before building a BM plant, HPS looks for two criteria:



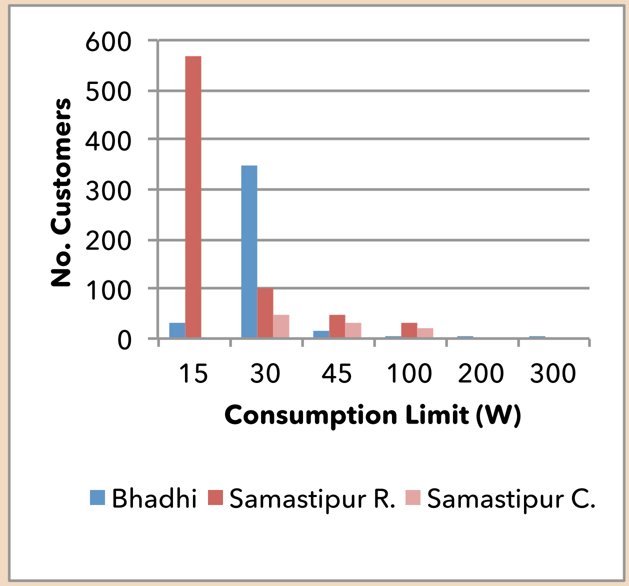


Figure 34: Price structure for HPS tariffs in Rupees (Rs) per month (L);
Figure 35: Number of customers at each tariff level (R). Samastipur charges a different tariff for commercial customers.

1) Serviceable population (based on density of village and how much they spend on kerosene)
2) Availability of rice husk (from a local rice mill, etc.).

HPS verifies the above criteria in addition to ensuring amicable relationships within the village and an ability to manage the system for the life of the system.

In almost all plants, HPS extracts a byproduct of gasification, char, to earn co-product revenue. The char is a key input to incense production.

Tariffs and Payment

Tariffs and collection methods vary with business model type. In most cases, customers are supposed to pay a connection fee of between 100 – 200 Rs (USD 1.63 – 3.26) prior to connection, and to then make monthly pre-payments in cash for electricity service. BOOM plants set their tariffs to minimize the cost to the consumer while still making a profit. Tariffs start at approximately 70 Rs/month (USD 1.14/mo.) for a 15W (one "point") connection. **Figure 34** and **Figure 35** show the tariff structures for the plants included in our field visits and the number of customers at each service level.

In the BOOM plants, payment collectors are incentivized with bonuses correlated to the percentage of expected revenue. BOOM plant payment collectors are supposed to visit each household every one to two days in order to collect payments and verify that the power is on in the households, so that customers would not try to claim a discount due to poor service.

Despite their move away from the BOOM model, HPS' tariff collection process appears to be effective for the BOOM plants. Average income across a selection of six plants is approximately 725,000 Rs (USD 11,800) for 2012. **Figure 36** compares the distribution of monthly expenses for each of the microgrids for which HPS provided data with the average monthly income for each grid. The expenses are shown as boxplots and the incomes are shown as horizontal bars. Note that only one grid frequently falls below cost recovery (Majhouliya), while the remaining grids are almost

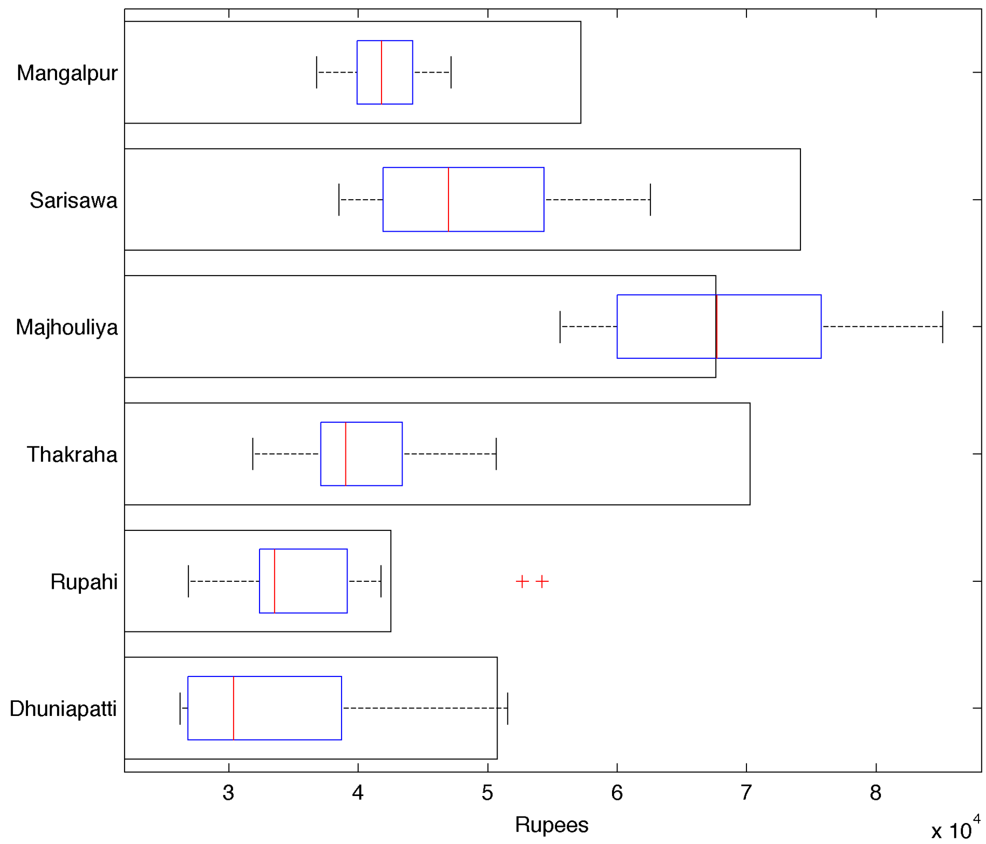


Figure 36: Average monthly income and boxplot of total monthly expenses, 2012.

always less expensive to operate than average income.

Cost recovery percentage for the year 2012 on these grids was typically well above 100%, with average gross margin at 25% for the six sample BOOM plants. **Figure 37** shows the cost recovery ratio for each of the six grids for the year 2012.

BM plant entrepreneurs set their own prices and usually try to maximize their profits by using the price of kerosene as a benchmark, and discounting by the amount they think is appropriate (anecdotally, by 25%). BM plant tariffs are typically higher than BOOM sites visited, but still less expensive than the fossil fuel alternative in the area. BM plant operators decide on their collection methods. Some collect the tariffs themselves and others hire collectors.

HPS is currently working on a third generation pre-paid meter that could be charged remotely. It is expected that tariffs will still be based on the number of Watts (to control the maximum wattage) and the duration of usage. As the new meters will offer a finer level of control, tariffs will likely be charged on an hourly rather than monthly basis.

Penalties

BM plant operators in general enforced much harsher penalties than BOOM or BOM plant operators. At the BOOM plant visited in Bhadhi, there were no fines actually enforced for late payments even though the written policy states that there is a fine of Rs 100 (USD 1.63) for late payments. The payment collectors rarely disconnect customers for non-payment. The payment collectors and plant operator confiscate incandescent bulbs when they see them. In Bhadhi, the payment collector reported confiscating incandescent light bulbs every two to three days. When asked when the last incidence of theft or over-usage occurred, a payment collector said that just the day before, one customer was caught using a 230W light bulb even though he was assigned to the 30W level. Theft is a significant problem throughout BOOM plants; as the CEO of HPS states: "we are currently working on five to six products attempting to curb theft in our BOOM plants." HPS is also trying to step up service drop voltage to 440V and then using a transformer in their meter to step it down to 220V at the household threshold in order to prevent customers from bypassing the meters.

HPS has, on occasion, turned the entire system off for days when non-payment or theft in a village became a significant problem. Withholding electricity from the entire village demonstrates that the microgrid is a collective resource that can only operate if everyone cooperates. This leads to community pressure for the non-payers or electricity thieves to change their behavior on behalf of the community.

At the BM plant in Samastipur, the plant owner disconnects customers after two months of non-payment. In cases of theft, the fine is 20-30 Rs (USD 0.33 – 0.49) for each case of theft and after two or three infractions he disconnects the electricity entirely. BM plants have had greater success in managing non-payment and theft because the entrepreneur lives in the village, has authoritative standing there, and is strongly motivated to recover his investment.

Coverage

HPS and its BM plant entrepreneurs are careful to select customers that are actually capable of making payments. In the BM plant we visited in Samastipur, only 25% of the community was connected to the microgrid. The entrepreneur plans to build a second plant to serve more of the community, but even if 50% of the village is served, it would still be a lower percentage than most of the other government funded or NGO developer microgrids visited. At the BM plant site, typical customer income is 4,000 Rs per month (USD 65), significantly more than customers on the other microgrid sites in India.

The Bhadhi BOOM plant serves 50% of the village, and the remaining households use kerosene lamps. The average customer income level was

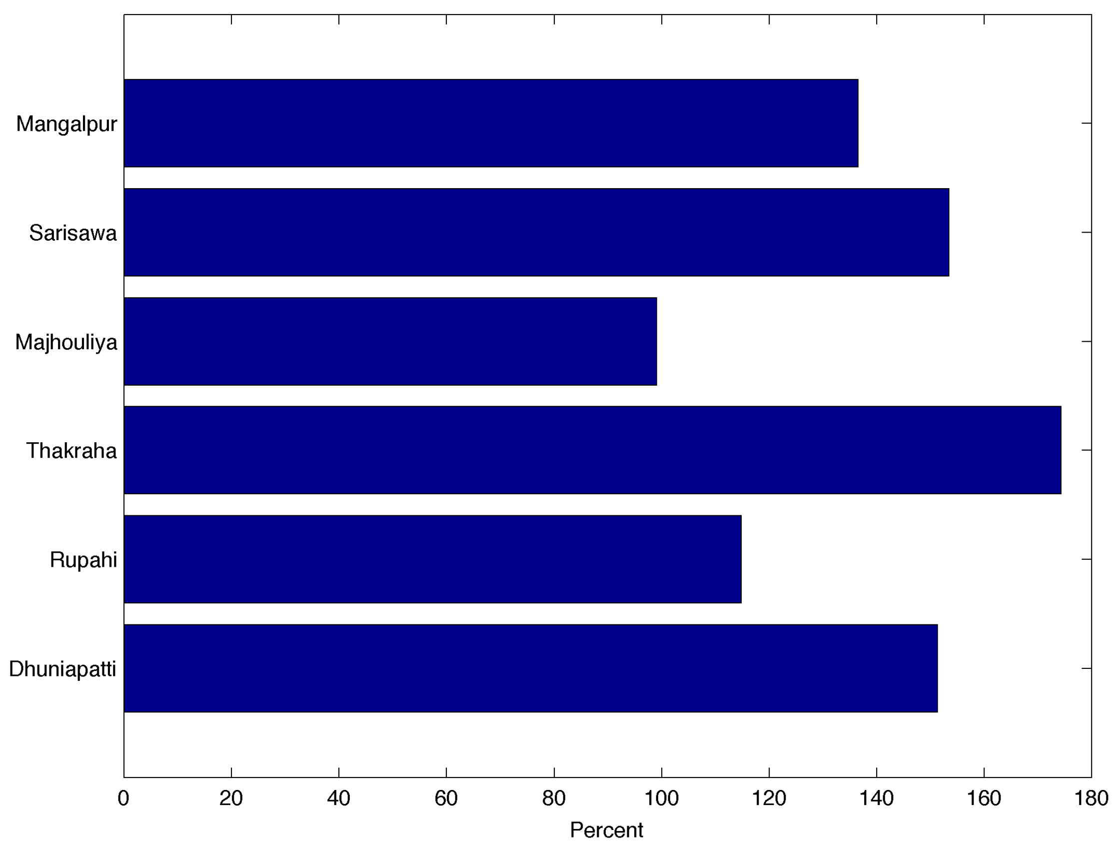


Figure 37: Operational cost recovery percent for HPS microgrids, 2012.

also 3,000 – 4,000 Rupees/month (USD 49 – 65/month). The operator reports that those not connected were either too far away or too poor to afford the service. HPS systems may not be able to serve the poorest in the village, but those that they do serve usually get a high quality of service.

Load Management Schemes

HPS struggles with load management, and has been experimenting with different social and technical strategies since its inception. Over-usage or illegal usage is a bigger problem at BOOM and BOM plants than BM plants, because BM owners are usually strict and on-site at most times.

HPS has tried various load management schemes to date, including:

1) A basic fuse installed on customer connections that interrupts the circuit if customers exceed the allowed load. This strategy is difficult to maintain because blown fuses require replacement after every event. Electricians who are sent to make the replacement are often met with resistance from customers.
2) Miniature circuit breakers (MCBs) that "pop" when customers draw more power than allowed. HPS has not found MCBs that work well at low loads. While they do not need to be replaced after every infraction, they do need to be reset manually.
3) Custom pre-paid "smart" meters that are programmed to restrict loads to less than 30W. Service cuts out after the customer has used electricity for the number of hours they have paid for. The development of these meters was a costly process, and the results of implementation have been mixed.
4) 100W incandescent bulbs are prohibited. They are supposed to be confiscated when found and sometimes customers are fined. We saw a pile of confiscated incandescent light bulbs at the Bahdhi plant during our visit.
5) Another solution HPS is experimenting with is to step up the distribution voltage from 220V to 440V and then step it down to 220V in the customers' meter.

None of the efforts have been foolproof so far, and HPS has spent considerable time and funds trying to invent solutions to manage demand. HPS's CEO conjectures that while technological solutions may help to control demand-side management, only manual checking can ensure customers abide by rules.

Performance

HPS plants usually operate according to schedule, for five or six hours per evening, reliably. In both Bhadhi (BOOM) and Samastipur (BM), both operate between 5 - 6pm to midnight daily. Each had only one day of down time in the month prior to our field visits, which were both due to routine maintenance. Plant operators reported multi-day service outages as being very rare. In most villages, HPS has provided reliable service - much better than the extremely unreliable central grid in Bihar - at a cheaper price than diesel generators or kerosene lamps.

Rice husk as a feedstock is generally cheap, easily accessible, and plentiful year round; therefore the plants were not subject to as much seasonal variability as PV or micro-hydro systems often are. Down time is most often caused by wet husk or tar build-up in the gasifiers. Other technical problems include issues with spark plugs, battery discharge, bottle coil (transmission of current to spark plugs), and faults in the distribution network, which tend to be due to theft or wear and tear.

Management issues generally have not led to down time, except when the community starts to default on payments regularly and the operators turn off the entire system for a couple of days intentionally.

Orissa Renewable Energy Development Agency (OREDA), India

Description

Established in 1984 to develop renewable energy projects in the state of Orissa, OREDA has two goals: 1) to electrify communities that currently do not have electricity, and 2) to expand the use of renewables in the state. OREDA closely coordinates its initiatives with the Orissa's state branch of the Ministry of Power and has been tasked with electrifying the 1,700 – 2,000 villages in the state to which it is too geographically difficult to extend

Table 14: OREDA microgrid development in Nuapada District - all are 2 kW PV systems.

Town
Anupgarh
Barkot
Bhojpurighati
Deosil
Ganiapada
Gatibeda
Haluapali
Jamgaon
Junapani
Kotrabeda
Kukurimundi
Majhagaon
Makhapathar
Matiapathar
Palasipani
Salepada
Soseng

the main grid. Thus far, OREDA has electrified 1,100 villages. 63 villages have been electrified with microgrids and the remaining villages with individual solar home systems. Some of the microgrids are over a decade old, and many lessons have been learned by this pioneering agency over that time.

OREDA's first microgrids were all built in Nuapada District and funded by the United Nations Development Programme (UNDP). The remaining microgrids were developed with MNRE funds in other parts of the state and tend to be larger, though not necessarily with more customers.

The OREDA microgrids usually consist of small photovoltaic systems with a battery bank sized to provide two lights and phone charging for each household for three to four hours per day, and street lighting all night in the village. The first three villages visited, Matiapathar, Palsipani, and Anupgarh, are located in the Nuapada District. The last one, Tuluka, is located in the Angul District in the middle of the Satkosia Tiger Reserve. The three microgrids in the Nuapada District were built in 2002, and Tuluka's microgrid was built in 2010.

Business Model

Several stakeholders are involved in the development and operation of OREDA microgrids. OREDA itself designs and builds the microgrids. During development, OREDA staff assists the village in creating a Village Energy Committee (VEC) that will be responsible for management, operations and simple maintenance. A third party service provider is contracted by OREDA to perform more involved maintenance and replace parts as needed. Contracts are awarded through a competitive public tendering process. The contracts have typically been awarded to Tata BP Solar, Central Electronics Ltd., and Bharat Electronics.

The microgrids developed with UNDP funds are co-owned by OREDA, UNDP and MNRE for the first ten years, and then ownership is transferred to the village. At that time, it is expected that the VEC will manage, operate and maintain the microgrid independently. We did not witness any systems where ownership had been transferred to the community yet (despite having visited microgrid sites with 10-11 years of operation) and the VECs expressed uncertainties about operations after the transfer to the community.

OREDA did not schedule a transfer of ownership for the later MNRE-funded grids.

Financing

Capital costs are wholly paid for with MNRE, State of Orissa or UNDP funds. A significant portion of maintenance is also funded from these channels. A fund for maintenance costs called a "corpus fund" was established with the UNDP microgrids. While such a fund was not initially established for the later MNRE microgrids, one is being proposed in OREDA's current budget proposal to the MNRE.

OREDA does not collect an initial connection fee or require in-kind contributions from the community. In all installations, the VEC is expected to collect monthly payments to support maintenance. In the UNDP-funded microgrids, the VEC is tasked with depositing the collections over the first ten years so that they would be able to pay for maintenance activities out of their own accumulated funds after ten years of regular deposits. In the initial UNDP microgrids, collection rates were very

Table 15: OREDA microgrid financing

	UNDP	11th Plan Period; Under MNRE	12th Plan Period Village Lighting Program Under MNRE
Number of Villages with Microgrids Funded through Program	18 out of 18	45 out of 600	TBD out of ~400
Size	2 kW	2 – 4.5 kW	2 – 4.5 kW
Year Started	2002	2007 – 2008	2013
PV Capital (Million Rs)	0.5	0.5 – 1.0	0.5
Balance of System (Million Rs)	1.0	0.5 – 1.0	0.5 – 1.0
Full System (Million Rs)	1.5	1.0 – 1.5	1.0 – 1.5
Years of Maintenance	10 years	5 years	N/A
Maintenance Contract Value (per grid)	500,000	50,000 – 100,000	N/A
Maintenance Contract Value, per annum (per grid)	50,000	10,000 – 20,000	N/A
Existing Maintenance Contract Fund Source	Corpus fund of 500,000 Rs (USD 8,100) from UNDP put in 10 year bank deposit at 10% APR, yielding the 50,000 Rs per year.	Paid out of OREDA general budget.	N/A
Destination of Corpus Fund Principal	Will be used to double the size of the existing installations from 2 kW to 4 kW	There is no corpus fund, so these will stay the same size after the end of the maintenance contract.	N/A
Contractor	Tata BP Solar (dealt through Kalinga affiliate)	Central and Bharat	N/A
Performance	90-day visits; performed well for 5 years; after, Maoists prevented activities for 1-2 years; since then, have restarted visits; using interest on corpus fund to pay the contracts	90-day visits to top up batteries and make necessary repairs; Includes replacements and spares – contractors usually avoid making replacements; Maintenance contracts working well; Tampering and overloading is the biggest issue; It is an issue because the people are closer to the central grid and know about irons, TVs, etc.	NA
New Maintenance Contract Start Date	2013	2013	2013
New Years of Maintenance	5	5	10
New Maintenance Contract Value (Rs)	TBD	TBD	500,000
New Maintenance Contract Value, per annum	TBD	TBD	50,000
New Maintenance Contract Fund Source	Corpus fund of 500,000 Rs from MNRE put in a five-year bank deposit at 10% APR, yielding the 50,000 Rs per year.	Corpus fund from MNRE.	Corpus fund of 500,000 Rs from MNRE put in a ten-year bank deposit at 10% APR, yielding the 50,000 Rs per year.

low and the communities were not prepared to pay for maintenance after ten years.

For the microgrids that are outside of Nuapada district, the MNRE, through the Remote Village Electrification Program (RVEP), provided 90% of the capital costs and the Orissa state government provided the remaining 10%.

The MNRE-OREDA grids were built under India's 11th plan period. OREDA has proposed that in India's 12th Plan Period, the MNRE's "Village Lighting Program" provide support to establish corpus funds for the existing MNRE microgrids. OREDA has also requested funds for completely new project capital and for corpus funds associated with those projects. Currently, there are 18 microgrids funded by UNDP, and 45 grids funded within India's 11th Plan Period by MNRE. In the latter part of 2013, MNRE allocated funds to build microgrids in some portion of 400 villages under the 12th Plan Period.

Details regarding the three distinct funding mechanisms are presented in **Table 15**.

Each village has its own individual VEC-managed bank account for village tariff collections. The OREDA district office does track those accounts, but doesn't have rights to withdraw those funds. The UNDP/MNRE's corpus fund is kept in an account that is jointly held by the local village government and OREDA.

Microgrid Costs

The three 2 kW photovoltaic systems visited each cost approximately 1,500,000 Rs in 2002, which was more than USD 30,000 at the time. This included the materials, the PV installations, transmission and distribution, and household connections for between 30 - 40 households. According to OREDA, future microgrids are expected to cost approximately 1,000,000 Rs (USD 16,300) for 2 kW systems and 1,500,000 Rs (USD 24,400) for 4 kW systems.

Tariffs and Payment

OREDA set tariffs to very low levels to ensure that every household in the village could afford electricity service. At between 10 - 30 Rs per month (USD 0.18 - 0.55 in 2013) and without a connection fee for a standard service level of 2 CFLs and one cell phone charging outlet, OREDA's tariffs

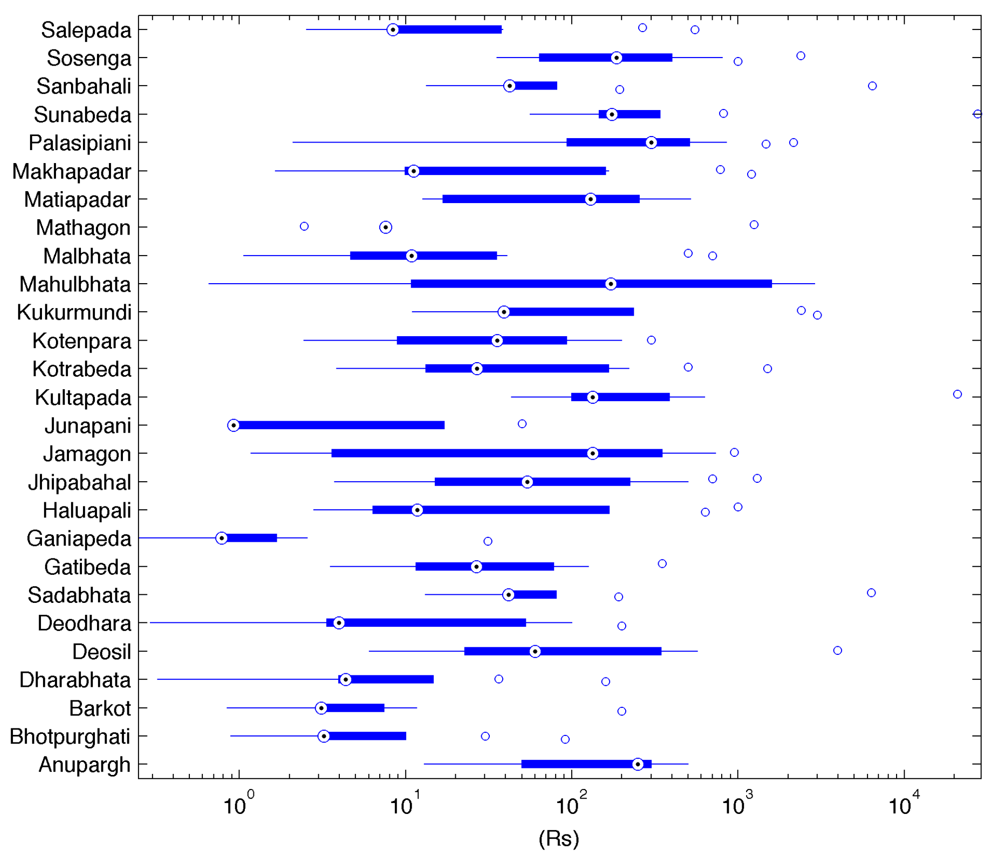


Figure 38: Distributions of VEC account average monthly deposits, 2001-2007.

are amongst the lowest of all microgrids in this report. Each VEC can determine its payment collection schedule. Many VECs collect tariffs monthly, but sometimes VECs allow customers to pay only around harvest time, every three to six months.

Data provided by OREDA show that average monthly collections from each VEC are highly variable, and tend to be low. **Figure 38** shows the distribution of average monthly collections on a log scale for each of the UNDP-funded microgrids. The figure shows that from one month to another, the collections range from less than 10 Rs (USD 0.16) for an entire microgrid to 1,000 Rs (USD 16) - on a rare month where tariffs were paid more completely.

The secretary of the VEC collects payments at a monthly village meeting and is tasked with depositing the collections. He does not get compensated for being the payment collector, as all VEC roles are voluntary. Even though the monthly fees were minimal, it has proven difficult to collect even these low tariffs in recent years. For example, for the three villages electrified in 2002, Matiapadhar had not collected any payments since 2005, Palsipani last collected a 15 Rs (USD 0.24) per customer monthly tariff in 2011, and Anupgarh had experimented with reducing the monthly payment from 30 Rs (USD 0.49), down to 20 Rs/month (USD 0.33/month), and again to 10 Rs/month (USD 0.16/month) before finally giving up on collecting payments altogether in 2004. Even in Tuluka, which was electrified in 2010, the VEC was already suffering from lack of payments, having collected approximately 20% of what they should have collected in the first two years of operation.

The Deputy Director of OREDA, Mr. Ashok Chaudhury, surmised that with such a low service level, OREDA needed to persuade the villagers to accept the electricity service at the time of installation. He observed that without the option to use electricity for income generating activities or entertainment, villagers saw little value in electrification and were less willing to pay. He believed collection rates could improve if OREDA had the option of providing greater capacity and enabling microenterprises so that customers would value their services and increase their average incomes.

The tariff payments are meant only to cover basic operating costs. Any funds remaining after operational expenses would be directed to a corpus fund for maintenance after the UNDP or MNRE maintenance contracts expire. However, the balances in the accounts at the time of the field visits were between just 300 and 65,000 Rs (USD 5 to USD 1,060).

Penalties

While the VEC is authorized to disconnect customers after a nonpayment period of 6-12 months or for theft, they rarely exercise this authority. Each VEC can decide on appropriate penalties. In all four villages, no fines were ever levied and only a handful of disconnections due to non-payment or "mischievous acts" were made despite many more violations.

Coverage

OREDA has managed to electrify 63 of the 1,700 un-electrified villages in the state with microgrids, and over 1,000 with solar home systems. Within many villages, there is an almost 100% electrification rate, sometimes requiring a combination of a microgrid and solar home systems to connect everyone in the village in the most cost-effective way. Three of the four villages visited had above 90% electrification rates in the village.

However, the depth of service level in each house is shallow. Each household is provided with two CFLs and an outlet for charging cell phones. Sometimes, the systems include capacity for street lighting and one shared village television or refrigerator. Beyond that, with only 2 – 4.5 kW systems for each village visited, OREDA cannot provide the option to increase service levels to certain households, even if that household is willing to pay more. In addition, the limited capacity of the system will not allow for adding business customers, power tools for village improvement, or electrical appliances for income generating activities.

Load Management Schemes

There are no effective load management schemes in place, other than providing customers with CFLs at the time of installation, and a community television as an alternative to each household getting a television of their own. Theft or misuse of the system is common amongst all the microgrids. In Matiapadhar, the system has been performing sub-optimally for over two years, and the remaining capacity was illegally connected to the village head's house, causing village disputes. Mr. Ashok Chaudhury estimated that at least 20 - 30% of microgrid systems are regularly overloaded or tampered with. He also noted that tribal communities with a strong village leader who actively manages the community's demand function much better than non-cohesive communities.

Performance

Compared with their peers, the OREDA microgrids operate less reliably. The field visits and interviews suggest that the poor performance of the microgrids is due to both poor planning at the state level and poor operations at the local level.

A key driver in system performance is the performance of the maintenance contractors. According to their contracts, maintenance contractors were expected to visit all sites every 90 days and respond to customer service requests promptly. In reality, maintenance contractors were found to have not serviced systems regularly, and when they did, they did so improperly. For example, in Matiapadhar, the PV system had been working at a very low capacity for the last three years. Even though the Village Energy Committee secretary wrote to OREDA two years ago, the system was still not fixed. This could be due to a lack of efficient communication between the village and OREDA or due to apathetic contractors. The contractor changed only two of the 24 batteries in Matiapadhar two years ago, and replaced another two batteries just two days before our visit – even though batteries are ideally changed all at once. In Tuluka, the village had significant logistical difficulties and expenses acquiring and transporting distilled water to fill the batteries in the middle of a national park, because the maintenance contractors did not fulfill their obligations to provide this service.

Poor performance is not only the fault of the maintenance contractors. Village disputes and a lack of confidence or incentive to maintain the systems on the villagers' part can also result in poor system performance. For example, even with a four-day training provided to two people in each village, the trained villagers felt uncomfortable fixing even minor problems with their system. In Tuluka, no one had cut the vegetation around the system or cleaned the panels for months, and in fact thought it was dangerous to touch the panels to clean them. In other villages, illegal connections and other problems easily solved by routine maintenance, such as removing vines from distribution lines, which can cause ground faults, went unaddressed.

West Bengal Renewable Energy Development Agency (WBREDA), India

Description

The West Bengal Renewable Energy Development Agency (WBREDA) is a state agency tasked with implementing renewable energy in West Bengal. Since its formation in 1993, WBREDA has installed renewable energy generation facilities to electrify isolated communities, including villages in the Sundarbans - a mangrove-filled delta in the Bay of Bengal and a Bengal Tiger reserve. Thus far, they have installed over 20 microgrids, including 18 photovoltaic, three biomass; one biomass-photovoltaic hybrid, and one wind-diesel hybrid microgrid. The microgrids together serve over 2,000 customers in West Bengal.

We conducted a site visit to a photovoltaic microgrid called Koyalapara on Ganga Sagar Island in the Sundarbans.

Business Model

Solar microgrid development in the Sundarbans can be traced back to a small, 2 kW installation developed in 1993 to provide power to the District Administration Office on Sagar Island. That same year, the West Bengal Renewable Energy Development Agency (WBREDA) came into existence, and enabled the development of more sophisticated microgrid systems.

In the early years, the WBREDA microgrid business model was to create a partnership with a local cooperative. All microgrid customers were members of the cooperative. The cooperative elected volunteer officials and a single paid employee responsible for tariff collection. The cooperatives were also responsible for selecting consumers, choosing routes for the distribution lines, setting tariffs in consultation with WBREDA, and resolving customer non-payment. Microgrid ownership was diverse in the beginning: WBREDA owned some of the microgrids while panchayat (municipal government) or other government organizations such as the Science & Technology

Department owned other microgrids. WBREDA facilitated the development of the cooperative institution, provided administrative and financial advice, and offered technical assistance via a junior staff engineer.

The original rationale for the partnership between WBREDA and the local cooperative was that, with only a few staff, WBREDA lacked the capacity to operate and maintain many remote systems. WBREDA also recognized that it lacked the local

Table 16: WBREDA microgrid development

Town	Island	Generation Source	Capacity (kW)	Year Installed	Total Residential Customers	Status
Kamalpur	Sagar	PV	25	1996	NA	Non-functional
Mritunjaynagear	Sagar	PV	25	1998	125	Functional
Khashmahal	Sagar	PV	25	1999	133	Functional
Mahendraganj	Sagar	PV	25	1999	140	Functional
Uttar Haradhanpur	Sagar	PV	25	2000	161	Functional
Mandirtala	Sagar	PV	25	2000	119	Functional
Natendrapur	Sagar	PV	25	2000	122	Functional
Gayenbazar	Sagar	PV	25	1999	124	Functional
Koyalapara	Sagar	PV	120	2005	232	Functional
Ramnganga	Sagar	PV	110	2004	NA	Functional
Indrapur	Pathar Pratima	PV	110	2004	NA	Functional
Rakhalpur	Sagar	PV	110	2005	NA	Functional
Daudpur	Sagar	PV	55	2006	NA	Functional
Tushkahali	Sagar	PV	55	2006	NA	Functional
Pathankhali	Sagar	PV	55	2006	NA	Functional
Bondadna	Sagar	PV	55	2003	NA	Functional
Baliara	Sagar	PV	110	2003	NA	Functional
Gangasagar	Sagar	Wind-Diesel Hybrid	200kW Wind; 360kW Diesel	NA	740	Non-functional; only one wind turbine working and diesel operations working
Gosaba	Gosaba	Biomass-Diesel Hybrid	500	1996	NA	Non-functional due to grid extension.
Chhoto Mollakhali	Chhoto Mollakhali	Biomass	500	NA	NA	Functional
Hiarmba Gopalpur	Gopalpur	Biomass	400	NA	NA	Functional
Mosouni	Mosouni	Biomass	NA	2000	NA	Functional

insight and trust from the community to be an effective institution for setting rules, monitoring, and enforcing. It acknowledged that a local institution would be more successful in implementing behavioral change in the community, and to induce customers to abide by rules and better preserve the system.

While the role of the cooperatives declined in later years due to conflicts or a lack of motivation, so-called "beneficiary committees", with a much smaller set of responsibilities than the original cooperatives, have taken their place in each village. The local beneficiary committees are volunteer-based, and consist of a small number of customers. They are responsible for monitoring usage and enforcing penalties, while in the case of the 15 functioning PV systems on Sagar Island, the responsibility of tariff collection has shifted to two full-time WBREDA employees.

Financing

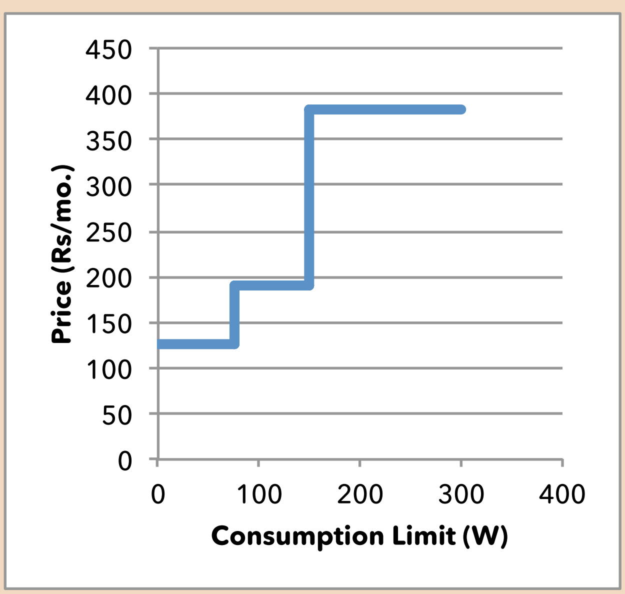
Capital costs are 100% government subsidized. WBREDA funds half of the capital costs and the MNRE funds the other half. Community tariffs are designed to cover all operational expenses, including maintenance.

Microgrid Costs

WBREDA microgrid capital costs have decreased significantly with the global price of photovoltaics declining over the past two decades. Current costs of a PV plant are currently half that of the Koyalapara plant installed in 2005. Snapshots of prices for a PV microgrid are as follows:

In 1992, a 25 kW PV microgrid cost 8,500,000 Rs, or nearly USD 300,000 based on 1992 exchange rates. Unit costs are thus approximately USD 12,000/kW installed. From 1999 to 2001, a 25 kW PV microgrid cost 10,000,000 Rs, or USD 220,000 based on 2000 exchange rates. Unit costs are thus approximately USD 9,000/kW installed. In 2005, a 150 kW PV microgrid, such as the one in Koyalapara cost 30,000,000 Rs, or USD 680,0000 based on 2005 exchange rates. Unit costs are thus approximately USD 4,500/kW installed. In 2013, WBREDA estimates that a 150 kW PV system could be built for 15,000,000 Rs (excluding distribution lines), or USD 270,000 based on 2013 exchange rates. Unit costs are thus approximately USD 1,800/kW installed.

Operational costs are entirely covered by local tariff collection. This includes the salaries of the maintenance contractor, linemen, the tariff collector, as well as the cost of spare parts. The present



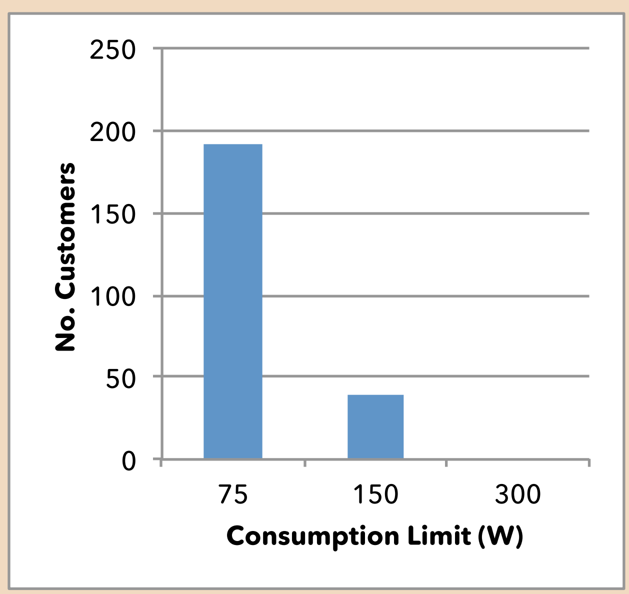


Figure 39: Price Structure for WBREDA Koyalapara Tariff in Rupees (Rs) per Month (L);
Figure 40: Number of Customers at Each Tariff Level (R).

contractor is an enterprise called AGNI, and is paid about 15,000 Rs (USD 244) per month per microgrid – just about equal to the average microgrid revenue. Maintenance contractors compete in a field of several service providers for a contract from WBREDA every year. The local staff members are each paid about 4,000 Rs/month (USD 65/month).

Tariffs and Payment

Tariffs were specifically calculated to cover known operational expenses plus an additional 20% for either unforeseen costs or for WBREDA's shared expenses. WBREDA collects an average of 22,000 Rs (USD 358) from a base of 230 customers each month at Koyalapara. They report an average of 10 – 15% default rates on tariff collections.

Because the WBREDA microgrid tariff is a monthly fee for a fixed supply of power, the effective per-kWh cost of electricity varies depending on how many hours and at what level customers are consuming electricity. As such, the effective per-kWh price ranges from 6 Rs/kWh (0.10 USD/kWh) for a high user to over 30 Rs/kWh (0.49 USD/kWh) for a moderate user. The one industrial customer served on the Gangasagar microgrid – the Kolkata Port Trust – was charged on a 7 Rs/kWh (0.11 USD/kWh) energy tariff for a 100 kW connection. Each household pays individual connection fees to pay for wiring and home connections.

The tariffs originally started out as a single tier, but have since has evolved to multiple service tiers. Customers can also switch tiers depending on capacity available in the system. **Figure 39** and **Figure 40** show service level options, corresponding monthly tariff prices and the number of customers on each service level in Koyalapara.

Penalties

Penalties exist in theory, but may not be enforced frequently. According to a site visit, customers are disconnected from the microgrid if they are behind by more than three months' worth of payments. The service drop is physically removed, and the customer must pay 100 Rs (USD 1.63) to be reconnected after he has settled his account.

Users can also be penalized for using more power than they are allotted according to their service tier. The beneficiary committee will manually withhold service to the offending customer for a few days. This is discussed in greater detail in the "Load Management Schemes" section.

Coverage

The Sundarbans microgrid systems were originally conceived to primarily serve household lighting loads to entire villages. Most of the microgrids in the WBREDA portfolio serve over 100 households. While data on total coverage is not available for the entire portfolio, the Koyalapara microgrid that was visited serves approximately 75% of the village households.

Exemplifying ESMAP's best practice recommendation for flexibility, some of WBREDA's microgrids have added generating capacity over time, allowing use of appliances with a higher electricity demand to power fans, DVD players, and TVs, in addition to lighting. Common-use refrigeration is also found on some microgrids. However, many communities still over-consume by using energy-intensive appliances.

According to surveys conducted during our site visit, customers would like to have 24-hour service. While many customers are satisfied with the level of service they receive, some higher-income households have tried to connect refrigerators. All customers would prefer being connected to the central grid, primarily because it is perceived to provide 24-hour service. According to the microgrid operators in Koyalapara, customers are comfortable with the price of electricity on the microgrid until the central grid arrives and offers electricity at a lower price.

Load Management Schemes

Village councils served as the basis for the cooperatives that started out as the operator of each microgrid developed by WBREDA. Amongst its other functions, the cooperative institution was designed as a mechanism to achieve behavioral change goals that WBREDA could not. Given the trust of the leaders within the community and their understanding of the specific local context, WBREDA looked to these groups to effectively communicate the rationale behind load limiting, reasoning that if customers understood that unmitigated usage would inevitably lead to brownouts, they would voluntarily limit their usage. In reality, many customers chose to maximize their own utility rather than consider the implications of individual over-usage for the entire community.

WBREDA introduced monitoring and enforcement measures through a customer contract as a means of dealing with excess usage from the outset of their activities. Customer contracts were devised by WBREDA and the cooperatives were responsible for executing them with their customers. Following the execution of the contract, customers understood that disconnection from the microgrid was the punishment for exceeding their limit. Unsure of the ability of the cooperatives - or other users - to be effective monitors and enforcers, WBREDA designed additional features to insure adherence to the load limits.

Given that customers were un-electrified before the microgrid development, WBREDA was responsible for home wiring. In the early days of the microgrids, only one service level was available to customers, and this service level included only two sockets for lighting. Therefore, a customer would need to make an effort to add points – either lighting sockets or outlets for appliances – to exceed the load limit.

Initially, users followed the contract. Within a few years, increased economic activity due to electrification increased household income. Users became vocal in their demands for more power, and indicated their willingness to pay a higher fixed monthly fee in exchange for higher load limits.

Before WBREDA could increase generating capacity, users began increasing their loads – more light bulbs, TVs, and, eventually, fans and refrigerators. When users were exceeding their load limits on a regular basis, WBREDA set out to design customized current limiters. The limiters used an accurate current sensor to measure the customer's load and would open a relay to interrupt their circuit if the reading exceeded a pre-programmed threshold. One problem with these limiters is that the inrush current would often trip the relay. Soon after deployment, customers figured out how to bypass the limiters and continued to exceed their limits. WBREDA did not take strong action against this given the tendency for the limiters to trip in response to usage of legitimate loads that just had high inrush currents.

In 2005, miniature circuit breakers (MCBs) were introduced as a low-cost alternative that was less likely to trip due to inrush currents. MCBs are commonly used in off-grid systems to limit loads, but they – like any other component – demand maintenance. In the Sundarbans, WBREDA found that MCBs became faulty due to the high salinity of the air. The effectiveness of MCBs also diminishes over time as they are exposed to high currents or large numbers of trips.

WBREDA estimates that it is presently losing 15% of revenues to electricity consumed above customer load limits. In Koyalapara, mutual monitoring amongst customers is still common, and they inform the beneficiary committee when their neighbors try to use more than their limit. The beneficiary committee enforces by cutting off power to offending customers for a few days. While this type of offense appears to be somewhat common, it is reported that there is virtually no outright theft because it is far more conspicuous.

WBREDA plans to install pre-pay meters in the near future to reduce losses. Pre-pay meters were installed on the microgrid in Mousuni in 2003, but they failed due to technical problems as they were newly developed and untested devices at that point.

Performance

Some of the installed plants are currently non-operational, and this can mostly be attributed to the central grid arriving to the site and delivering electricity at a lower price than the existing microgrid. Non-operational plants include two Biomass sites and three PV sites. Additionally, two PV plants are only partially operational, and the wind-diesel hybrid plant is powered primarily on diesel because only one wind turbine out of four is still operational. These systems have ceased operations due to a lack of interest from the community in paying for or maintaining the microgrid.

The performance of the systems in the portfolio is variable, but the operators of the Koyalapara site claim that it operates very consistently in adherence to the stated schedule of 6 - 11pm. The rainy season affects the output and can limit operations to three to four hours per night.

The high quality of service of the microgrids in the villages not yet connected to the central grid appears to be driven by diligent maintenance, both by the village staff and the maintenance contractor, as well as an active beneficiary committee that is willing to enforce penalties.

Community members washing solar panels and cutting weeds at an OREDA microgrid site in Orissa, India

The following section adds the perspective of our case studies to the three "best practice" clusters in the microgrid literature presented in Chapter 4, as reiterated in **Figure 41**.

Figure 41: Clusters for best practices: strategic planning, operations, and social context

Our case studies, which included site visits, developer and operator interviews, and physical observations, supported the best practices presented in Chapter 4 in certain instances, and refuted them in others. Often, they provided a more nuanced view that did not necessarily contradict the best practices, but rather gave useful examples of how such practices evolve in the field.

This analysis is focused on the six developers whose sites were visited and the in-person interviews with CREDA.

Strategic Planning

Observations and interviews support the literature's recommendation to plan microgrids in a thoughtful manner, and imply much more than site analysis and technological solutions (ESMAP, 2000). This approach involves an in-depth study of the way a community functions, the economic circumstances of potential electricity consumers, and even some projection of future development in the community. As the ESMAP guide highlights, not every community needs or wants a microgrid. If suitability for a microgrid is determined, careful thought must be given to sizing, management, maintenance, feedstock availability, tariffs, expected loads, central grid expansion, and other "growing pains" the microgrid might face.

Market assessment

Organization

Developers approach microgrid initiation in different ways depending on their mission and business model. The GE/T/P partnership in Malaysian Borneo – a partially-subsidized (PS) model – has had success by requiring communities to organize themselves and contact GE/T/P with a request for a microgrid and an agreement to provide 10,000 hours of labor to build the project. DESI Power took an alternative, but equally successful route of surveying 100 villages and deciding in which few to install microgrids. They also took it upon themselves to "build markets" and increase demand for electricity services within the community by investing in productive uses. A good indicator for a successful microgrid project is to select villages that have existing, poorly-run or expensive diesel microgrids, and offer electricity services for less than the price of stand-alone diesel solutions or kerosene lighting. This strategy was chosen by HPS for its Build-Own-Operate-Maintain (BOOM) plants.

Some developers choose to install microgrids in a place with a business "anchor" customer to ensure at least a minimum level of revenues. Alternatively, a developer could look for a "plant manager" first, and expect that the microgrid will operate well if managed by a qualified person. The HPS Build-Maintain (BM) model involves advertising in the newspaper for village entrepreneurs, and siting plants in villages with the most promising entrepreneurs - and who meet their minimum threshold requirements.

Developers whose goal is to target the poorest un-electrified portion of the population – via fully subsidized (FS) models such as CREDA and OREDA - will inevitably choose sites that may not have the above characteristics to begin with, but a significant amount of interest creation, training, and community building accompanies the microgrids to maximize success.

Resource Availability and Variability

The logical place to begin an assessment of a potential microgrid installation is the feedstock or resource attributes. For example, DESI and HPS research the availability and price of rice husk before installation. Flow rates in the nearby stream should be measured over an extended period of time for a micro-hydro plant to account for seasonal variations, as exemplified by GE/T/P. Insolation throughout the year must be accounted for in PV systems, such as OREDA's and CREDA's installations.

Once customers have electricity on a regular schedule and level, they re-adjust their lifestyles to match that schedule and level. At that point, customer satisfaction and quality of service become defined as receiving service at the advertised level and following the schedule promised. Over time, customer lifestyles change as a result of access to electricity, and associated loads change as well. Resource variations, if they drop below the minimum threshold service level at the initial set of expectations or ones that have evolved over time, can cause a decline in the quality of service and disappoint customers. This is regularly seen during the dry (low river flow) seasons at the GE/T/P microgrids. It also occurs in WBREDA's and OREDA's PV grids when the microgrid operates for only half of the time scheduled. This variation in resource and the projected change in expectations over time must be strategically accounted for in the planning process.

To account for resource variability, a developer can either build capacity (more PV panels, batteries, and/or micro-hydro turbines), include a backup source (an HPS BM plant had a backup diesel generator), or manage customer allotments and expectations carefully. The GE/T/P Buayan microgrid tried to get all customers to scale down their usage during the dry season, but struggled to get customers who were used to certain appliances to limit their usage to lights-only. This situation suggests that it is best to not allocate usage allowances based on the highest generation capacity (e.g., available output during the rainy season), but design allocations based on a lower capacity instead. A more expensive alternative is to implement a technical demand-side solution that could adapt to changing capacity limitations.

Demand Projections

Electricity demand is extremely hard to predict, especially in a village that has never had access to electricity. The ESMAP guide and conversations with developers indicate that predicting demand is key to sizing the microgrid, as they must balance the goals of minimizing costs while still building an adequately-sized microgrid. A sensible way to predict demand is to visit a nearby village that already has electricity and deduce the likely demand of the target village, as the ESMAP guide suggests. Given the cases of CREDA, OREDA and GE/T/P, demand can quickly outgrow a static capacity. Benchmarking demand against a nearby village that has had electricity for some time can help avoid this predicament. That said, it is difficult for developers to size a microgrid at the time of installation in a way that could meet electricity demand growth for the life of the system. Therefore, developers are left with two alternatives: 1) build their microgrids so that they are incrementally expandable or 2) manage demand effectively. Based on our field visits, there does not seem to be an affordable, incrementally expandable microgrid that a low-income community could feasibly sustain through tariff collection, so this leaves demand-side management as the more feasible alternative. In addition to the technical challenge of incrementally expanding the microgrid, erratic investment over time is often difficult for donor agencies and governments to feed into microgrid projects. These funders often prioritize a "spread the wealth" approach by funding projects in disparate communities rather than funding additional capacity the same community over time.

Technology choices

When developing a microgrid, it is difficult to assess how sophisticated its technology should be. Most developers who were interviewed indicated that they regretted not having more sophisticated technology integrated into their installed microgrids, such as smart meters, automated payment collection technologies, or load controlling devices. Many of them did not have the option to install all the devices they would have liked, because they were either not available or too expensive at the time of installation.

Off-shore transmission line connecting the Sundarbans Islands to the West Bengal central electric grid

Regardless of the ultimate decision on technology, the choice comes down to balancing the dependence on human resources against the additional cost of technological devices. Every village is different, but if one foregoes an automated solution, then one must invest the appropriate time and effort into identifying, training, and motivating people to carry out the necessary operational activities for the lifetime of the system, especially those pertaining to demand management.

Public policy and legal issues

Contracts and Business Customer Service

Well-designed contracts with customers, feedstock providers, and businesses are not absolutely necessary for success, but can contribute to the smoothness of operations in the years after installation. The majority of microgrid developers in our sample do initiate some type of contract with customers in order to specify tariffs, penalties and safety protocols, among others. Such contracts are often developed jointly with the community itself.

Developers have benefited from contracts that ensure reliability and low prices with feedstock providers. In the case of HPS, they discovered cases of collusion between HPS employees and local rice mills that significantly increased the price of rice husk.

If tariff collections are dependent on a single or a few anchor customers, then well-researched contracts should accompany the decision to site the microgrid near them. DESI Power experienced a failed contract with a Vodafone cell phone tower operator when the tower operator contracted DESI Power to purchase electricity but did not notify Vodaphone, whose diesel supplier continued to deliver fuel to the tower, which the tower operator then sold at a profit. When Vodafone discovered this, they forced the operator to end the contract with DESI Power. In this case, DESI would have benefited from conducting more due diligence on its customer to ensure that their contract was legitimate. One basic principle of a contract is to allocate risk to the party most able to bear it; once that is done the party bearing the risk is incentivized to control the risk, but must allocate sufficient effort to do so.

Agency Cooperation and Central Grid Expansion

Failing to include cooperation with government agencies that might affect a microgrid's operations will inevitably lead to poor performance. Such cooperation can resolve issues around central grid expansion and increase the likelihood of sustainability over time. Private or public developers must investigate what the future plans and possibilities are for other government agencies or even competing electrification organizations. As evidenced by our field visits, it is not uncommon for central grid expansion to curtail the life of a microgrid.

OREDA has made efforts to coordinate with the state electricity agency to delineate exactly which communities should be electrified using distributed generation sources as opposed to central grid expansion. This coordination enables them to install their systems without being displaced by a central grid connection that delivers less reliable power than what their microgrids are capable of.

WBREDA has seen central grid expansion into the Sundarbans severely disrupt its operations. When news that the central grid would be extended to their village arrived, WBREDA customers became unwilling to continue paying for microgrid electricity, which was slightly higher than the cost of electricity from the central grid. Customers wrongly assume that the central grid will deliver unlimited power on a 24-hour basis, reducing their willingness to pay for the microgrid which offers limited power for fewer hours per day. From the beginning, WBREDA recognized that their microgrids are an interim solution until the central grid reaches every village in the state. WBREDA recommends building microgrids that can easily be integrated into the central grid when it does arrive. However, its interactions with the nodal agency of the Ministry of Power, which ultimately decides on central grid extension routes, have not prevented sub-optimal outcomes for customers.

CREDA views its solar PV microgrids as a stopgap solution before central grid extension due to the limited loads that the microgrids can support. Since the agency has this clarity, it makes provisions to relocate its microgrids from communities that get connected to the central grid to areas that are far from the central grid.

The Government of Haiti has sought to provide regulatory clarity for microgrid developers with respect to central grid electrification. A new provision ratified by the Board of Directors of the national utility, Electricité d'Haiti (EDH), indicates that private developers can build, own and operate microgrids in areas not presently covered by EDH, so long as they are public-private partnerships. It further indicates that the towns being served by the microgrid operators may continue to do so upon the arrival of and interconnection with the central grid.

While interactions with the government and its electrification initiatives vary by country, state, and even village, it is likely that circumstances will change during the lifetime of the system due to government decisions. As such, it is best to either coordinate with the relevant government actors to prepare for - or control - certain factors and adapt to the changing government context.

Operations: Commercial and Financial Considerations

All developers are limited by their financial resources and funding sources. Donor- or investor-funded business models can both work, but all cases point to the need for ensuring funding for more than just the upfront installation. On the one hand, initial capital costs for OREDA's microgrids were funded by government subsidies, but insufficient funds and effort were put into training and auditing operations throughout the life of the systems. While they succeeded in deploying a large number of microgrids, many of them are currently not operational. On the other hand, the Chhattisgarh state government ensured adequate subsidies for ongoing maintenance, auditing and training activities to support its microgrids. Before beginning an installation, it is essential to ensure that there are sufficient funds from subsidies, grants, tariff collection, or other sources for the financial viability of the microgrid throughout its life.

A key input to most of the models discussed in this report is tariff and penalty design, which vary depending on each developer's business model, as well as the local cultural context. General observations from our site visits indicate that having an independent and/or paid payment collector usually increases the likelihood of payment collection, as does clearly defining and strictly enforcing penalties. While performance quality appears to correlate with success in payment collection, it is

Table 17: Comparison of costs to be recovered by tariffs

Developer (Business Model)	Tariff Price (Local Currency)	Tariff Price (USD, January 2014 exchange rate)	Operating Expenses	Major Maintenance	Capital Costs[3]	Profit (for Developer)
CREDA (FS)	5-10 Rs/mo.	0.08 – 0.16/mo.	Partial	No	No	No
DESI Power (PS)	5 – 8 Rs/kWh	0.08 – 0.13/kWh	Yes	Yes	Partial	No
Green Empowerment/ Tonibung/PACOS (PS)	3 – 20 Ringgit/mo.	0.91 – 6.09/mo.	Yes	Partial	No	No
Haiti (PS)	~200 HTG/mo.	4.55/mo.	Yes	No	No	No
Husk Power Systems (FP)	~150 Rs/mo. (average)	2.41/mo.	Yes	Yes	Yes	Yes
OREDA (FS)	10 – 30 Rs/mo.	0.16 – 0.48/mo.	Partial	No	No	No
WBREDA (PS)	80 – 270 Rs/mo.	1.28 – 4.32/mo.	Yes	Partial	No	No

unclear if higher payment collection is due to the fact that customers who are satisfied with the quality and capacity of service are more willing to pay their tariffs. It is possible that reliably collecting tariffs enables the operator to employ reliable staff who makes more of an effort to collect payments.

Our field observations support the common assertion that "people don't take care of things that they get for free" (Martinot et al., 2002). Observations also support the notion that tariff collection success often has benefits beyond financial sustainability (Alliance for Rural Electrification, 2011). In most business models, appropriate and regular tariff collections are a key driver of the virtuous or vicious cycle of microgrid performance.

Cost Recovery Requirements Determine Tariff Structure

Different business models, cost structures, and categories of organizations (NGOs, government agencies, or for-profit entities) determine tariff structures and can have substantial differences. It is impossible to compare tariff design without first looking at the elements of the microgrid that tariffs are expected to cover.

Comparing developers in **Table 17**, it is possible to see the linkages between developer type and cost recovery requirements that must be addressed in tariffs. For-profit companies need tariffs to cover all costs including their return to investors. Due to their high cost requirements, their tariffs are some of the most expensive. The NGO developer, GE/T/P, has designed its microgrid program to enable financial self-sufficiency of the village-owned microgrid once it has been installed. Tariffs are therefore intended to cover all aspects of the microgrid other than the capital costs, except in a few rare maintenance situations. Finally, government-owned grids usually expect to cover operational costs and regular maintenance. The O&M costs of the EDH grids in Haiti are much higher than those in India because they are powered by diesel generators. The government-owned microgrids can and often do serve poorer customers due to their lower tariffs.

Aside from cost recovery, other factors contribute to tariff design differences. The difference in cost structure of each type of generation technology plays a role as well. For example, biomass gasifiers require a constant supply of feedstock, while photovoltaic systems require an expensive battery re-

Table 18: Tariff payment types used by developers[4]

Tariff type	Tiered*	Untiered
Energy basis (per kWh)		DESI, WBREDA
Time basis (e.g., fixed monthly fee)	WBREDA, GE/T/P, HPS, EDH, DESI	OREDA, CREDA

* "Tiered" signifies there are multiple capacity levels at different prices customers can choose to sign up for.

placement every few years, but have low costs for routine maintenance in between. Another driver is the level of in-kind operational contributions to the microgrid. The OREDA, GE/T/P and some of the EDH systems depend on volunteers within the community to operate and maintain the microgrid. In some cases, in-kind community involvement is required on the planning and commissioning side of the microgrid, such as those developed by WBREDA and GE/T/P. Lastly, the tariff design must also account for the ability of the customers to pay. One of the most complex external social dynamics to understand is the income disparity between villages. OREDA-powered communities may have incomes of just 500 – 1,000 Rs (USD 8.13 – 16.27) per household per month, which puts them amongst the poorest in the country.

In other words, there is no standard formula for tariff design, but it must balance the factors driven by both the developers' motivations and the customers' expectations. Whatever "financially sustainable" means for those specific microgrids, the tariffs must meet that requirement in order to keep that microgrid running according to its stated schedule and level of service. The Haitian microgrids provide an example of tariffs often set too low to operate reliably. Even with 100% payment collection, microgrid income fails to cover diesel costs and minor maintenance activities required to keep the microgrid operating according to schedule, which promptly forces it into the vicious cycle. These tariffs have been set by the municipality itself or by elected members of the community. The choice of tariff levels seems to be dictated more closely by the tariffs found in neighboring systems rather than an accurate calculation of cost recovery requirements.

Tariff Design

Most developers choose to charge based on a fixed monthly fee, because it is the simplest type of tariff design and does not require metering. In some cases, this type of tariff is also somewhat aligned with the cost recovery goals. For example, GE/T/P's microgrids do not require re-payment for capital and have essentially zero marginal costs. They have recurring, nearly fixed O&M costs that can be accounted for with the fixed monthly tariff payment.

DESI Power utilizes conventional energy meters to charge its commercial customers on a post-paid energy (per kWh) basis. Some HPS microgrids use prepaid meters that deduct payments from the customers' balance on an hourly basis. They charge fixed monthly fees on other microgrids.

The remaining operators included in our study charge a fixed monthly fee and allow unlimited energy use within the customer's load limit. Some operators provide a single service level option and charge the same price to all customers. However, these developers usually aim to provide lighting and mobile phone charging only. Other developers offer a wider variety of service level options. For example, WBREDA offers three options varying between 75W and 300W at between 80 Rs and 270 Rs (USD 1.30 – 4.39) per month.

Frequency of Tariff Collection

Tariff collection is often designed to accommodate the income streams in the village, and, as such, collection frequency ranges from a daily to monthly basis. Monthly collection was most common among the microgrids included in these case studies, and flexibility in payments is often granted, allowing for non-payment of up to three months. However, the more flexible payment collection options tended to align with less successful collection overall. It is worth noting that those sites with greater flexibility also prioritized electricity penetration in the community over payment collection rates, and therefore may have

[4] This is the most common collection type for that developer. Variations may exist within each developer portfolio.

Table 19: Frequency of payment collection

Frequency of Payment Collection	Developer*
Flexible	GE/T/P, OREDA, EDH
Monthly	OREDA, HPS (BM), EDH, CREDA, WBREDA
Weekly	DESI, GE/T/P
Daily	DESI (residential), HPS (some BOOM visit daily for monthly collection)
Pay as you Go (pre-pay)	HPS

expected suboptimal collection rates. **Table 19** lists the frequency of payment collection for each of the developers.

Developers that strictly enforce penalties and actually shut off service to non-paying customers soon after a violation occurs tend to maintain high collection rates, as is the case in HPS BM micrograds. Alternatively, some developers that are averse to enforcing penalties have maintained high collection rates by collecting payments more frequently. DESI Power and some HPS BOOM plants collect tariffs daily. As gleaned from our interviews with DESI Power staff, the daily collection period resolves two issues: The first is that customers are not self-motivated to make payments and the second is that due to individual circumstances, customers may not be able to make the payments at the exact time or place they are supposed to. In response to these constraints, DESI Power designed their payment collection system around daily household visits and daily tariff collection from residential customers. Similarly, HPS BOOM employees, who are incentivized to maximize payments, have discovered that daily visits to non-paying customers increase the likelihood that they will pay their monthly bill. Of course, while more frequent household visits can increase payment collection, it also costs significantly more to carry out than monthly collections from a single, centralized location.

What factors influence the likelihood that customers will pay?

Based on our case studies, successful tariff collection is most likely when strict penalties (or required pre-payment), and salaried collectors are present. Salaried collectors who are external contractors, rather than within the community, may improve collection rates as well. Pre-payment, door-to-door collection and frequent collection also increases customer payment rates. As has been discussed previously, some developers do not have strong incentives to collect tariff payments, as funds to support operations may be available through alternative means. In general, developers who have these resources at their disposal do not obtain high levels of payment collection. **Table 20** below provides a comparison of these factors for each developer. There are other factors that influence a customer's ability or interest to pay, but these are the factors a developer or operator can decide upon or influence to the greatest extent. Within these selected tariff collection factors, making a tariff higher or lower does not seem to influence the likelihood of collection as much as the decision to pay a collector from outside the community and enforcing penalties reduce the frequency of non-payment.

Collectors

In many communities, payment collectors from within the community struggle with confronting their own friends and relatives about non-payment or enforcing penalties. WBREDA discovered

* All these developers with the exception of DESI Power rely at least on partial capital subsidies provided by their governments or donors. In India, for example, the Ministry of New and Renewable Energy provides a 150 Rs/W subsidy for solar installations and also up to a 30-40% capital cost subsidy for all renewable sources (Deshmukh et al., 2013). Capital cost recovery, therefore, refers to recovery on the portion of capital costs paid with debt or equity by the developer.

Table 20: Tariff collection process details and frequency of non-payment

Developer	Tariff Price (Local Currency)	Tariff Price (USD, January 2014 exchange rate)	Collector Internal or External to the Community	Collector Paid	Penalties Enforced	Frequency of Non-payment
CREDA	5-10 Rs/mo	0.08 – 0.16/mo.	Internal	Yes	Sometimes	Moderate
DESI	5 – 8 Rs/kWh	0.08 – 0.13/kWh	External	Yes	Sometimes	Low
GE/T/P	3 – 20 Ringgit/ mo	0.91 – 6.09/mo.	Internal	No	Rarely	Moderate
Haiti	~200 HTG/mo.	4.55/mo.	Internal	Varies	Varies	High
HPS – BM	70 – 190 Rs/mo.	1.13 - 3.06/mo.	Internal	Yes	Strictly	Low
HPS – BOOM	60 – 180 Rs/mo.	0.97 - 2.90/mo.	Internal	Yes	Somewhat strictly	Moderate
OREDA	10 – 30 Rs/mo.	0.16 – 0.48/mo.	Internal	No	Almost never	High
WBREDA	80 – 270 Rs/mo.	1.28 – 4.32/mo.	External	Yes	Sometimes	Low

this issue and transitioned from payment collectors from within the community to hiring an external payment collector to visit multiple communities, which increased their payment rates.

Strict Penalty Enforcement

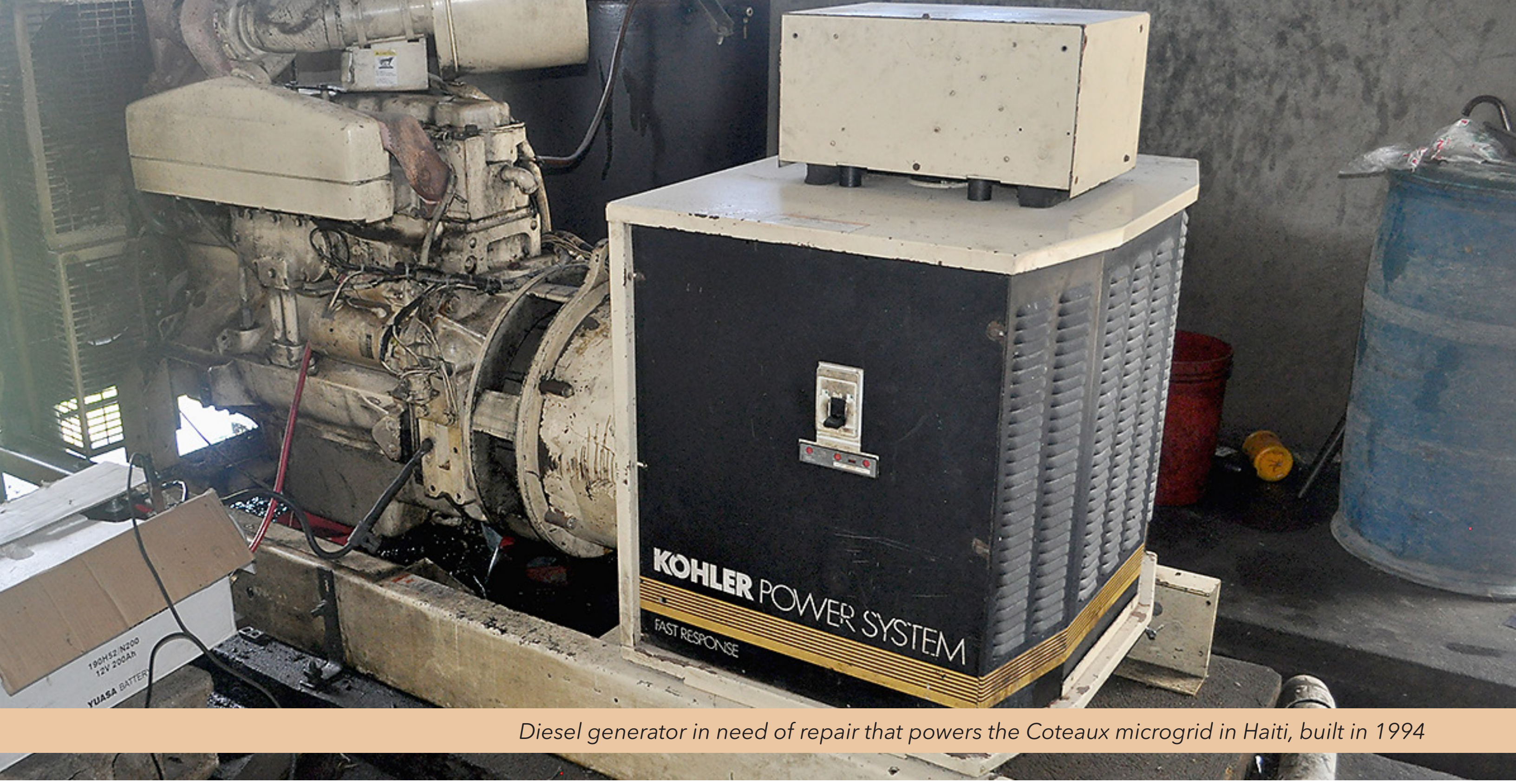
Enforcing penalties does not guarantee high collection rates, but they do appear to be correlated. Perhaps the correlation is due to penalty enforcement being reflective of the generally good practices of the microgrid operator. The GE/T/P case study includes a notable example comparing two different villages – one with a leader that enforced penalties and another where the leader not only did not enforce penalties but also broke rules himself. HPS threatens to turn off electricity to an individual customer or even the entire village if non-payment is prevalent. Within HPS microgrids, HPS BM plants enforce penalties much more strictly than HPS BOOM plants and have higher collection rates.

Developer Motivation

It appears that microgrids that have a greater dependence on tariffs to fund their operations end up with higher collection rates. Lacking a back-up option for operational funding is likely the motivation for imposing penalties and experimenting with different methods to maximize payments. For example, extensive government subsidies are available to CREDA to cover its ongoing expenses. Tariff rates are low and collections are not a high priority compared to providing access to electricity. OREDA grids also suffer from this lack of motivation. They have no immediate need to collect tariffs because the government is a committed funder and their daily or weekly collections did not seem to actually affect the immediate performance of the microgrid, because this did not directly fund the maintenance work. Rather, maintenance was contracted out to a third party by OREDA, creating a disconnect between tariff collection and microgrid operational reliability. Tariff collections were supposed to fund operational costs ten years after the microgrid was built – a large temporal disconnect that was perhaps too long to influence customer behavior. On the other hand, HPS has experimented with collection methods because its operations directly depend on collected payments.

Other Considerations

- After payments are collected, funds must be kept in a safe place. If an individual can withdraw funds, the community puts itself at risk for theft. At the OREDA microgrid in Palsipani, the payment collector stole all the funds a few years ago and forced the community to start collecting from scratch. Soon



Diesel generator in need of repair that powers the Coteaux microgrid in Haiti, built in 1994

after, the community essentially gave up on tariff payments entirely. This issue can be resolved by ensuring that the account into which funds are deposited is jointly held by diverse community members, or in tandem with the developer itself.

- HPS incentivizes the payment collector financially based on collection success, which they report in their collections. Yet HPS has found that payment collectors reach a threshold of interest, and beyond that bonuses do not work well.
- Keeping records of payments is also important for tracking patterns and enforcing penalties. The GE/T/P microgrid in Buayan did not have proper records, and the managers found it difficult to determine how much they were collecting each month and which members owed what amount of payment.
- An initial connection fee or labor contribution may contribute to willingness to pay or to take care of the system. HPS and WBREDA both charge connection fees and have moderate levels of payment collection while GE/T/P requires labor contributions in lieu of a monetary contribution. OREDA has felt that they have had to convince customers to take the electricity service in the first place, does not charge a connection fee, and has poor rates of payment collection.

Operations: Technical

Demand Side Management (DSM)

In this section, we discuss to what extent the implementation of these measures was aligned with the consensus on "best practices" for microgrid DSM, and the degree to which these measures were effective.

With the exception of the Haitian government, all of the developers included in this study used at least one type of DSM measure with the intention of increasing microgrid reliability and reducing operating costs. **Table 21** lists the demand-side measures commonly found in microgrids, and indicates which ones are used by the developers.

DSM Appropriateness

Most of the developers included in this study faced problems that could be solved through demand-side interventions, and some were successful in their implementation. With the exception of DESI Power (and, at times, HPS), all other tariffs were, in some way, power-based. Power-based tariffs require some mechanism for restricting customer demand, such as over-use penalties, efficient appliances and load limiters, which are effectively demand-side management measures. Most of the implemented measures were aligned with best practices.

Table 21: Demand side management measures utilized

Developer	Efficient Appliances	Limiting Business Hours	Restricting Residential Use			
			Customer Agreements	Home-Wiring Restrictions	Over-Use Penalties	Load Limiters
CREDA	✔		✔	✔		✔
DESI				✔	✔	✔
GE/T/P			✔		✔	✔
Haiti						
HPS	✔		✔	✔	✔	✔
OREDA	✔		✔	✔		✔
WBREDA	✔		✔	✔	✔	✔

Five of the developers in particular stood out as being particularly constrained by available power – GE/T/P, OREDA, WBREDA, and CREDA. As such, demand-side measures were most critical for these developers for the sake of preserving microgrid reliability on a day-to-day basis. The microgrids in Haiti were unique in that they were not at all capacity-constrained, as their generators were sized at a level that is far greater than even the peak load – and especially greater than the average load – on the systems. The importance of using demand-side interventions for HPS was related primarily to its use of a power-based tariff, which can be loosely followed even without strict demand-side controls. Power consumption was not a threat to reliability, as it very rarely neared the 32 kW limit on their generators.

The only developer in this report to utilize an energy-based tariff for their residential customers was DESI Power. DESI Power stood apart as the sole developer that did not encounter scenarios appropriate for demand-side measures to control power consumption. We attribute this to the fact that DESI caters primarily to a relatively small number of commercial customers, and its grids tend to be very well-sized relative to its loads. Only one of its microgrids serves residential customers directly, and it is a small number – about 75 households. The main issue on this microgrid is that residential customers bypass their meters, which adds up to theft of about 2-3 kWh/day. An energy-limiting controller may be more suitable for DESI's customers, as a load-limiting device is not appropriate for its case.

Efficient Appliances

The literature strongly advocates for energy-efficient microgrid loads, and specifically recommends that developers go to lengths to make energy efficient light bulbs accessible. HPS, GE/T/P, OREDA, CREDA, and WBREDA pursue this strategy. Such a strategy was not appropriate for the Haiti microgrids, as demand is far below available supply, and further reducing demand would actually have the detrimental effect of increasing unit energy costs. DESI Power actually has an incentive for its customers to use inefficient appliances as it sells power on an energy basis, and cannot significantly increase its customer base. GE/T/P educates consumers about efficient appliances during installation, but outcomes vary depending on self-regulation and the frequency of community inspections. While OREDA and WBREDA provided light bulbs to their customers initially, they have not done sufficient work to follow up with their customers to provide them with efficient light bulbs when one breaks or fails. CREDA also provides CFLs to consumers and provides replacement bulbs through its operators. HPS's load limits are suitable only for usage of CFL or LED lights, but it is not uncommon to find incandescent bulbs being used by customers on grids without a load limiting device.

Customer Contracts and Home Wiring Restrictions

The ESMAP guide provides detailed guidance on customer contracts and advocates for their usage (ESMAP, 2000). WBREDA implemented such contracts early on, and relied on behavioral change efforts to manage loads. They hoped that if customers understood that overuse would lead to poor reliability, that they would voluntarily limit their usage. WBREDA also wired homes for just two lighting sockets, which proved to be an effective mechanism for curtailing over-use early on. The contracts indicated that penalties would be imposed for over-use, but the contracts and even the home wiring restrictions were ineffective in preventing frequent overuse as customers began to use higher consumption loads over the years.

In OREDA's grids, over-use was frequently found in microgrids located in proximity to areas with central grids, where higher power appliances were available. Customer contracts and an understanding within the community that exceeding limits would lead to brownouts were insufficient to prevent widespread use of incandescent light bulbs, fans and TVs in certain microgrids.

Load Limiters

Strongly recommended as a best practice in the literature, load limiters were found on GE/T/P, HPS, CREDA, and WBREDA's microgrids. GE/T/P utilized MCBs to limit customers' usage. As mentioned previously, customers were able to circumvent the MCBs in some cases. However, they did prove to be effective in microgrids where penalties for bypassing MCBs were enforced.

HPS has gone through several different types of load limiting, from fuses to MCBs to pre-pay "smart" meters with current sensors and relays. Each of these measures was flawed – fuses needed replacement each time the customer exceeds the load limit; MCBs needed to be reset by the operator, and the MCB hardware apparently did not work well for low-power customers; and customers were able to bypass the HPS-designed smart meters. HPS leadership believes that in cas-

An HPS plant staff member with recently confiscated incandescent light bulbs in Bihar, India

es where there is difficulty in establishing credible threat of penalty from over-use, more technical solutions are necessary, such as a "smarter" meter or one that takes an input of 440V and converts to 220V internally to prevent bypassing.

WBREDA had similar experiences over the years. It started with MCBs, then shifted to a custom-designed limiter with a current sensor and relay. Customers complained about the MCBs once they started to demand more power and tripped them on a regular basis. As for the custom solution, they found that the inrush current on some appliances tended to trip them off. Eventually customers simply bypassed the limiters. MCBs were reintroduced to replace the custom limiters. These have been only modestly successful - WBREDA estimates that it is presently losing 15% of revenues to electricity consumed above customer load limits. The key lesson from these experiences is that an ideal solution for load limiting has still yet to be found, but that a low-cost solution like an MCB is better than no limiting device.

Overuse Penalties

Few of the developers have instated overuse penalties. As noted previously, while the literature is clearly supportive of penalties for non-payment as a best practice, it is conspicuously silent on whether customers should be penalized for over-use. The experience of the developers studied in this report does not suggest that such penalties are necessarily a "best practice." When established, it seems that the operators sometimes do not enforce such penalties.

For example, HPS bans the use of incandescent light bulbs on its systems. There seemed not to be a penalty for using these banned bulbs other than confiscation. Even though bulbs were confiscated – in one grid as often as every two to three days – customers clearly continue to use them. On the other hand, customer overuse tends to be less of an issue in grids that are owned by a local entrepreneur rather than HPS itself. The explanation offered is that these local entrepreneurs are imposing figures in the community who have credibility to threaten penalties and also follow through with penalties in the case of a violation.

In one GE/T/P grid, it was discovered that the village headman bypassed his MCB and was consuming above his level of service. As the designated enforcer of the penalty for doing this, the threat of a penalty to other community members was tacitly removed. In another village, however, the headman is firm about disconnecting users who violate their service level. It was found that in this village, Bantul, the microgrid was reliable, and community members credited the strong enforcement policy with its reliability.

In WBREDA microgrids, the customer contract clearly states that customers who exceed their load limit would be disconnected. During the first few years of operations, demand was low and customers did not exceed usage. However, as demand increased, customers exceeded their load limits on a regular basis. Penalties are reportedly enforced more often in cases of non-payment than in cases of over-use. Thus even the credible threat of penalty enforcement is ineffective in deterring over-use.

Maintenance and Safety

We find that maintenance performance is determined by a physical and an institutional element. The physical element pertains to the microgrid itself – the quality of components used, the quality of construction, and the ease with which components can be maintained. The institutional element pertains to the entity that is ultimately responsible for maintenance, and the institution's plan for carrying out maintenance. That institution must somehow be monitored – be it by the owner, the operator or some third-party entity. If the microgrid will be owned and operated by the developer, then the developer must set up appropriate mechanisms for management and make sure that its maintenance plan is feasible. OREDA, on the other hand, has grids all over the state in extremely remote areas. An inadequate maintenance contractor, and long-term maintenance contracts without adequate performance incentives, along with infrequent interactions with villagers partly explain why many of the microgrids had fallen into and stayed in a state of disrepair.

If ownership and maintenance activities are to be transferred to the community, time and funds must be allocated appropriately to ensure that the community is willing and prepared to manage the system on their own for 20 - 25 years. GE/T/P has developed a model for this that appears to function well. Even if systems are transferred completely to the community, catastrophic events can happen that even a diligent community may be incapable of fixing – for example, we witnessed

Onsite water distillation tables (above) to service its massive battery system (below) helped WBREDA maintain reliability on its solar PV microgrid in Sagar Island, West, Bengal, India

a landslide that destroyed all the civil works in the GE/T/P micro-hydro microgrid in Terian. Planning to set aside some additional funds to assist in the event of extreme circumstances can rescue a microgrid from a situation that is otherwise irreparable by the community.

Key findings on system maintenance from our site visits and developer interviews include two points: (i) there is a great deal of variation across maintenance plans, including how maintenance is funded and who provides it, and (ii) there are distinct differences between how preventive maintenance is carried out and corrective maintenance for more significant repairs. While the literature stresses the importance of ongoing maintenance, and details specifically what should be included in preventive maintenance procedures, it does not delve into the practical realities of maintenance implementation, nor into how to deal with major repairs.

Preventive Maintenance

The prevailing best practice with respect to preventive maintenance is to train the local microgrid operator to take on maintenance tasks, and provide them with the necessary tools for doing so. The conventional expectation is that tariffs are designed to cover expenses associated with maintenance tasks, such as trimming branches, removing illegal connections, maintaining the generator (in the case of hydro and diesel), topping up batteries with distilled water, and cleaning solar panels. Our case studies indicate that when maintenance tasks are entrusted to the local operator, they are carried out, so long as funds are available. There is also a correlation between good maintenance performance by the local operator and diligent record-keeping of expenses for items like filters and lubricants. When there is ambiguity over who is responsible for routine maintenance, outcomes are not as good. An alternative model not mentioned in the literature is the use of third party contractors to provide routine maintenance. Such a model is in use by the three government entities in India included in the case studies – OREDA, CREDA and WBREDA – with varying success.

The local operators of the GE/T/P systems – that is, the communities themselves - are responsible for routine maintenance, and seem to be able to service the hydro generator and maintain the system with success. While every system suffers from down time, the reasons for poor performance tend to be due to customer overuse and sub-optimal power-rationing during the dry season rather than poor maintenance.

In Haiti, while major repairs are explicitly carried out by the government, even preventive maintenance issues are sometimes too expensive for local operators to cover with tariff collection.

DESI Power's microgrids are maintained by the local operators, who also keep detailed written records of their activities. They are trained intensively by DESI Power employees to remove tar build-up, change filters, and maintain the generator on a near-daily basis. While preventive maintenance appears to be adequate, DESI struggles with other issues that prevent daily operations of the microgrids, discussed in the "Major and Corrective Maintenance" section below.

The HPS site visits called attention to the fact that operationally, many things can go wrong with gasifiers. On a daily basis, tar build up or wet husk can prevent operations. HPS's local operators are well-trained and care for the gasifiers and engines on a near-daily basis.

OREDA's entire maintenance plan is based on the use of contractors to carry out routine maintenance and implement major repairs. However, performance is not guaranteed, even when contractors are chosen through a competitive public tender and are well compensated. The contractor is expected to visit each system every few months and ensure it is working properly, but in reality, many systems remain in a non-functional state for years. Absence of on-site distillation tables results in the need to transport distilled water through rural, logistically challenging places; distillation tables at villages would provide an easy, reliable source of distilled water for the batteries at remote sites. This issue has prevented the contractor from delivering water at each of the microgrid sites visited for the purpose of this case study.

Like OREDA, WBREDA contracts third party maintenance providers. Unlike the OREDA contractors, though, WBREDA's contractors keep a lineman and an operator at each of WBREDA's microgrid sites. The presence of solar distillation tables for water and on-site staff appears to ensure reliable maintenance.

CREDA either contracts third party service contractors that are different than the contractor responsible for installation, or has the same contractor provide maintenance services for five years as part of their overall contract.

Major and Corrective Maintenance

The ESMAP guide is somewhat resigned to the inevitable difficulties in dealing with major repairs. The guide views the issue of repair as a trade-off between designing a higher-cost system at the outset that takes advantage of on-site installation expertise and a lower-cost system that uses less durable materials, with the expectation that repairs and improvements will be made in subsequent years (ESMAP, 2000). This framing of the issue as a tradeoff is reasonable, but microgrid developers must be given some reference regarding the probability that repairs and improvements will be made over the years if a lower-cost system is chosen. Our case studies lead indicate that developers should be pessimistic on this point, and the case studies included in the ESMAP guide lead to the same conclusion. This sentiment is captured by an engineer implementing projects in Indonesia who was quoted in the ESMAP guide:

> "I've come to the conclusion that 'distribution' must be planned with a long term perspective - it's a nice idea to say we build and use bamboo posts temporarily and will gradually replace them with steel or concrete as they rot but how many people ever get around to doing it?" (ESMAP, 2000).

The guide acknowledges that, "without properly trained local staff and possibly a mechanism for providing technical backstopping, most repairs may not be properly made." This has the effect of increasing "life-cycle costs or [decreasing] system life over what was planned. Consumers are put at risk and the initial investment may not yield the expected benefits" (ESMAP, 2000).

Our case studies echo this anecdote and support the pessimistic view on the likelihood of major repairs being carried out. Many of the grids visited during our field visits were in need of corrective repairs. In GE/T/P's case, the Terian microgrid was rendered non-operational due to a landslide for several months prior to the field visit. While GE/T/P's preventive maintenance plan depends heavily on community work, they lack the funds and the expertise needed to implement the necessary repairs after the landslide – including laying new

Landslide that destroyed GE/T/P microhydro penstock and forebay in Sabah, Malaysia penstock and re-building the forebay. For these repairs, GE itself must find the funds to assess the site, develop a repair plan, purchase materials, and make the repairs.

In fact, all of the developers were ultimately responsible for making major repairs, and in most cases the financing for such repairs was provided by the government or an NGO. Major repairs in Haiti generally concern damaged transformers in need of replacement and generator overhauls, and such repairs are explicitly to be carried out by local offices of the national utility, Electricité d'Haiti. However, such repairs are often unfulfilled. The microgrids in Roche-à-Bateau and Pestel have both been in need of new transformers since early 2012, and the diesel generator at Coteaux has been in need of an overhaul for two years, though it is still somewhat operational. It was only through the intervention of an NGO - EarthSpark International - that a transformer was purchased for Roche-à-Bateaux. Three months after the transformer was delivered, EDH fulfilled the microgrid operator's request to install it. It is questionable whether EDH would have purchased the needed transformer in a reasonable timeframe.

At the time of our field visits, DESI Power's microgrids seemed to be suffering from major issues. The underground cable connecting the generator house to the distribution system on the Gaiyari microgrid had been identified as being problematic, resulting in 13 continuous days of inoperability. However, DESI had not been able to discover the precise problem. The gasifier on the Bara microgrid was said to have problems every other day. For the two days prior to our field visit, the gasifier was inoperable. For such problems that are difficult to diagnose, it is clear that local training is insufficient. DESI acknowledges this and sends its own employees to work on such severe problems. The close proximity of all of the microgrids to the DESI Power office enables DESI to quickly dispatch its technicians to its microgrid sites.

The third-party contractors used by OREDA, CREDA and WBREDA are responsible for making major repairs to the systems. In WBREDA's case, high levels of routine maintenance have prevented major maintenance issues from occurring. Cases where major repair issues have come up are ones where the central grid has arrived, or is expected to arrive, and customers stop making payments. Even though WBREDA does not depend on tariff collection to pay for maintenance, it ceases to award third party maintenance contracts on micro-grids that do not pay for service. As a result, the microgrids fall into disrepair and eventually cease to function. This has been the case in the Kamalpur PV microgrid, the Gangasagar wind/diesel microgrid and the Gosaba biomass/diesel microgrid.

Failure to provide routine maintenance on OREDA's microgrids has led to the need for repairs and major problems. For example, in the case of the Anupgarh microgrid, customers have not had power for 16 months as a result of poorly executed routine maintenance. The poor performance led to an unspecified number of customers stealing solar panels from the roof of the powerhouse, rendering the microgrid essentially inoperable. The Palsipani microgrid did not have power for 18 months, and the Matiapadhar microgrid has not provided power to more than one or two customers for 30 months. In the case of both of these microgrids, their operators have not been able to provide power due to incomplete battery replacement. The primary maintenance contractor, Tata BP, replaced eight out of 20 batteries four days before the site visit. Such an action is "too little, too late." Partial battery replacement is poor practice, and the replacement came across as a gesture meant to give the illusion of decent performance by the contractor given that they were aware of our pending field visit.

Exacerbating OREDA's maintenance problem is the confusion over how villages "call in" maintenance requests. OREDA managers indicate that a Village Electricity Committee (VEC) can either call or visit the vendor or OREDA offices (either in their district or their headquarters), but the VECs seem to have been under the impression that it was necessary to write a letter to OREDA headquarters in order for OREDA to contact the maintenance provider. This suggests that in such arrangements, the developer should clarify the service request procedure with VECs from the beginning by providing documentation.

CREDA has a robust process of monitoring the performance of their systems, and expects regular reporting from its maintenance contractors. Consumers from CREDA's microgrids can convey their complaints through the operator, then the service provider and finally to the CREDA office. Consumers can also directly contact the CREDA office. Major repairs are funded through state government subsidies.

Table 22: Maintenance implementation

Implementer	Contractor		Developer		Operator		Community	
Maintenance Type	Preventive	Corrective	Preventive	Corrective	Preventive	Corrective	Preventive	Corrective
DESI				✔	✔			
GE/T/P				✔			✔	
Haiti				✔	✔			
HPS				✔	✔			
OREDA	✔	✔						
WBREDA	✔	✔						

Table 23: Funding sources for maintenance

Funding Source	External (Government/NGO)		Internal (Tariff-Based)	
Maintenance Type	Preventive	Corrective	Preventive	Corrective
DESI			✔	✔
GE/T/P		✔	✔	
Haiti		✔	✔	
HPS			✔	✔
OREDA	✔	✔		
WBREDA	✔	✔		

Table 22 and **Table 23** list the type of maintenance conducted by the developers and the sources of funding for carrying out maintenance.

Social Context

Enabling Income Generating Activities

There is a degree of agreement within the literature that developing income-generating activities powered by the microgrid is necessary to produce sufficient revenue for the developer. While there is no doubt that such activities result in positive social and economic outcomes within the community, our case studies do not support the notion that income-generating activities will necessarily lead to high revenues, nor that they are necessary at all for fully recovering operating costs. Furthermore, as with most aspects of microgrid operations, developing income-generating activities is no simple task. DESI Power, for example, has found that developing income-generating activities requires significantly more time and resources than they originally expected. In most areas, especially village markets, electricity is not necessarily linked in the minds of villagers to productive activities – just lighting.

DESI Power's business model rests on the notion that income generating activities will lead to higher revenues and profitability. In Baharbari, its primarily residential microgrid, DESI assisted with the introduction of a rice huller and other income-generating loads. Their hypothesis that

Mill for flattening rice on a DESI Power microgrid in Bihar, India

doing so would increase the incomes of their residential customers has been borne out, and these increased incomes have led to more customers being able to pay for electricity. DESI Power's experience is aligned with ARE's perspectives, as they have stated explicitly that no plant can run on household loads only (Alliance for Rural Electrification, 2011). As such, prior to investing, DESI seeks to combine residential loads with larger loads– irrigation pumps, value-add agricultural services, and refrigeration. This "consumer creation" is essential to their operational sustainability, as a small number of such loads can provide a significant and continuous revenue stream.

The literature on best practices for income-generating activities does not go far beyond merely supporting the idea. That is, the literature does not provide much guidance on how to go about developing such activities. DESI Power's experience provides a couple of examples that offer guidance:

- In Bara, DESI is giving loans to existing industries to convert their diesel engine-driven loads to motor-driven loads. The cost of the motor can be recovered within a few years by DESI through increased electricity sales.
- DESI Power complements its investment in loads with a staff position that is dedicated to assisting commercial customers to develop businesses and increase electrical load.

DESI's perspective is more aligned with the common rationale behind introducing income-generating activities than the rationale discovered by OREDA. OREDA found that villagers do not value lighting enough to pay for a lighting-only electricity service. Villagers have told OREDA administrators that they do not want to dedicate the time needed to collectively maintain the system that could never facilitate power for income-generating activities. The lesson learned from OREDA, therefore, is that a microgrid should be sized to accommodate the loads that are truly desired by the prospective customers. Thus, the rationale discovered by OREDA for income-generating activities is more fundamental than the common view that such activities will lead to higher incomes and therefore better financial performance for the operator. Rather, the rationale for income-generating activities on OREDA's microgrids is that villagers themselves, who, in OREDA's case, are some of the poorest in the country, view such activities as a means for escaping poverty. Developers should take heed when aspiring to make a difference in the lives of villagers by providing only high quality lighting services. For some communities, this may simply be insufficient and not worth paying for or looking after.

HPS' systems do not fully support the view that income-generating activities must be present to deliver cost recovery revenues, or that all communities demand such activities. However, they do not refute that view either. One HPS BM grid

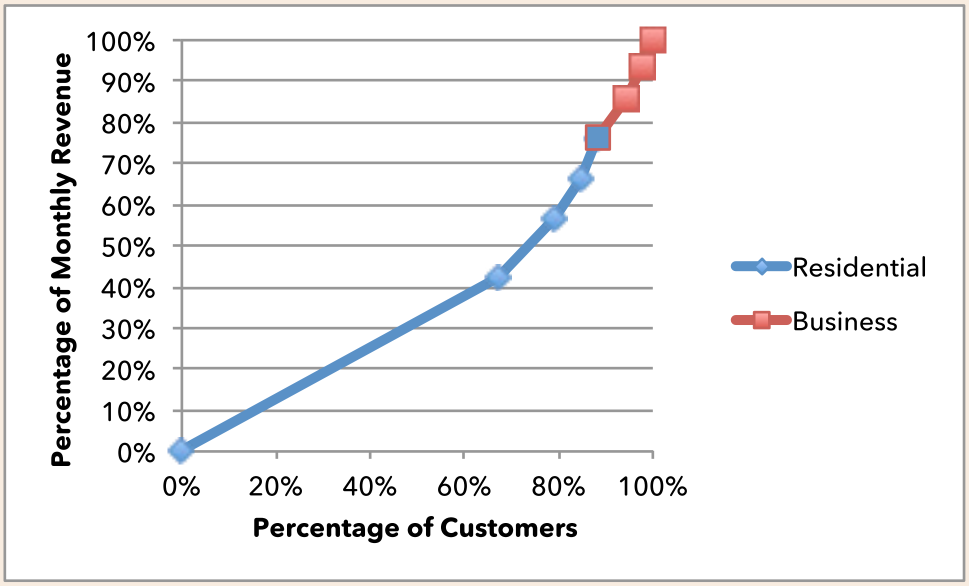


Figure 42: Percentage of Monthly Revenues Attributed to Customer Classes on one HPS microgrid.

serves 100 business customers and 750 residential customers. While that grid's owner did not set out to develop income-generating activities and is not actively doing so, it is clear that he earns more from an average business customer than from a residential customer. As shown in **Figure 42**, business customers make up just 12% of his customer base, yet they account for 24% of his monthly revenues.

Residential customers are arranged, from left to right, into 15W, 30W, 45W and 100W classes. Business customers are arranged, from left to right, into 30W, 45W and 100W classes.

Community Involvement

Microgrid best practices recognize that levels of community participation vary depending on the developer's business model. The literature also generally supports the idea that microgrids need community or stakeholder participation at different stages to be successful and that there are challenges to maintaining community interest and involvement.

Based on our observations and research, we support this conclusion but also believe that many private - and some public sector - models are actually moving towards reducing their dependency on the community, and in some cases completely bypassing the community leadership and collaboration after the initial planning and commissioning stages as part of their strategy. Additionally, almost all developers found that community cohesiveness varied drastically,sometimes depending on culturally inherited social structures, and were often disappointed by a community's inability to work together to keep the system running due to conflicts, lack of motivation, or other reasons. Finally, our experience in India and Malaysia suggests that community involvement is a highly local issue, with particular social, cultural, and political conditions that should prevent cross comparison among microgrids. **Table 24** shows the types of community participation used by each developer.

Levels of community involvement vary drastically. Black checks signify voluntary activities, and green checks signify paid activities.

Green Empowerment Maximizing Community Involvement

Green Empowerment/Tonibung/PACOS (GE/T/P) provide a strong example of community involvement and the only example of a community-owned system of all microgrids studied. They invested most of their resources into building community leadership around the microgrid, gave the community the main responsibility over the system, and succeeded in their goal of creating a community-owned and operated microgrid. GE/T/P up-front costs are USD 8,000/kW installed on average, of which only USD 2,600 goes to capital equipment. A significant portion of the up-front

Table 24: Community involvement in microgrid management

Categories (of Voluntary/ Paid Village Participation)	DESI Power	GE/T/P	EDH	HPS (BM Model)	OREDA	CREDA	WBREDA
Daily Operations	✔ (Paid)	✔ (Voluntary)	✔ (Paid)	✔ (Paid)	✔ (Paid) ✔ (Voluntary)	✔ (Paid)	✔ (Paid)
Major Maintenance							
Collect Tariffs	✔ (Paid)	✔ (Voluntary)	✔ (Paid) ✔ (Voluntary)	✔ (Paid)	✔ (Voluntary)	✔ (Paid)	
Enforce Penalties			✔ (Paid) ✔ (Voluntary)				✔ (Voluntary)
Initiation/ Planning Strategy Help		✔ (Voluntary)		✔ (Voluntary)		✔ (Voluntary)	✔ (Voluntary)
Construction Labor		✔ (Voluntary)				✔ (Voluntary)	
Village Energy Committee Existence	✔ (Voluntary)	✔ (Voluntary)	✔ (Paid) ✔ (Voluntary)		✔ (Voluntary)	✔ (Voluntary)	✔ (Voluntary)
VEC Bank Account Existence		✔ (Voluntary)	✔ (Voluntary)		✔ (Voluntary)	✔ (Voluntary)	
Contribute Land	✔ (Voluntary)	✔ (Voluntary)		✔ (Voluntary)	✔ (Voluntary)	✔ (Voluntary)	✔ (Voluntary)
Initial Community Ownership		✔ (Voluntary)					
Community Eventually Owns					✔ (Voluntary)		

investment went into community leadership formation, technical training, or other community development initiatives. They found that the strength and cohesion of the community was the greatest determinant of success of the system.

GE/T/P employed multiple strategies to strengthen the community involvement in the project. Firstly, GE/T/P built projects in villages that formed energy committees and reached out to them of their own volition. Secondly, GE/T/P requires at least 10,000 hours of community labor, which results in a vested community interest from the beginning, as well as familiarizing community members with the system, its operations, and its limitations. Green Empowerment and Tonibung were also unique in partnering with PACOS, an NGO which specializes in community organization and how to involve a community in such a project. The three organizations collaborated to provide in-depth training to a few members of the micro-hydro committee, as well as a more basic training on rules, safety, cooperation, and load management to the entire village.

The training of and investment in the community prior to operations has succeeded in keeping the system operating under full community ownership. Operations are done voluntarily and the community is almost always able to either perform maintenance themselves or pay for it out of their community funds. Yet even with this investment in community building, certain GE/T/P microgrids suffered from the shortfalls of community-ownership. Sharing responsibilities among too many volunteers sometimes led to inefficiencies (e.g., in payment collection) and the community did not always cooperate (e.g., by failing to reduce loads to only lighting during the dry season). Certain leaders were better than others at regulating usage and encouraging cooperation. The best community leaders usually were from more remote and tribal villages. Other leaders or community members have even tried to sabotage the microgrid.

The GE/T/P model shows that community-owned microgrids can be sustainable, and the likelihood of success is increased by prioritizing and planning training and community-building from the outset. In addition, PACOS and many of the villages also recognized the benefits of community organization beyond just maintaining electricity in their village. The investment in leadership and social organization also enabled the village to combat the encroachment of palm oil and timber companies, raise their voices against corrupt politicians, and defend their very existence. In the GE/T/P case, the investment in community was justified by more than just the ability to keep the lights on.

Disappointments with Community Involvement and Alternative Strategies

Besides GE/T/P, none of the other developers regularly transfer ownership to the entire community even though many have intended to. With the exception of WBREDA in its early years, they have not invested nearly as much into building up the community organization around the microgrid.

India's renewable energy nodal agencies – WBREDA, OREDA, and CREDA – maintained ownership and tried to involve the village as much as possible, but this involvement led to failure. After experiencing disappointment with community involvement, these developers began to internalize more of the operational responsibility of the microgrids. WBREDA's initial model was centered on a partnership with a local cooperative in order to ensure local capacity to fulfill many operational functions and gain the trust of the rest of the community. The local cooperative was supposed to collect tariffs, help in planning, administer penalties and operate the system on a voluntary basis. This model worked for as long as a few years in various locations, but fell apart due to political disagreements, changes in leadership, or lack of financial motivation. WBREDA changed their model and hired employees to carry out the tariff collections, operations, and other ongoing operational roles. While the cooperatives were important to get the community buy-in initially, cooperatives now mostly exist nominally.

Like WBREDA, OREDA originally expected the community to manage the daily operations, community involvement and education, and tariff collections. In all cases, OREDA helped form Village Energy Committees in each village. The initial 17 microgrid installations were scheduled to entirely transfer ownership to the village after ten years of payment collection and operations. For the microgrids that were built in 2002 and 2003, the transition has yet to occur due to their poor or non-functional state of operations. While this is partially due to under-performing maintenance contractors and unforeseen political issues, much of the performance problem can also be attributed to poor community cooperation. As the OREDA officials stated, "community ownership means no one's ownership." OREDA has not changed their village training strategy or customized it to each village, as it has changed its deployment strategy to invest in far more individual solar home systems than microgrids in order to ensure a sense of ownership of those systems. As for future microgrids, OREDA plans to maintain ownership of the system for the entire life of the project.

CREDA also helps create Village Energy Committees, but does not truly depend on them to keep the "virtuous cycle" going. With heavy ongoing subsidies, CREDA ensures the microgrids are properly maintained by an outside contractor, and has the capacity to expand the system if demand exceeds supply.

EDH microgrids in Haiti are owned by the municipality, rather than by the developer (the national utility) or the community itself. In some EDH microgrids, community involvement is present through a volunteer committee appointed by the mayor's office responsible for O&M. However, in most cases, the committee is made up of the mayor's staff or by a local NGO. In some cases, a technician paid by EDH who lives near these microgrid systems performs basic operations and maintenance.

Reduced Community Involvement

HPS and DESI Power are the least dependent on community involvement. All of their systems are privately owned, and most are profit-driven entities. The involvement of the community for each of these developers is, at most, the initial expression of interest, provision of land and paid local labor to perform operational activities. It is also important to note that these developers, while reducing dependence on the community for operations, still emphasize customer relations. The developers have instated a clear method of communication with their customers and respond quickly to customer complaints.

DESI Power focuses on commercial customers entirely, or as anchor customers for a village. It has determined that selling to only residential customers will not enable financial sustainability, and therefore focuses its microgrids on income-generating activities rather than household customers. This greatly reduces the importance of and dependence on a community for collaboration.

HPS believes that village cohesion is the exception rather than the rule, and avoids depending on community cooperation for its success. HPS now makes it a standard policy to adopt strict standards, do regular in-person check-ups, invent technological solutions, and circumvent local leaders in the village. A local entrepreneur franchises a HPS gasifier through the BM model, and hires his own local employees and maximizes his own profit through careful management of the system. In the other models, HPS hires local villagers and all functioning roles are incentivized with wages and bonuses.

Community Involvement Revisited

Microgrid developers have been told that community involvement is essential for success (ESMAP, 2000). Based on our sampling of microgrids, if the developer wants to disengage from daily operations, while a sincere effort in training a community will increase the upfront costs, it will also increase the likelihood of the success and longevity of the system. Alternatively, a false trust in the natural or self-motivated interest and enthusiasm of a community to maintain a microgrid over the long run without considerable training and investment by the developer will often lead to failure and disappointment, as seen in some of the government-owned microgrids.

For many private operators looking to make systems profitable instead of aiming to provide the lowest cost electricity to the poorest villages, the community is involved in a calculated, financially incentivized manner. Some developers are unwilling to deal with the variability in cohesiveness and volunteerism. Private developers instead rely on hired employees, no-nonsense payment collection policies, and a more transactional, business-like approach that prioritizes individuals' willingness to pay over communities' willingness to cooperate.

As an alternative view on community involvement, our cases support the relevance of customer creation and education. Successful developers expend effort in their initial deployment to explain to their customers how to better use their systems and how to avoid penalties, disconnections, or technical issues. Community involvement as customers rather than operators has been relatively overlooked in the literature, but our cases support the relevance of the behavioral change efforts behind introducing these communities to electricity as a service.

Along the spectrum of village involvement, there is no better or worse approach in terms of "success" defined as reliability and self-sufficiency. Low, medium, or high community involvement systems all have the ability to be successful microgrids. But when we look at alternative definitions of success such as serving the poorest, or positive externalities of village cohesion, such as GE/T/P's example of community building to defend their existence, one can re-evaluate the goals of the microgrid, and what level of community involvement best fits those goals.

The "vicious" and "virtuous" cycles for microgrid operations as presented in Chapter 1 lead microgrid developers to search for best practices to maintain the "virtuous" cycle. The existence of these empirically verified cycles found on each of the microgrids visited implies a generalized or systematized set of factors that can be either reined in or left uncontrolled by best (or poor) practices. Indeed, the systematized grouping of best practices commonly found in the microgrid literature presented in Chapter 4 agrees with this implication. We conclude this report by discussing the groups of best practices – strategic planning, operations and social context – in relation to the factors that compose the vicious and virtuous cycles.

It should first be noted that, while it is useful to think of best practices as being generalizable across factors that determine virtuous and vicious cycles, the analysis of best practices through the lens of our case studies in Chapter 7 suggests that each "lesson learned" may not necessarily be applicable to all microgrids. Similar to the discussion of lessons learned in Chapter 5, the experience of one developer may be too unlike another's to justify the inclusion of a particular practice that bore significance to their sustainability in a generalized framework.

With this caveat in mind, **Table 25** shows the linkages between factors that drive virtuous and vicious cycles with the best practices identified in Chapters 4 and 7.

Table 25: Best Practice Categories and Factors of the Virtuous and Vicious Cycle

Macro Area / Best Practice Factor	Strategic planning	Operations	Social context
Cost recovery (Tariff pricing; Tariff collection)	Resource availability and variability, Organization, Demand projections, Contracts and business customers, Central grid expansion	Frequency of tariff collection, Tariff design, Factors affecting likelihood of payment	Enabling income generating activities, Community involvement, Tariff collector selection
Maintenance, repairs and contractor performance	Contracts	Preventive maintenance, On-site water distillation, Communication,	Competitive hiring, community maintenance for non-critical components
Theft	Business model designed around meter use or reliable collection mechanisms	Customer contracts, penalties	Community involvement
Local training and institutionalization	Organization	Community involvement	Community involvement, incentives
Load limits	Demand projections, Technology choices	Customer contracts, home wiring restrictions, load limiters, overuse penalties	Consumer creation and education, community based monitoring
Unmet demand growth	Demand projections, grid system design	Demand side management	Forecast of income-generating activities

Business Models and Insights on Sustainability

In Chapter 1 we introduced a typology of business models based on the developers' cost recovery requirements and funding sources. The for-profit (FP) category includes developers that need to fully cover ongoing costs from tariff collection, in addition to a return on the non-subsidized portion of the capital cost, if any. The partially subsidized (PS) category is based on large subsidies for capital costs, but relies on tariff based cost recovery to cover operations and maintenance. The fully subsidized (FS) category is a model in which the costs are fully subsidized by governments, in-kind contributions from the community are common, and below cost recovery tariffs nominally cover part of maintenance, operation, and administration expenses, but often do not end up being collected over time.

Lessons learned from Chapter 5 are discussed below to offer specific insights on best strategic, operational, and social context practices based on the developer's business model. Following these insights may allow microgrid developers to enter virtuous cycles that support their grid reliability and financial viability for the future.

For-Profit Model Insights

In terms of Strategic Planning, FP developers can secure virtuous cycles by carefully studying and selecting their customer base. DESI Power purposefully designed their model around commercial customers with whom they worked closely to define their requirements and expectations. HPS chooses villages that have access to biomass feedstock. Unlike other developers, HPS's experience suggests that extensive government outreach within the villages is detrimental in the planning stage. Both developers find that diesel can pave the way for biomass, and places with existing diesel-powered microgrids are likely to be good candidates for their systems.

Operationally, FP developers are mostly concerned with adequate tariff collection, for which there does not seem to be a silver bullet. Methodologies ranged from high-tech solutions such as pre-paid meters that were being tested by HPS, to high frequency collection schedules such as those carried out by DESI. In an attempt to increase tariff collection rates, HPS has offered bonuses, but found that these rarely induce higher performance from their collectors.

Social context is not as critical to the FP model as to other business models. However, successful developers strive to provide prompt customer service through 24/7 hotlines and prompt on-site visits to solve technical problems, thus ensuring a loyal and paying customer base. This perspective is exemplified by a quote from one of the developers, who said, rural electrification is not grassroots.

Partially Subsidized Model Insights

In terms of strategic planning, the concerns of these developers tend to be more aligned with for-profit business models than their fully subsidized counterparts. Aspiring to obtain sufficient funds for O&M through tariff collection, this model depends on revenue derived by serving customers with reliable power. As such, the strategic planning phase is geared towards forecasting load, planning for expandability, and ensuring resource adequacy. These developers have limited control over customer selection, though they tend to strike a mid-point between serving only those that a for-profit developer would cater to, and the entire village regardless of individuals' ability to pay as in the case of fully-subsidized developers.

Operationally, PS developers prioritize grid reliability to maintain a steady flow of revenue that covers their ongoing expenses. Since these developers usually cover relatively poorer villages and hamlets, it is fundamental for them to strive for schedule and energy service reliability in an effort to keep customers loyal. If not, the results are disastrous, as in the case of Haiti's municipal microgrids. As discussed, these grids fall into a vicious cycle of schedule unreliability due to fuel and maintenance costs that exceed tariff collection.

Social context is important for these developers insofar as virtuous cycles have shown to prevail on microgrids with adequate community management. The PS model, which simultaneously espouses private sector values for financial sustainability and public sector values for inclusion, must balance the focus on factors that improve cost recovery with effort on factors that improve community cooperation.

Fully Subsidized Model Insights

Strategic planning for FS operators in virtuous cycles focuses on building local capacity for managing, operating, and maintaining the microgrid prior to its deployment. OREDA and CREDA grids used Village Electricity Committees as an institution responsible for nearly all aspects of microgrid operations. Another critical aspect of strategic planning that FS developers are concerned with is scale, as they are often mandated to prioritize service coverage to large portions of their villages, even if many are unable to pay cost recovery tariffs. To meet these goals of scale and service coverage, these developers often deploy many low-capacity grids designed to serve a large number of customers with lighting only. While this level of service is often sufficient in the near term, customers quickly demand power for larger loads, especially when tariffs are minimal or not collected. Lessons learned from both OREDA and CREDA underscore this point.

Since cost recovery is not a relevant issue for these developers, the virtuous cycle in operations requires dedication to preventive and corrective maintenance, both by contractors and community labor contribution. WBREDA's strategy to competitively bid contractors to ensure high performance may very well be borrowed to replace long-term, ambiguous, and difficult to monitor contracts, such as OREDA's.

As mentioned before, social context for virtuous cycles requires the ongoing legitimization of the Village Energy Committee or its equivalent as well as the microgrid itself. However, broader social and cultural historic arrangements will affect a community-based microgrid even to the point where a vicious cycle is inevitable, such as we witnessed in the OREDA case. Avoiding such a vicious cycle would require institutional structures that prevent community dynamics from interfering in reliable operation of the microgrid.

Insights on Policy Elements

Regardless of their business model category, microgrid developers rely in many ways on government policies. In India, the deployment of renewable energy microgrids significantly increased when the 2003 Electricity Act deregulated tariffs and allowed third party service providers in specific rural areas, providing a basic legal framework for these investments. In PS and FS models, national, federal, or state governments are directly involved in the deployment and operation of microgrids. In all cases, capital subsidies have shown to be essential to improve the project's financial outlook and to reduce equity requirements.

Similarly, government decisions and policies can also deter microgrid development in a number of ways. We provide a brief account of specific problems that developers encounter below, which can be solved through prompt governmental action.

Firstly, the uncertainty of a microgrid's fate once the central grid is extended to a village or hamlet is reached by the central grid has yet to be resolved in many jurisdictions. While a number of alternatives exist, a promising option is to highlight that converting microgrids into "islandable" systems that can feed electricity into the central grid or island themselves during shortages in the central grid may be a good solution (Deshmukh et al., 2013). This "small power producer" approach has been successfully applied in Cambodia, Thailand and Tanzania, among others, and can provide long-term sustainability to the assets and operations while also improving local electricity service quality. This has been advocated for by WBREDA for many years, and is under consideration as a policy in Haiti.

Secondly, forcing affordability through retail tariff regulation can be detrimental for business models that rely on cost recovery to cover their financial obligations. Should governments pursue this price regulation, they should implement parallel ongoing subsidy schemes to either the developers or the consumers. For FP business models, a monthly cash transfer directly to the consumer may be a less disruptive method to ensure affordability while allowing developers to maintain their practices.

Thirdly, many FS and some PS developers entered vicious cycles due to their inability to keep the grid operating for energy service and schedule reliability. While in Chapters 5 and 7 we identify several factors that are behind this, a transparent and expedient ongoing subsidy should allow these developers to secure maintenance contracts, comply with manufacturers' preventive maintenance schemes, and build a fund for larger expenditures, such as battery replacement. The difference between CREDA's virtuous cycle and OREDA's vicious one can be partially attributed to the former's access to this ongoing support. This ongoing subsidy is also in harmony with the type of tariff regulation measures described above.

Fourthly, renewable energy-based microgrids displace either diesel consumption in generators or kerosene for lamps, thus effectively abating carbon dioxide (CO_2) emissions. HPS is attempting to monetize this abatement on its own through Certified Emissions Reductions under the Clean Development Mechanism. Governmental policies to assist with monitoring and verification and reduce certification transaction costs can make many of these ventures more profitable and visible.

Finally, sources of capital can be diversified away from purely governmental support if an adequate institutional framework is developed by state or national governments. A scheme where the government provides guarantees on private debt would allow state funds to multiply their effect and to incentivize significant private capital investments into microgrid deployment. In this case, developers with trustworthy robust cost-recovery mechanisms or and low maintenance costs through community involvement may gain access to cheaper capital and foster their expansion.

A hydroelectric generator installed by Green Empowerment in Sabah, Malaysia.

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A Husk Power Systems biomass gasifier in Bihar, India.

Government of India transmission lines pass above a town with a DESI Power microgrid in Bihar, India.

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