Making Small Work: Business Models for Electrifying the World

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1. Rethinking Rural Electrification

Despite over a century of investment in electric power systems, there are roughly 1.6 billion people who lack access to electricity service, mainly in rural areas. While there are some open questions regarding the precise cause and effect relationships between rural electrification and human welfare, it is generally considered an important social, economic, and political priority to provide electricity to all. Unfortunately, the very complicated links between electricity and development are often obscured behind two idealized visions of rural electrification.

On the one hand is the image of the high-voltage transmission line, its tendrils reaching out into the countryside and bringing with it opportunities for jobs, communication, improved education, better health and a host of other welfare improvements. Vaccines will be refrigerated, small industries can be made more productive, and children will be able to read their schoolbooks at night. This has been the traditional view of electrification: large power plants with long transmission and distribution lines. It is still the model favored worldwide by utilities and often, implicitly or explicitly, by regulators and policy-makers as well.

Figure 1: Transmission Towers at the Three Gorges Dam, China (author photo)

On the other hand is the “small is beautiful” image of a solar home system providing clean electricity for a remote farmer or household. Many of the benefits are the same as with grid electricity: children reading their schoolbooks at night; farmers getting weather reports and market prices on the TV; household activities becoming easier and less labor intensive. This is how many in the NGO and international donor communities envision the future of rural electrification – environmentally sustainable and beneficial to the users. Many governments know that this imagery is also how they can get investment in their rural electricity projects, investments that would not occur without the linkage to sustainability and renewable energy projects in particular.

Figure 2: Cambodian Home with Solar Panel on Roof (author photo)

The problem with both of these images is that they are idealized visions of a much more complicated reality and fail to convey the complexities of solving the rural electrification problem. Rural electrification is a challenging task because it involves delivery of a service to populations that are remote and dispersed and whose consumption is low. This means it is generally more expensive while at the same time the customer base is generally poorer and less able to pay the full cost of service. Combine these factors with utilities that are often poorly managed and have limited finances, and it is often not feasible to expect extension of the grid to unserved rural populations in the near future. Such conditions are also challenging for the development of new renewable energy technology markets.

In addition to the large number of people without any access to electricity, there are an untold number of people with access that is inadequate. Electricity is often limited to meeting the basic needs of households, and those basic needs tend to be in lighting and entertainment. Electricity for productive activities or for welfare enhancing community structures (e.g. schools or clinics) tends to lag behind basic household electrification or sometimes is completely neglected in rural electrification objectives, making integration of electrification into larger development goals difficult. Finally, electricity is often supplied by a wide variety of actors outside the traditional utility system, sometimes using technologies that are considered undesirable from an environmental perspective (e.g. diesel engines). Without subsidies, the high cost of serving rural populations, either through the grid or through renewable and non-renewable off-grid options, results in high prices and consumption that is constrained by the ability and willingness to pay of the rural consumer.

The next section of this working paper discusses the role that electricity plays in the development process and its importance in rural areas. This is followed by a discussion in Section 3 of the contest between centralized and distributed solutions to the rural electrification problem and how their relative competitiveness is affected by the institutional context as well as inherent technical and economic characteristics. Section 4 outlines the previous experience and research on distributed generation for rural electrification and then summarizes our own research on which business models for distributed rural electrification have proven most successful. The paper concludes in the fifth and final section with some broader lessons that can be extracted from the work.

2. Importance of Rural Electricity Supply

Access to electricity is considered a basic indicator of rural development, potentially contributing to income generation, improved educational and health outcomes, increased gender equality and a host of other social welfare improvements. (Goldemberg and Johansson 1995; World Bank 1996; WEC 1999; International Energy Agency 2004; Cabraal, Barnes et al. 2005) These improvements come from both the direct benefits of electrification (e.g. higher productivity of agricultural producers due to use of electric motors and pumps) and from the indirect effects that come from access (e.g. improved knowledge of weather conditions and crop prices due to access to television and radio). However, the role that energy plays in development, either directly or in creating the enabling conditions for other development interventions to succeed, is still arguably underappreciated. For example, when the Millenium Development Goals were created as a way to highlight key development needs, energy indicators were not included explicitly. However, electrification will be necessary to meet many of the goals laid out in the MDGs, whether it is through refrigeration of vaccines (MDG4: Reduce Child Mortality) or lighting to improve evening study conditions (MDG2: Achieve Universal Primary Education). This led to a follow-on effort to delineate how energy contributes to the MDGs, but this was an ex-post effort rather than being integrated into the MDG development process. (Modi, McDade et al. 2006)

Significant efforts have been made globally to provide electricity to both urban and rural populations. The global electrification rate went from 49% in 1970 to 73% in 2000, associated with 2.3 billion people gaining access during that time. (International Energy

Agency 2002) This represents a massive effort on the part of governments, international donor agencies, utilities and other actors. Much of this success can be attributed to the phenomenal success of China's rural electrification programs, particularly in the use of small hydro power. China went from having hundreds of millions without electricity in 1980 to less than 30 million today. However, the gap between electricity needs and current levels of electrification remains large. Currently 1.6 billion people worldwide are unelectrified, primarily in rural areas. Even that figure, large as it is, leaves out the electricity necessary to contribute to broader patterns of rural development, since it only counts households and not income generating activities.

There are large regional disparities in electricity access, as shown in Table 1. South Asia and Sub-Saharan Africa have the lowest electrification rates while North Africa and the Middle East have reached greater than 90% total electrification. However, the rural/urban disparity within regions shows where the majority of those 1.6 billion people are located. Only in East Asia and North Africa are the rural electrification rates above 80%. The differences in Sub-Saharan Africa (8.4% rural versus 51.5% urban electrification), South Asia (32.5% rural vs. 69.4% urban) and Latin America (61.4% rural vs. 97.7% urban) are particularly striking. The rural electrification problem is challenging enough on technical grounds alone. The populations are often remote, sometimes in difficult terrain, and often widely dispersed. This makes the costs of grid extension high and is a major reason that distributed power generation alternatives are key to solving the problem.

Table 1: Urban, Rural and Total Electrification Rates by Region, 2002

Region	Population	Urban Population	Population Without Electricity	Population With Electricity	Electrification Rate	Urban Electrification Rate	**Rural Electrification Rate**
	million	million	million	million	%	%	**%**
North Africa	143	74	9	134	93.6	98.8	**87.9**
Sub-Saharan Africa	688	242	526	162	23.6	51.5	**8.4**
Africa	**831**	**316**	**535**	**295**	**35.5**	**62.4**	**19.0**
China and East Asia	1,860	725	221	1,639	88.1	96.0	**83.1**
South Asia	1,396	390	798	598	42.8	69.4	**32.5**
Developing Asia	**3,255**	**1,115**	**1,019**	**2,236**	**68.7**	**86.7**	**59.3**
Latin America	428	327	46	382	89.2	97.7	**61.4**
Middle East	173	114	14	158	91.8	99.1	**77.6**
All developing countries	**4,687**	**1,872**	**1,615**	**3,072**	**65.5**	**85.3**	**52.4**
Transition economies and OECD	**1,492**	**1,085**	**7**	**1,484**	**99.5**	**100.0**	**98.2**
World	**6,179**	**2,956**	**1,623**	**4,556**	**73.7**	**90.7**	**58.2**

Source: (International Energy Agency 2004)

For the majority of people without access to electricity from the grid, the most basic benefit of electrification, lighting, is provided by costly fuels like kerosene and candles, or indirectly via labor intensive traditional fuels such as wood or other biomass burned during cooking. These fuel sources can also have negative externalities, adversely affecting safety and indoor air quality. The use of televisions and radios or home appliances is either precluded or limited to low consumption appliances that use expensive disposable batteries. In rare cases, electricity will replace traditional biomass for cooking purposes. However, the high energy requirements for cooking and the cost of electricity usually result in either continued use of biomass or a transition to a more suitable modern energy source such as LPG.

Lack of electricity also affects the services provided by community buildings and local businesses. As with rural households, lighting for community buildings and for streets is seen as an important first use for electricity in rural communities. Another important use is refrigeration of medicines in local clinics. Access to electricity can also improve the productivity of local businesses – both in providing light to allow work to continue after dark, and in enabling the use of labor saving appliances and machinery.

Electrification can indeed enhance social welfare through augmented incomes, improved community health, and increased educational attainment. However, it should be noted that electrification, whether through the grid or by distributed means, cannot achieve these goals by itself and requires the presence of other enabling conditions. (Barnes and Floor 1996; Martinot, Chaurey et al. 2002; Elias and Victor 2005) Without trained health and education professionals, there are limited gains that can be made by providing electricity to clinics and schools. Electrification of agricultural production can only increase incomes if the transportation system allows farmers to deliver their product to market in reasonable time.

3. The Contest to Electrify

Providing electricity in rural areas, particularly in developing economies, is challenging for three primary reasons. First, rural populations are usually dispersed and have low consumption, resulting in high capital costs spread over low returns. Second, the ability to pay of many rural populations is low, making centralized grid expansion unable to recover costs. Third, generation shortages, long rural feeder lines and poor maintenance often result in low quality power being delivered erratically to rural consumers.

Provision of electricity service worldwide has predominantly been through a large centralized system of power generation, transmission, and distribution. This system has developed over time due to the economies of scale provided by ever larger generating plants and the (perceived or real) natural monopoly characteristics of transmission and distribution. Accompanying the technical centralization of the power system has been an institutional centralization, with control over the systems resting with a small number of organizations (both governmental and private). Similarly, the regulation of these systems became centralized. Regulation has been limited to national or state level organizations or is implicit within the centralized utility itself. Even major efforts to restructure have mainly kept the technological, and much of the institutional, centralization of the system intact. (Haugland, Bergesen et al. 1998; MacKerron and Pearson 2000; Victor and Heller 2006)

In many cases, this system has functioned relatively well. However, the economics of grid extension rely on spreading high costs over a maximized density of customers in a given region and a certain level of consumption. Ideally, those customers would all have the ability to demand and pay for electricity at the levels necessary to recoup costs. In reality, only a few or sometimes none of the customers in rural areas will be willing or able to pay the full costs of grid extension. However, universal electrification goals mean that grid extension will usually target all rural households, regardless of their demand level, willingness to pay or ability to pay. Even if it made economic or technical sense, it would be politically difficult for a centralized entity, often a state owned enterprise, to allow for differential electricity access within a small geographic area. As noted by Foley, this creates a "conflict of objectives" for utilities between financial performance and universal access and means that rural electrification is both a low priority and possibly a losing proposition. (Foley 1992b)

Furthermore, centralized utilities in many countries simply do not have the managerial and financial resources to meet all rural electricity needs. Even in those areas where the grid does reach, electricity is often sporadic and of low quality, making it difficult to use for productive purposes or for vital tasks like vaccine refrigeration. For example, in India, voltage drops across rural feeders extend well beyond the limits considered acceptable by electrical engineers. Poor quality power can damage electrical equipment and result in more frequent loss of service. (Tongia 2007) Even if these barriers could be overcome, it is not technologically and financially feasible or even desirable to use the grid to reach all rural customers.

Despite these challenges, with a few notable exceptions, universal access programs have generally been implemented through the centralized utility system.[1] Of course, centralized utilities do have an important role to play in rural electrification. For many rural customers, the grid is the lowest cost option available and will thus be the dominant mode of electrification. However, the high costs of extending grids to rural areas, the lower ability of rural customers to pay for electricity service, and the financial instability of many utilities in these regions mean that some rural areas will not gain access to the grid in the foreseeable future. There is nothing, however, in the theoretical goal of universal electricity access that requires it to be met through centralized utilities. However, a combination of regulations, historical path dependence and deep-seated norms have led to the predominant use of the centralized utility system for rural electrification. Utility responsibility has, at times, even been extended to cases where distributed generation technologies have been selected. Brazil provides the perfect example, with regulations dictating exclusive service territories for its utilities (thereby effectively eliminating competition) and allowing those utilities to meet their universal

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[1] China has supported local utilities and renewables markets to meet its impressive service goals. Other countries, such as the Philippines, have relied on cooperatives to meet needs in some areas.

service obligations through a combination of grid extension and distributed generation sources.

Given that utilities are often not interested in rural electrification due to the poor returns and technical difficulties, there are a number of possible options for removing rural electrification responsibility from the main utility.[2] (Foley 1992a; Foley 1992b) Traditionally, these have included establishing an autonomous division within the utility, creating a separate rural electrification agency, and devolving more responsibility to local organizations such as cooperatives and local communities. (Foley 1992b) As this study shows, private and semi-private options have the potential to play a large role. Each option, including maintaining responsibility within the main utility, has implications for the use of distributed power generation. Not only may the approach chosen affect technological priorities and biases, but it may also affect access to resources and the various other institutional support mechanisms that are important for successful rural electrification.

Over the past few decades a number of small-scale, distributed power generation (DG) technologies that are suitable for rural areas have been developed or improved.[3] Distributed power generation is attractive for rural electrification for a number of reasons. For example, the low population densities and low consumption of rural customers are well matched to the scalability and autonomous operation possibilities of distributed power. Grid extension is expensive in rural areas and generally means trying to provide electricity that is available (in theory, at least) 100% of the time and at levels that may be much higher than typical rural consumption levels. In addition, rural customers will have an even greater imbalance than urban ones between their minimum and maximum (peak) loads. Many rural customers do not have refrigerators or other appliances requiring constant power and will use their electricity in the evening hours only for lighting, entertainment and, in some cases, cooking. While rural consumption is relatively low, its additive effect right at the time of peak power demand on the system can force the utility to run more expensive generating units more often or even to invest in new peaking generation. This can significantly raise the cost of supplying rural customers. (Howells, Victor et al. 2006) Distributed power is able to provide power at levels and at times that are well-matched to rural customers. Finally, the possible set of organizational models is much larger with distributed power, including the possibility of decentralized local organizations (either private or public). This can alleviate some of the high transaction costs inherent in a centralized organization like a utility administering a customer base that is large and geographically diffuse. (Hansen and Bower 2003; Chaurey, Ranganathan et al. 2004; Banerjee 2006)

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[2] Foley notes other institutional problems with utilities that are rural electrifiers, including the low prestige garnered among engineers for working on low-voltage systems, administration problems due to a diffuse customer base and their centralized nature which favors a small number of large projects. Foley, G. (1992b). "Rural Electrification: The institutional dimension." Utilities Policy **2**(4): 283-289.

[3] The definition of distributed generation is complicated and often context dependent. For the purposes of this book, electric power generation is considered to be "distributed" when it is produced locally and primarily consumed locally. See the Appendix A for a more detailed discussion.

There are a number of ways that distributed power can provide rural electricity service. In addition to the various technologies that can be used (both fossil fuel based and renewable), there are several possible modes of installation and operation. Electricity generation technologies can be directly installed in homes, shops, factories and community buildings. Alternatively, service can be provided to end-users through a small grid system. For example, a DG owner could provide electricity to immediate neighbors, to a village mini-grid, or even to a multi-village local grid. A third option is to use the distributed power generation source for local battery charging. These batteries are often car batteries that can be used in households to power lights and small appliances.

Installed systems range widely in size and usage depending on technology choice, installation mode, and the institutional model chosen (see below). Some provide only enough power for basic needs, while others allow for higher consumption appliances like refrigerators, blenders, and sewing machines.

While DG technologies may be the best (or only) option in many circumstances, it must be recognized that there are also disadvantages to their use. Many of these technologies are more expensive than grid-generated electricity on a per kW basis and would not be competitive if the grid was eventually extended (or if existing grids were strengthened to provide reliable power). (ESMAP 2000; ESMAP 2005) When combustion engines are used, there are limited pollution controls (if any), contributing to both local and global environmental problems. Depending on the institutional model that resulted in the DG installation, there may also be little or no support for operations and maintenance, leading to shortened technology lifetimes. (Nieuwenhout, van Dijk et al. 2001; Martinot, Chaurey et al. 2002)

Despite their inherent advantages in some contexts, the diffusion of these technologies and the supply of electricity in rural areas generally remains far below the technological and economic potential due to various institutional factors that existing studies of rural electrification tend to ignore. A systematic assessment of those institutional factors is one focus of this study.

The scope for distributed power generation on the one hand is a function of fundamental technical factors related to topography, population density, and the like that make centralized systems ill-suited to serving some rural populations. On the other hand, it is also a function of managerial and institutional factors related to the operation of the utility and its ability to expand, willingness to pay, investment incentive, and subsidies that change the relative economics of centralized versus distributed systems. The zone where centralized systems and distributed systems could both meet demand is therefore not fixed. In any system there will be a contestable area where both distributed and centralized solutions are competitive with one another for service provision. This can be seen in
Figure **3**.

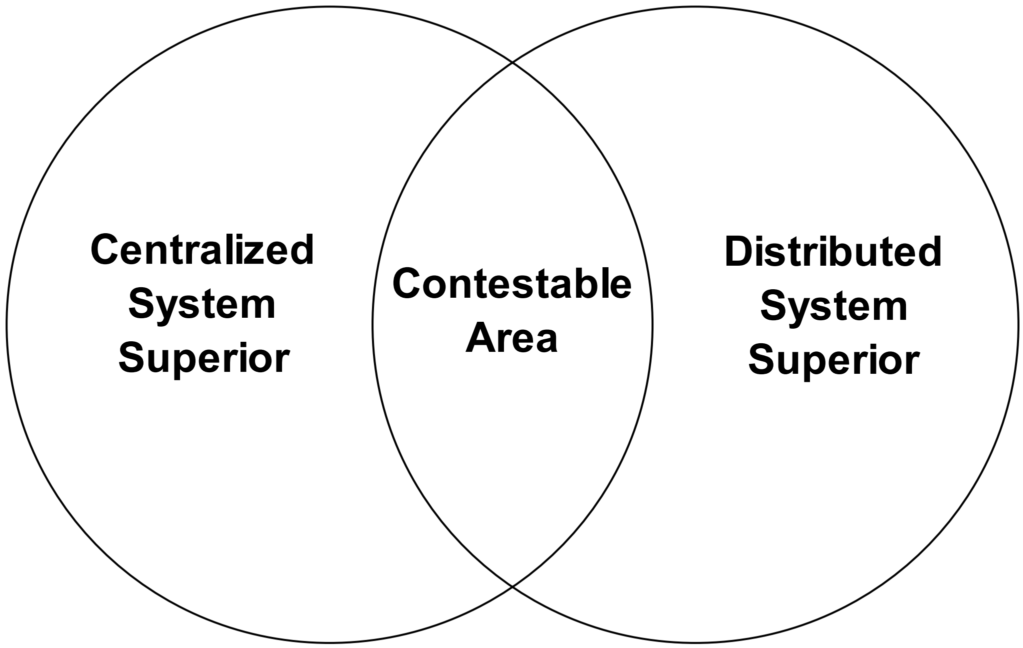

Figure 3: The Scope for Centralized and Distributed Systems

This contestable area is not fixed and can move in either direction, expanding or shrinking the space for distributed or centralized solutions. Technological changes that reduce costs will increase the area where DG is competitive. Alternatively, changes in the utility system that make it able to expand further into rural areas – for example, the provision of subsidies to the utility – will cause the contestable area to impinge further into the domain of distributed generation. Conversely, limitations on grid extension into rural areas due to poor finances, mismanagement or simple neglect of these areas will effectively increase the space in which distributed systems are competitive.

4. This Study: Distributed Rural Electrification

While both centralized and distributed technologies are needed to tackle the rural electrification problem, this study focuses only on the options related to distributed electrification. Given the wide diversity of distributed electrification options that are available, a better understanding of how distributed electrification has been implemented in the past is necessary in order to guide future policy and investment decisions.

4.1 Prior Experience with Distributed Generation

The use of distributed power sources for rural electrification is not new. In a limited way, distributed power generation has been used for decades. In the 1970s, a large effort was made by international donors to provide off-grid technologies for rural electrification as well as to expand grids and solve other rural energy problems; that work has continued in one way or another to the present. As for the success of distributed power generation in providing rural electricity, the historical record is mixed at best. (Barnett 1990; Martinot

2001; Martinot, Chaurey et al. 2002) Larger scale successes include Kenya's photovoltaic market and China's small hydropower systems. (Acker and Kammen 1996; Duke, Jacobson et al. 2002; Pan, Peng et al. Working Draft 2006)

There are more numerous examples of individually successful installations across a wide range of technologies and organizational models.[4] The use of diesel generators by Brazilian utilities, particularly in the Amazon, demonstrates the success of both that technology and a centralized mode of implementation. However, while diesel generators are widely used, their operation in remote areas by centralized utilities is not a model that has been widely replicated, and even in Brazil, their use by the utilities to power remote mini-grids remains a measure of last resort. Other localized success stories can be found worldwide. For example, a South African solar home system dissemination project had only limited success in installations and little success in its larger institutional goals. However, those systems that were installed did work and provide their customers with electricity as designed. (Green, Wilson et al. 2001) This is typical of many success stories, in which a relatively small number of units are installed successfully, but once the project is over, there is no further dissemination.

However, there have been very few examples of broader success in establishing viable and self-sustaining distributed generation models that expanded beyond their initial, limited scope. One example of success is the use of small hydro stations in China, which now total more than 42,000 units with generating capacity reaching 28 GW (units less than 50 MW). (Tong 2004) Another often-cited success story is the photovoltaic market in Kenya, which originally started as a donor program and spawned a viable private industry. (Acker and Kammen 1996) Similarly, there are PV cash markets in a number of other countries, some selling tens of thousands of units per year. The literature on distributed rural electrification tends to focus on the success of renewables, particularly wind and photovoltaics. However, diesel generators have also played a large role in many places and should be considered a successful technology from an electrification point of view. (World Bank 1996; Enterprise Development Cambodia 2001; ESMAP 2005)

There have also been numerous failures in using distributed power generation in rural areas. These failures occurred at the installation or project level as well as in translating individual small successes into larger ventures. In some cases, particularly in the 1970s, failure was simply due to problems with the technology itself. Arguably, technical failure in the early stages is not an inherent problem and provides opportunity for learning. However, if a distinction is not made between experiments and programs for wide-scale diffusion, such technical failures can cause serious problems for further diffusion efforts. (Barnett 1990) In other cases, the technology itself was successful, but the institutional mechanisms were not put in place to sustain the system over a longer

[4] Here we use the rather limited definition of "success" to mean that the installation meets the expectations of the parties involved in terms of cost and service, and the technology remained operational for a reasonable amount of time. A more nuanced and precise definition of success is used to assess projects in the actual analysis.

period of time. Early solar home system programs in which it was assumed that the technology was essentially maintenance free are one example.

There are also cases in which projects move beyond the technology demonstration phase and are successful in providing electricity within a given area. However, there has been a general failure to capitalize on that success and translate it into a replicable model for rural electrification. The earlier focus on technology demonstration projects meant that even when the technology worked, there was no effort to create and demonstrate a viable model for further diffusion or the necessary structure for maintenance, financing and continued operation. (Martinot, Chaurey et al. 2002) A recent example is the set of solar home system programs funded by the Global Environment Facility (GEF). While projects in individual countries have been successful in providing solar home systems to thousands of households, they have not become self-sustaining and replicable, despite some resources being put towards institutional strengthening. Each additional set of installations requires international donor funding and coordination, and the scale of installations remains small compared to the need.

While it is necessary to apply technologies that are appropriate for the context, it is the institutional factors which determine whether a particular implementation is successful and whether it is replicable and sustainable over the long term. In 1992, Foley noted the tendency to focus on the technology (often emphasizing the suitability of renewables) while ignoring the important questions regarding institutional arrangements for installing, operating and maintaining the system. (Foley 1992a)

While there has been an increasing emphasis on institutional factors, there continues to exist a technology focus in rural electrification projects, with insufficient attention to institutions and particular biases in favor of renewable technologies. For example, government programs for provision of renewable energy systems continue to create obstacles to the development of sustainable technology markets for long-term diffusion. As noted recently, there is still a tendency among donors to provide large capital cost subsidies or even to donate equipment, despite the history of such programs being unsustainable and harming the creation of viable markets. (Martinot, Chaurey et al. 2002)

Zimbabwe is a perfect example of this phenomenon. Through an international donor program dozens of local enterprises for photovoltaic systems were founded in the mid-1990s. However, due to their dependence on the donor funds and lack of provision for a transition to a more market-oriented approach or sustainable support structure, the enterprises all failed once the donor program ended. This not only meant that new systems were no longer being sold, but also that service and maintenance of existing installations disappeared. (Martinot, Chaurey et al. 2002)

These problems have been exacerbated by issues of technological lock-in, in which choices made now restrict the range of choices possible in the future. Such path dependencies are a familiar problem in technology diffusion and can often occur for technical reasons (economies of scale in production, long capital lifetimes, etc.). However, lock-in can also occur for institutional reasons as lessons fail to be learned and donors and governments find it difficult to adapt. As Barnett notes, "the process of technology diffusion often requires such a strong commitment to a particular device that the leadership is reluctant to admit that there are problems." (Barnett 1990)

4.2 The State of Research on Distributed Electrification

Unfortunately, the existing literature on successes and failures in distributed electrification is only partially helpful as a guide for general policy-making. We can divide the literature into three broad categories.

First are the technology specific analyses: These are the numerous reports, articles and books that focus on the opportunities (and sometimes the challenges) of using a particular technology to meet rural electricity needs. Almost invariably the technologies examined are renewable energy. In some cases, it is the broad category of renewables (Allderdice and Rogers 2000), while in others it is a specific renewable energy source or technology, such as biomass or photovoltaic systems. (van Campen, Guidi et al. 2000; Li, Xing et al. 2001)

Second are the micro-level project reports. These report on a particular activity, usually within a few years after implementation. This category includes numerous village level projects ("technology X was installed in village Y and worked/failed"), as well as reports on broader programs covering a larger region. (Green, Wilson et al. 2001; Santos and Zilles 2001; Stroup 2005) These are useful for understanding some of the micro-level factors that contributed to that particular success or failure (though generally it is only successes that are reported). However, a broader understanding is only possible by aggregating such individual project experience. As with the first category, Technology X is almost always a renewable energy technology. Non renewable sources are generally included only as a baseline against which to contrast the renewable technology.

Third are the business success stories. This literature is a start towards filling a major gap in the literature, namely the need to understand why business models for distributed electrification succeed or fail. However, far too often this category overlaps with the first and what is reported is relevant only for a specific technology, such as photovoltaics. More importantly, the studies in this category tend to only focus on successes, often reporting on "best practices" for a technology or type of project. (ESMAP 2001)

What all these studies have in common is their ad-hoc approach in studying a limited set of previous projects to determine what did and did not work for providing electricity to rural uses. (Hurst 1990; Erickson and Chapman 1995; Allderdice and Rogers 2000; Martinot, Chaurey et al. 2002; Etcheverry 2003; Fishbein 2003) While these studies provide some useful information, they can suffer from a case selection bias since their scope is limited in geography (one country, region or even village), technology (only PV or only wind or only renewables), or end-use (household electrification, productive uses). Often they also suffer a bias in selecting "success" cases while ignoring the failures. As will be discussed in the next section, it is difficult to avoid some of these pitfalls and no study could examine every distributed rural electrification effort undertaken. However, this study attempts to avoid systematic biases by not selecting or rejecting cases a priori on the basis of technology, end-use or outcome.

This study also fills a gap in previous work by addressing many of the institutional issues that are known to impact outcomes in rural electrification through a carefully constructed case-based analysis. Many of the individual case studies discussed above do include discussion of institutional issues such as regulations, electrification policies, access to financing, etc. However, for the same reasons as above, it is difficult to generalize because of their scope. On the other hand, there is prior literature that covers many of the institutional issues addressed in this research. The findings in this literature have been generalized from the secondary literature and from the authors' admittedly extensive experience. (Barnett 1990; Foley 1992b; Barnes and Floor 1996; Radulovic 2005; Reiche, Tenenbaum et al. 2006) One exception is recent work by Barnes that looks at rural electrification programs across a number of countries. (Barnes 2007) However, while providing valuable information and comparative analysis, the analysis is not focused on the role of distributed electrification options as in this work.

4.3 Research Methods Used in This Study

There are many countries in which some form of distributed electrification has been attempted. From this universe of countries, we have chosen to focus on three: Brazil, Cambodia and China. These three countries have very different institutional environments (particularly in their regulatory and policy regimes) and different business models for distributed rural electrification — in fact multiple business models within each country. In all, there are roughly 20 different models across the three countries. We exploit the variation between the models in each country and the variation between the institutional contexts of the three countries in order to examine factors important for success and failure.

Based upon a review of the literature, discussed above, four independent variables were chosen to capture the important elements of the **business models used for distributed rural electrification**: Organizational Form, Technology Choice, Target Customers and Financial Structure. The Organizational Form variable looks at whether the primary organization responsible is centralized or decentralized and whether it is governmental or non-governmental. The Technology Choice variable categorizes business models according to whether they use renewable versus non-renewable energy technologies and whether the system is a mini-grid or individual installations. The Target Customers variable is used to examine how models that electrify households perform differently than those that electrify productive activities or community structures. The Financial Structure variable provides information on how capital is obtained and how operational costs are covered.

Table 2 shows the variation in the independent variables in each country as well as the number of cases studied in each country. The cases are divided into a dominant model and alternative models. The dominant model in each country is the one that is most widely used and it differs between the countries due to local conditions (as discussed below in the section on results). Six cases were studied in detail for each country. In addition, there were other cases for which detailed information could not be obtained. Information from these cases was used, as appropriate, to draw larger conclusions about distributed electrification efforts in the three countries.

Table 2: Independent Variable Variation for the Different Models in Each Country

	Brazil (6 Cases)	**Cambodia (6 Cases)**	**China (6 Cases)**
Organizational Form	Dominant: Centralized utilities Alternative: Coops, NGOs, small entrepreneurs	Dominant: Small entrepreneurs Alternative: Government and international donor projects	Dominant: Local governmental and private, some hybrid/dual Alternative: Decentralized private tech dealers, centralized governmental
Technology Choice	Dominant: Diesel Alternative: Biomass, PV	Dominant: Diesel Alternative: Biomass, PV, small hydro	Dominant: Small hydropower Alternative: Small thermal, PV, wind
Target Customer Base	Dominant: Households Alternative: Varied	Dominant: Village electrification Alternative: Households	Dominant: Village and higher electrification Alternative: Individual systems
Financial Structure	Dominant: Subsidized connections and low income consumers Alternative: Market prices with cost recovery	Dominant: Market prices Alternative: Highly subsidized	Dominant: Cost-plus regulated prices Alternative: Subsidized, cash markets

Since it is not feasible to gather data on every single distributed generation initiative or project ever installed in the country, there are three potential sources of bias:

1. Lack of information on older projects, particularly those that have failed. In some cases, it was possible to obtain limited information on these efforts through interviews. In those instances, they were not treated as full cases for the study, but this information was used to help support general conclusions drawn from the cases.

2. Lack of information regarding smaller and less public efforts, such as independent diesel generators in the Amazon. Similar efforts to fill in some information about these distributed models were pursued as with the first case.
3. In some cases, detailed information came only from the parties responsible for a particular electrification model. This could lead to potential bias in some of the results, though in all of these cases, there were both negative and positive assessments provided, indicating that there was no systematic bias towards presenting the information in an overly positive light.

While the variables described above cover the important aspects of the business models themselves, they do not include some key information for understanding outcomes. Two categories of data were added to the study in order to capture institutional factors and physical context dependent factors.

Data relevant to the institutional context were added as control variables. The presence of subsidies for either capital costs or operating costs makes a large difference regarding the viability of a distributed electrification model. It improves the finances of the model (as long as the subsidy is sustainable) and makes other models less competitive. The level of capital and operating subsidies were given scores on a low-medium-high scale. In addition to subsidies, there was a need to categorize the policy and regulatory regimes more generally in order to capture the impact of the institutional context on the distributed electrification models. The policy and regulatory regimes were characterized as favorable, neutral or unfavorable.

Data relevant to the physical context were also included as control variables. We are particularly interested in the remoteness and the density of the population. Remoteness bears directly on the potential viability of grid extension and on the potential difficulties related to project management and operations and maintenance. The density of the population is relevant for the relative viability of the grid, micro-grids and individual installations.

Each business model was assessed based on three main dependent variables: Changes in Electricity Service, Sustainability and Replicability. Changes in Electricity Service primarily measures the increase in electricity access as a result of the business model. Secondary measurements are of the sufficiency and quality of the electricity supplied. Sustainability is primarily a measure of the ability of the model to cover its costs and provide functioning systems over a long period of time. Replicability is a measure of whether the particular characteristics of the business model can be used to provide electricity services to new customers. Together these three dependent variables measure the short and long-term impact of a business model on the electricity supply situation.

Data for the study were collected through a combination of secondary sources, site visits and interviews. In particular, officials within relevant ministries and regulatory authorities were interviewed as well as donors, academics and representatives of non-profit organizations. This provided valuable information about the history of electrification efforts and the institutional context for rural electrification. Interviews and site visits were used where possible to collect information about specific distributed electrification efforts and to supplement information from secondary sources. The dependent variables used to assess the performance of the business model for distributed rural electrification were scored on a High-Medium-Low scale according to a set of pre-specified criteria shown in Table 3.

For example, the diffusion of solar home systems by the centralized utility in Brazil, COELBA, is given high scores for access, sustainability and replicability. This program, currently being implemented, will eventually diffuse roughly 30,000 solar home systems by the 2008 deadline and is the primary way in which COELBA meets the electricity needs of its customers it cannot reach by the grid, accounting for its high score on the Access variable. Due to the ability of COELBA to cross-subsidize its service and its obligations under the regulatory system, this model is given a high score on the sustainability parameter since the utility can reasonably be expected to continue its service. Replication of the solar home system program beyond the initial phase with expectations of full service to all households is evidence that replication has been widespread, and so Replicability is also scored as high. It should be noted that, in this example, the utility is able to take advantage of favorable policy and regulatory regimes and subsidies for capital (through government grants) and operating expenses (through cross-subsidies). This is reflected in the control variables, and it is therefore possible to see that this model's outcomes rely upon those favorable regimes and subsidies.

Table 3: Criteria Used to Score Dependent Variables

	High	Medium	Low
Electricity Access	It is the dominant mode of service delivery in that area and has extended beyond the pilot phase.	It has extended beyond the pilot phase but is not the dominant mode of service delivery.	Occurs in a handful of communities.
Sufficiency	Enough power is available to meet general demands and there is little or no exit from the system	Enough power is available to meet general demands but the system is run at full capacity and/or some portion of customers exit the system	Enough power is available only to meet basic demands (e.g. lighting and one low-consumption appliance in the case of households) even if customers require more.
Quality	Outages approach those of the main grid utilities and power fluctuations and line voltage drops are not a major issue.	Outages are higher than the main grid and power quality is lower but long outages (> 1-2 days) and damage to equipment are rare.	Frequent longer outages, high voltage drops over mini-grid lines and damage to equipment are common.
Sustainability[5]	Continued performance up to the expected lifetime of the technology is demonstrated or reasonably expected without major changes to the basic model.	Continued performance up to half the expected lifetime of the technology is demonstrated or reasonably expected without major changes to the basic model.	Failure to continue to deliver electricity beyond five years or major changes required to the model in order to continue electricity beyond five years.
Replicability	Only marginal changes required to either the financial structure or institutional arrangements in order to replicate and evidence of actual replication.	Some changes required but relatively adaptable.	Significant changes would have to be made to the business model in order for it to be replicated. This can be the result of failure of the original model, reliance on specific financial resources that may not be widely available or reliance on institutional arrangements that are unique and difficult to reproduce.

[5] The Sustainability metric also includes a score of Very Low to account for those cases in which the business model fails almost immediately (i.e. within two years after installation). These are generally cases where technology failure occurs quickly and the business model is not able to provide for service.

4.4 Case Study Results

Brazil's distributed rural electrification experience has been dominated by highly centralized efforts. This includes government ministry programs for electrifying community buildings and utility run programs for household electrification. The utilities in Brazil are required to serve all customers in their monopoly service territory, whether through grid extension or through the installation of distributed systems and charge rates that are below cost of service. The historically slow pace of rural electrification, however, has led to a number of models outside the utility and government systems, including solar home system leasing schemes, cooperatives, private diesel micro-grids and renewable energy based systems for agricultural producers. The recent push for universal electrification by the government (through the utilities), which has included high capital costs subsidies for the utilities, does pose a threat to these other models. Summary information about each of the cases studied in Brazil is provided in Appendix B.

The Cambodian situation differs remarkably from the Brazilian one. The Cambodian government is not heavily involved as of yet in rural electrification. Official electrification rates remain low (15%) and the state utility only serves the largest population centers. Despite a low official rate of electrification, the number of households with access to at least a minimal amount of electricity (e.g. enough to run a lightbulb and maybe a small television) is extremely high (50% of the households have a television and an estimated 85%-90% have a lightbulb). Their electricity primarily comes from rural electricity entrepreneurs that run diesel based micro-grids, battery charging stations or a combination of the two. Prices are high to cover costs, but consumption is low and overall monthly expenditures are kept low. Some of the entrepreneurs are licensed by the government and included in the official 15% statistic, but most are unlicensed operators. Cambodia also has a small solar home system market that serves slightly wealthier consumers and has had some donor projects. Appendix C provides information on each of the main cases examined in Cambodia for the study.

China has had stunning success in rural electrification since the early eighties. From a starting point of hundreds of millions of people without electricity, the electrification rate is now nearly 100%. Small hydropower has played a major role and currently provides power for over 300 million rural Chinese (more if one includes systems with only partial hydropower supply). The government was heavily involved, but often in a supporting role through low interest loans and guarantees and technology programs. Technology development and support has also been key to China's success in creating rural markets for solar home systems and small wind and wind/pv hybrid systems. Recently the Chinese government instituted the Township Electrification Program, which was a much more top-down centralized effort. While successful in the short term, the future of the installed systems is in doubt due to lack of local involvement and planning for post-installation operations. Appendix D provides summary information on each of the cases examined in China for the study.

This study of distributed rural electrification in Brazil, Cambodia and China shows that a wide diversity of distributed rural electrification models exist and can be successful in providing electricity to remote rural populations. However, while their individual successes and failures are not always due to the same set of factors, there are some common themes and clear trends that emerge. The various models examined in this study can be roughly divided into four broad categories:

Government/Donor Model: These models, such as the Chinese Township Electrification Program or the Brazilian Programa de Desenvolvimento Energético de Estados e Municipios (PRODEEM), are directed and funded centrally. They generally aim to provide the bare minimum electricity for households or community structures. These models are characterized by high subsidies for capital costs and low tariffs. Not only do these tariffs not cover capital costs, they are often insufficient to cover operating costs. They are only able to be sustainable when the operating subsidies are sufficient. The result is high increases in access, but mixed results on sustainability and replicability. Those that are sustainable and replicable are heavily dependent on ongoing financial support. In effect, there are two sub-models, a "**Technology Dump**" model in which large-scale diffusion programs are not supported with sustainable institutions and/or subsidies and a "**Sustainably Centralized**" model in which governments or donors create viable on-going mechanisms for sustainability.

Utility Model: This model is observed in Brazil, where centralized utilities are implementing distributed generation technologies to meet their regulatory obligations. As with the government/donor model, the utility model is dependent on high capital subsidies and focused on meeting basic needs in rural areas. Unlike the government/donor model, operating costs are generally covered through a combination of tariffs and cross-subsidies. However, since the customer base for rural distributed generation is lower income, the tariffs are kept artificially low, making the utility model also dependent upon the subsidies to be sustainable and replicable.

Mixed Model: In the mixed model, implemented particularly in China, the government acts as a strong supporter of distributed generation technologies without organizing and implementing programs centrally. China's support for its renewables industry, such as the PV market and the use of household wind power in Inner Mongolia, are prime examples of this model. The government provides incentives and technical support for technology development. This creates stronger markets while allowing for cost recovery and sustainability. The customers are either richer (since subsidies are more modest) or the technologies are sized small enough for poorer customers with limited consumption.

Decentralized Model: These are fully decentralized models in which local actors implement distributed generation technologies. The impact on access and improved electricity service varies greatly. In many cases, the impact of these models is limited due to lack of resources. However, with only an exception or two, sustainability and replicability are medium or high for the models examined. This is due, in part, to the ability of decentralized models to tailor their service to the customer mix and to the need for these models to recoup all or most of their costs due to their limited access to subsidies. There may be limited amounts of donor funding available, but unlike the donor model, the decision-making and implementation in the decentralized model is local. The decentralized models can be roughly divided into three categories: first, the well established and independent mini-grids running on fossil fuel (in all three countries) and small hydro-power (in China); second, the established models which serve niche markets such as renewables for productive activities (e.g. Brasil Sustentável – BRASUS in Brazil) or solar home system programs for richer customers (e.g. Khmer Solar); and third, the "new" models that employ either novel technologies or novel business models. These new models typically serve niche markets but have not been around long enough to have a significant impact and allow evaluation of sustainability or replicability.

Figure 4 through Figure 6 show how these different models score on electricity access and sustainability as a function of centralization and operating subsidies. Figure 4 compares the models on the criterion of access. Models using well-known technologies that can serve varied customer groups (e.g. the small hydro facilities in China or the diesel micro-grids in Cambodia) provide high rates of access. Decentralized models serving niche customers (e.g. the productive activities supplied by the BRASUS program in Brazil) have lower impacts on overall access to electricity, though their impact on the niche they serve can be quite high. Models using newer technologies (e.g. biomass gasification systems as in the Cambodian cooperative case) or financing schemes (e.g. leasing solar home systems, such as the IDEAAS case in Brazil) have been most limited so far in broadening access, primarily because they have not had an opportunity to be proven and replicated. However, their future potential could be quite high. The mixed models, based largely on supporting key technologies as is done in China, are mid-range in centralization and have been quite successful in improving access. Finally, there are the highly centralized models associated with government ministry, donor or utility efforts. When supported strongly by the central actor responsible, they can result in high levels of access. However, unlike the decentralized models which can and do serve a wide variety of customers, the centralized models tend to be focused on supplying only a basic level of household electrification. Technology dumps, in which technologies are installed in rural areas by a central actor without any ongoing support mechanism, can vary in their impacts on access. Some, such as the dissemination of PV systems in Brazil, have greatly increased short-term access. Others, such as the Japanese PV/Hydro project in Cambodia, have been more limited in their access impacts.

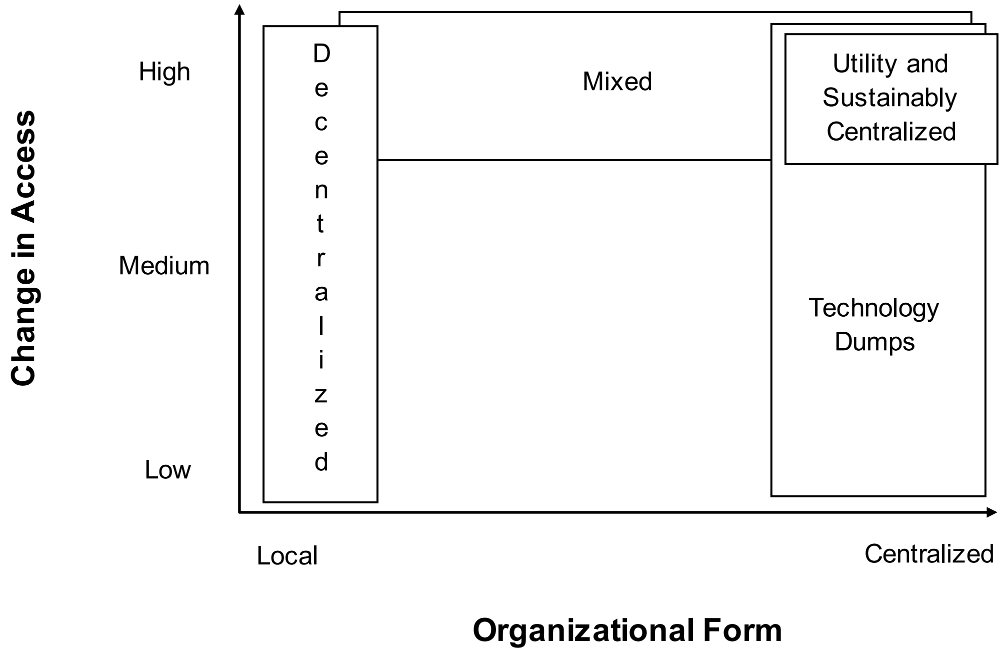

Figure 4: Centralization and Access for Distributed Rural Electrification

In terms of the sustainability of the model over the longer term, there is also a relationship with the degree of centralization of the model (Figure 5). While there is some variation among the decentralized models, many of them are quite sustainable. Mixed models, because they have been based on modest subsidies and cost-recovery, also score high on the sustainability metric. Meanwhile, the highly centralized models can be split into those that have some mechanisms for sustainability (such as strong cross-subsidy systems that function well, as in Brazil) and those in which inadequate provisions have been put in place for ongoing operations (i.e. the technology dumps).

The centralized models that can be considered sustainable are dependent upon continued commitments to high subsidies (either direct or indirect), as illustrated by Figure 6. In the case of the decentralized models, on the other hand, the absence of subsidies or a strong central actor from the start compels an emphasis on cost-recovery, even if this means high prices to consumers. The mixed models also generally have low (or zero) operating subsidies and a correspondingly high score on sustainability. There are some exceptions, for example some Chinese small hydropower projects, in which outside pressures have resulted in an inability to recover all costs but the model continues to operate due to support from local or centralized government institutions. Technology dumps, lacking organic local project development at the outset (including incentives for cost recovery) and provision for ongoing support, tend to fail quite rapidly as routine technical failures take equipment permanently out of operation.

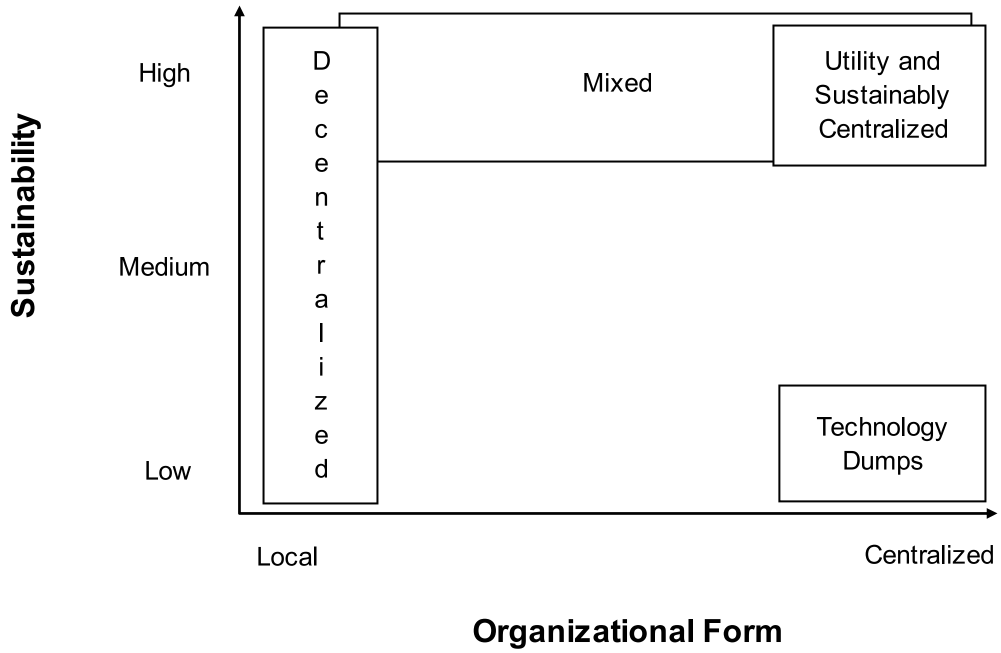

Figure 5: Centralization and Sustainability for Distributed Rural Electrification

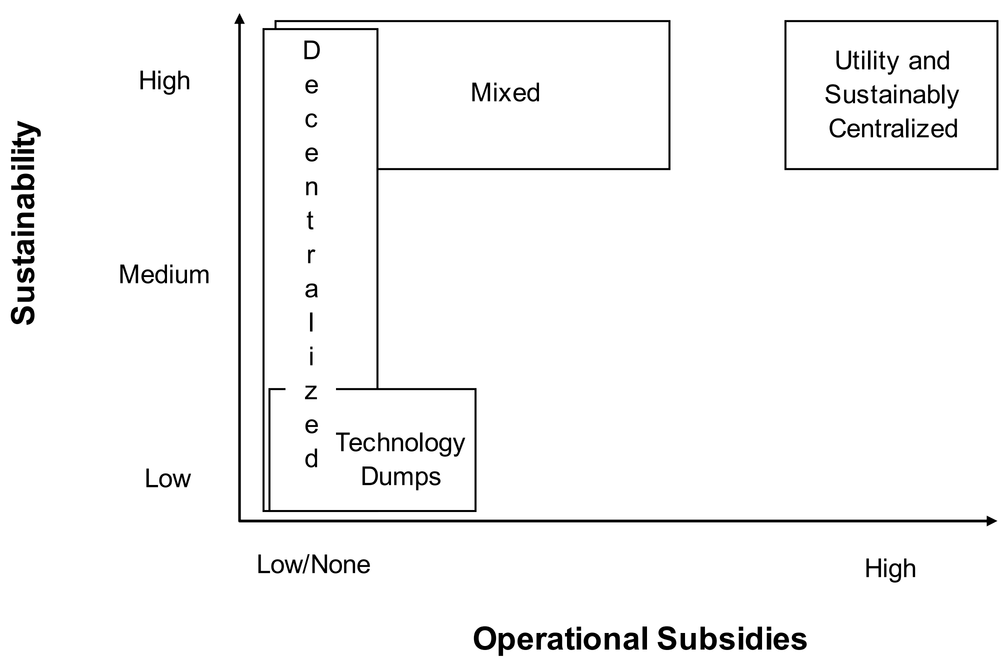

Figure 6: Operating Subsidies and Sustainability for Distributed Rural Electrification

An important conclusion of this study is that, in the absence of strong central support for rural electrification, alternative electrification models (e.g. private diesel operators, cooperatives, NGOs providing alternative energy) emerge to meet the needs of different consumers. Lacking financial support from the central government, successful models have had to meet requirements for financial sustainability in other ways. These independent efforts tend to serve a customer base exhibiting the following characteristics:

- Users include productive activities or other high energy consumers (e.g. coops and NGO projects in Brazil)
- Relatively wealthier (e.g. PV customers in Cambodia, wind and hybrid customers in China)[6]
- Willing to pay very high prices for very low consumption (e.g. unlicensed diesel genset customers in Cambodia)

Another point that emerges from the study is that all distributed technologies can be used successfully. There have been and continue to be situations in which technologies are inadequately piloted before wider distribution, are manufactured poorly or have other technological shortcomings. In the great majority of recent cases, however, technology implementations have failed more for institutional reasons than technical ones. In the absence of outside support to introduce renewable technologies, local technology choice will tend towards diesel generation (e.g. diesel mini-grids in Cambodia and Brazil, battery chargers in Cambodia). Renewable energy technologies have generally relied on regional, national or international institutional support for introduction, product improvement and market improvements (e.g. wind, PV and small hydro in China, PV in Brazil). However, this can become a problem when renewables introduction goes hand in hand with the technology dump approach.

5. Main Conclusions of the Study

In many countries, the question is not whether distributed generation has a role to play. Rather it is a question of *how* it will play a role. This study set out to look at the historical experience with DG for rural electricity supply in order to answer a couple of fundamental questions:

- How can DG systems be installed and run in way that is financially sustainable and replicable and in a way that meets the needs of rural populations?
- What is the role of the institutional context in determining choices in technologies and business models?

Wider use of distributed electrification in a manner that meets local needs requires a new vision, one that moves beyond a focus on basic household electrification and on particular technologies. Electrification should be based on the diversity of local needs and decision-making processes, including the need for electricity to improve productive activities. At the same time, there remain good reasons for regulator oversight, and new regulatory mechanisms have to take into account the particular nature of distributed systems. (Reiche, Tenenbaum et al. 2006)

[6] These are customers that are at the top of the "base of the pyramid". The base of the pyramid, a term covering the vast majority of the population that is usually ignored by commercial enterprises due to assumptions of their low buying power, has become a powerful organizing idea for creating new opportunities to make money while solving societal problems and meeting environmental goals. See, for example, Hart, S. L. (2005). Capitalism at the Crossroads: The Unlimited Business Opportunities in Solving the World's Most Difficult Problems. Upper Saddle River, New Jersey, Wharton School Publishing.

The financing of the business model emerges as one of the key issues to be resolved in the use of distributed electrification in rural areas. Providing technology for free has proven to be unsustainable and difficult to replicate. If subsidies are to be used, they should be primarily for helping overcome the high capital costs of technologies. However, the effects of subsidies can be both positive and negative and care has to be taken in developing subsidy programs. They can force a more centralized solution and undercut options that might be better suited to contribute to overall development in rural communities. New and innovative financing schemes need to be developed and have the opportunity to be tested.

The results of this study point to five major conclusions that bear on efforts to provide distributed rural electrification and reach a goal of sustainable universal service and improved rural development. We have cast these conclusions as major lessons learned:

Lesson 1: Observations Are Not Analysis
There is a clear need to move beyond analysis based primarily on anecdotal evidence or single-N studies (e.g. one place, one technology or one business model). More formalized and rigorously developed research designs are necessary in order to develop better policies and inform actors in the distributed rural electrification field. The good news is that the data needed to conduct such analyses are available or can be developed through careful study design (e.g. surveys, semi-structured interviews, etc.). This study was based on work in three countries and examined roughly 20 business models. Similar work could be done in more countries and could address a broader set of questions regarding rural energy patterns.

Lesson 2: Free Lunches Are Not Sustainable (And They Kill The Restaurant Industry)
There are a number of factors that determine success and failure in distributed rural electrification. One clear lesson is that all technologies can work and various organizations can be successful (or can fail) depending on local conditions, institutional context, and a host of other factors. However, one factor which is clearly important across all cases is the need to have some level of cost-recovery and financial sustainability. If subsidies are to be used to ease the burden of high costs, they should focus primarily on keeping down first costs, and they should be carefully considered and designed before implementation. Subsidy programs that result in free electricity are usually unsustainable over the long-term and can prevent the implementation of options that are ultimately more sustainable and replicable.

Lesson 3: Electrons Do Not Equal Development
Electrification on its own does not guarantee development, either from an income generation perspective or in improving social welfare outcomes. The focus on pushing electrons is due in part to the tyranny of indicators in international development activities. In the case of rural electrification, that indicator is generally the number of households electrified. Rather than focusing on household electrification to the exclusion of other rural needs, it is important for maximum impact to improve electrification in the context of larger development patterns. This also means that the emphasis needs to change from

whether a given technology can provide electricity to *how* a given technology will supply electricity. It is necessary to stop pilot testing the technologies themselves and begin rigorously pilot testing and evaluating institutional models for implementing those technologies. This has to be coupled with an approach that looks at overall rural energy needs, particularly for income generating activities, not just household needs. It is also vital to overcome the bias towards promotion of renewables by outside actors. The contribution of rural communities to climate change is minimal and they should not be forced to bear the burden of mitigation at the expense of development. Renewables and more conventional generation sources should compete equally to meet rural development needs, taking into account capital costs, maintenance costs, fuel costs and variability, local institutional factors, local environmental factors and a whole host of other parameters.

Lesson 4: Think Globally, Act Locally
The stock phrase of the environmental movement applies equally well when thinking about what it takes to realize large-scale electrification that contributes to rural development. Centralized organizations, particularly government energy ministries and large utilities, focus primarily on pushing electrons and not on rural development. They have a difficult time understanding local conditions, which are key determinants of whether an electrification program is successful and furthers the development objectives of the community. The involvement of local actors provides greater versatility in meeting rural electrification goals, draws upon a wider range of actors, and results in a greater diversity of activities being undertaken. Rural electrification is an important country-wide and global objective, but it is often best achieved through local means.

Lesson 5: Unbias the Social Contract
The push for rural electrification flows from the social contract that governs the relationship between the state and its people. Due to the economies of scale usually associated with electricity, fulfillment of that social contract has tended to be biased towards centralized organizations, typically ministries or utilities, as the agents of the state. This study shows the need to unbias the social contract and open the system up to a wide variety of actors that can provide service on a local level. In other words, the provision of services should be performance based, not size based. This type of institutional change may be difficult in some places and has to be done in a way that minimizes the increase in transaction costs that can occur from more decentralized action.

Appendix A: Defining Distributed Generation

There is, unfortunately, no agreed upon definition of distributed generation (DG). Small generators fired on diesel and natural gas, as well as small renewables (hydro, solar, wind, etc.) are presumably the most familiar DG technologies. The two fuels least likely to be associated with distributed power are coal and uranium. However, in China a large number of coal-fired power plants were built in the 10 MW range which served primarily local distribution networks. While nuclear power reactors for civilian purposes have tended to be large centralized installations for a variety of reasons, the use of nuclear reactors onboard ships shows the degree to which they can be made compact and indeed, plans for future generations of nuclear reactors have included smaller reactors in the tens of MWs, which would be suited to power supply through distribution systems.

Formal definitions have tended to be highly context dependent and focus on one or more particular characteristic of either the technology or its use. (For a detailed discussion of how to define distributed generation see Pepermans, Driesen et al. 2005 and Ackermann, Andersson et al. 2001). Often, distributed generation is defined according to the generation technology and fuel (at least implicitly). This leads to the assumption among some that DG implies the use of renewable technologies or, conversely, the use of small natural gas or diesel engines. In fact, nearly every source of electricity generation can be (and has been) made small enough to be considered "distributed." Ownership is sometimes used to define DG, usually to mean that the unit must be owned by the end-user. However, this precludes a number of possible institutional arrangements, such as utility co-ownership or energy service company ownership. A third characteristic often used is the operational mode—whether power generation is dispatchable or can be scheduled.

All three of these characteristics are limiting and result in an overly narrow definition of distributed generation. Ackermann et al. provide a useful discussion of these and other characteristics often used to define distributed power generation. (Ackermann, Andersson et al. 2001) Their conclusion is that distributed generation can only be defined as generation that is located within the distribution network or "on the customer side of the meter" (which accounts for both off-grid and on-grid applications). They then place various qualifiers to account for other characteristics (e.g., micro vs. small vs. medium vs. large distributed generation). While this definition is very flexible, and allows for technologies of different sizes, operation modes, and purposes to be included, it is too expansive for the purposes of this study.

This paper adopts a narrower and more precise definition. Generation is considered "distributed" if the power is generated and consumed locally (this would be close to what Ackermann et al. define as "embedded generation," wherein the power output is used only within the local distribution network). This definition allows for significant flexibility in technologies and operation modes as well as institutional arrangements. Technologies can range from solar home systems to diesel engines. These can be operated completely off-grid or as part of a local mini-grid. The "local distribution network" includes under this definition completely off-grid technologies such as solar home systems where no network actually exists. However, as noted, the usefulness of this definition is in limiting power generation and consumption to the local level. Ownership can include individuals, groups of individuals, communities, private commercial actors, and national governments. Given that this study focuses on the use of distributed generation to meet the power needs of rural populations, this more limited definition of embedded generation is appropriate.

Appendix B: Scores on Individual Business Model Cases in Brazil

		Utility Diesel	Utility SHS
Business Model Parameters	Organization	Centralized Utility	Centralized Utility
	Target Customers	Villages	Households
	Technology	Diesel mini-grid	Solar Home System
	Financial: Capital	Grants/Loans/Soft Budget	Grants/Loans/Equity
	Financial: O&M	Tariffs/Cross-Subsidy/Soft Budget	Tariffs/Cross-Subsidy
Control Variables	Capital Cost Subsidies	High	High
	Operating Cost Subsidies	High	High
	Customer Density	Medium	Low
	Customer Remoteness	High	High
	Policy Regime	Favorable	Favorable
	Regulatory Regime	Favorable	Favorable
Outcomes	Access	High	High
	Sufficiency	Medium	Low
	Quality	High	High
	Sustainability	High	High
	Replicability	High	High
Notes on Institutional Factors	Policy Measures	Luz Para Todos providing significant funds	Luz Para Todos providing significant funds
	Regulatory Measures	-Regulatory requirements forcing electrification -Subsidies allow for high sustainability and replicability	-Regulatory requirements forcing electrification -Subsidies allow for high sustainability and replicability
	Other	Subsidies and soft-budget constraints for CEAM to make it affordable	Subsidies make it affordable

		BRASUS	PRODEEM
Business Model Parameters	Organization	NGO plus Regional Coalition	Central Government
	Target Customers	Productive Activities plus others	Community Structures
	Technology	Varies	PV
	Financial: Capital	Loans	Government Program
	Financial: O&M		No O&M recovery
Control Variables	Capital Cost Subsidies	Low	High
	Operating Cost Subsidies	None	High
	Customer Density	N/A	Medium
	Customer Remoteness	High	High
	Policy Regime	Neutral	Favorable
	Regulatory Regime	Unfavorable	Favorable
Outcomes	Access	Low	High
	Sufficiency	High	High
	Quality		
	Sustainability	High	Low
	Replicability	High	Low
Notes on Institutional	Policy Measures	-Integrated Action plans of MME envision partnering with NGOs on productive activities	Replicable as long as gov. willing to continue to fund.
	Regulatory Measures		
	Other		

Note: BRASUS – Brasil Sustentável; PRODEEM – Programa de Desenvolvimento Energético de Estados e Municipios

		IDEAAS SHS	SBC
Business Model Parameters	Organization	NGO – For Profit Partnership	Entrepreneur plus NGO
	Target Customers	Richer Households	Households
	Technology	Solar Home System	Solar Battery Charging Station
	Financial: Capital	Loans/Grants – Installation Fee	
	Financial: O&M	Monthly Fee	Fees
Control Variables	Capital Cost Subsidies	Low	Low
	Operating Cost Subsidies	Low	None
	Density of Customers	Low	Medium
	Remoteness of Customers	High	High
	Policy Regime	Neutral	Neutral
	Regulatory Regime	Unfavorable	Unfavorable
Outcomes	Access	Low	Low
	Sufficiency	Medium	Low
	Quality	High	Low
	Sustainability	High	Low
	Replicability	Medium	Low
Notes on Institutional Factors	Policy Measures	-LPT reducing incentive for individuals to obtain SHS since connection is free under LPT	
	Regulatory Measures	Universalization requirements on utilities bringing them into competition with IDEAAS	
	Other		-Frequent recharging -Expensive

Note: IDEAAS SHS – Instituto para o Desenvolvimento de Energias Alternativas e da Auto Sustentabilidade Solar Home System; SBC – Genesis Solar Battery Charging project

Appendix C: Scores on Individual Business Model Cases in Cambodia

		Licensed REEs	Unlicensed REEs
Business Model Parameters	Organization	Entrepreneurs	Small Entrepreneur
	Target Customers	Medium sized communities	Households and Home Based Businesses
	Technology	Diesel mini-grids	Diesel mini-grids plus battery charging stations
	Financial: Capital	Loans	Informal Loans
	Financial: O&M	Cost-Recovering Tariffs	Cost-recovering Tariffs
Control Variables	Capital Cost Subsidies	None	None
	Operating Cost Subsidies	None	None
	Density of Customers	High	High
	Remoteness of Customers	Low	Low
	Policy Regime	Favorable	Unfavorable
	Regulatory Regime	Favorable	Unfavorable
Outcomes	Access	High	High
	Sufficiency	Medium	Low
	Quality	Medium	Low
	Sustainability	High	Medium-High
	Replicability	High	High
Notes on Institutional Factors	Policy Measures	Move to bring all electricity supply under single regulatory and policy framework	
	Regulatory Measures	Licensing requirements, protection of licensed distributors	Expansion of EDC jeopardizing REE model over long term but varies by area
	Other		

Note: REE – Rural Electricity Entrepreneur; EDC – Électricité du Cambodge

		Solar Home Systems	NGO PV
Business Model Parameters	Organization	Dealer	National/International NGO
	Target Customers	Households	Community Structures
	Technology	PV SHS	PV
	Financial: Capital	Cash Market	Donor
	Financial: O&M	Warranty plus Cash	Warranty plus Cash
Control Variables	Capital Cost Subsidies	Low	None
	Operating Cost Subsidies	None	None
	Density of Customers	High	Low
	Remoteness of Customers	Low	High
	Policy Regime	Neutral	Neutral
	Regulatory Regime	Neutral	Neutral
Outcomes	Access	Low	Low
	Sufficiency	High	High
	Quality	High	High
	Sustainability	Medium	Medium
	Replicability	Medium	Medium
Notes on Institutional Factors	Policy Measures	Lack of agreement on eliminating tax keeping prices inflated	Lack of agreement on eliminating tax keeping prices inflated
	Regulatory Measures		
	Other	Sustainability will depend on Khmer Solar's continued operation	Sustainability will depend on Khmer Solar's continued operation

Note: SHS – Solar Home System; PV – Photovoltaic (i.e. solar power)

		Japanese PV/Hydro	Biomass Cooperative
Business Model Parameters	Organization	International Donor / National Government	Community Based Coop / National NGO
	Target Customers	Households	Households
	Technology	PV/Hydro mini-grid plus battery charging stations	Biomass Gasification mini-grid
	Financial: Capital	Donor	Donor plus Community
	Financial: O&M	Insufficient Tariff	Cost-recovering Tariff
Control Variables	Capital Cost Subsidies	High	Medium
	Operating Cost Subsidies	None	None
	Density of Customers	Medium	High
	Remoteness of Customers	Medium	Low
	Policy Regime	Favorable	Neutral
	Regulatory Regime	Neutral	Neutral
Outcomes	Access	Low	Low
	Sufficiency	Medium	Medium
	Quality	Low	Medium
	Sustainability	Low	Medium
	Replicability	Low	Medium
Notes on Institutional Factors	Policy Measures		
	Regulatory Measures		Expansion of EDC jeopardizing Coop model over long term
	Other		Replicability will depend on emergence of financing structures other than international donor grants

Note: EDC – Électricité du Cambodge

Appendix D: Scores on Individual Business Model Cases in China

		SHP-Early	SHP-Recent
Business Model Parameters	Organization	Central-Local Government Hybrid	Local-Central Government Hybrid + Private
	Target Customers	Primarily Productive	Productive plus households
	Technology	Small Hydro Power mini-grids	Small Hydro Power mini-grids
	Financial: Capital	Central Gov. subsidies/loans plus labor equity	Mix of funds
	Financial: O&M	Supposed to be cost-recovering tariff	Supposed to be cost-recovering tariff
Control Variables	Capital Cost Subsidies	High	Medium
	Operating Cost Subsidies	None	None
	Density of Customers	High	High
	Remoteness of Customers	High	High
	Policy Regime	Favorable	Favorable
	Regulatory Regime	Favorable	Favorable
Outcomes	Access	High	High
	Sufficiency	High	High
	Quality	Medium	High
	Sustainability	High	High
	Replicability	High	High
Notes on Institutional Factors	Policy Measures	Numerous favorable policies	Numerous favorable policies 1998 policy decision for centralized take-over of grids Rural grid renovation policy to improve quality
	Regulatory Measures	Favorable Regulations	Favorable Regulations
	Other	Relationship with local government	Change in State-Local relations

Note: SHP – Small Hydro Power

		Wind/PV Hybrids- Inner Mongolia	Wind Power – Inner Mongolia
Business Model Parameters	Organization	Regional Government and International	Private-Regional Government Hybrid
	Target Customers	Households	Households
	Technology	Wind/PV hybrid	Wind
	Financial: Capital	Consumers with modest subsidy	Consumers with small subsidy
	Financial: O&M	Consumers	Consumers
Control Variables	Capital Cost Subsidies	Low	Low
	Operating Cost Subsidies	None	None
	Density of Customers	Low	Low
	Remoteness of Customers	High	High
	Policy Regime	Favorable	Favorable
	Regulatory Regime	Favorable	Favorable
Outcomes	Access	Medium	High
	Sufficiency	High	Medium
	Quality	High	Medium
	Sustainability	High	High
	Replicability	High	High
Notes on Institutional Factors	Policy Measures	Subsidy and industry support policy	Subsidy and industry support policy
	Regulatory Measures		
	Other	Higher income consumers	Higher income consumers

Note: PV – Photovoltaic (i.e. solar power)

		TEP	PV Cash
Business Model Parameters	Organization	Central Government	Private Central-Local hybrid
	Target Customers	Households	Households
	Technology	Renewable mini-grids	PV Solar home systems
	Financial: Capital	Central government	Cash Sales plus modest subsidy
	Financial: O&M	Unaccounted for in planning	Consumers
Control Variables	Capital Cost Subsidies	High	Low
	Operating Cost Subsidies	High	None
	Density of Customers	Medium	Low
	Remoteness of Customers	High	High
	Policy Regime	Favorable	Favorable
	Regulatory Regime	Favorable	Favorable
Outcomes	Access	Medium	High
	Sufficiency		
	Quality		
	Sustainability	Medium	High
	Replicability	Low	High
Notes on Institutional Factors	Policy Measures	Project of central government	Subsidy and industry support policy
	Regulatory Measures		
	Other	Sustainability due to government priority on rural electrification.	

Note: TEP – Township Electrification Program; PV – Photovoltaic (i.e. solar power)

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