Causes of Success and Failure of Stand-alone Solar Electric Systems in Rural Guatemala

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Abstract

The causes of success and failure of stand-alone solar electric systems in rural Guatemala may be technical, institutional, cultural or economic. This research examines these causes using a mixed-methods approach that includes interviews with members of poor, rural communities to which stand-alone solar electric systems have been donated, physical inspections of these systems, and conversations with development professionals working in rural electrification. “Success” is a complex concept, here defined as a combination of user perception of success, utility to users, and optimality as a source of energy. Economics are a strong driver of system success: systems generally offer users cost savings, but few income generating opportunities; access to capital when components need replacement is a significant obstacle; and relatively wealthier beneficiaries are better able to maintain donated systems than are their poorer neighbors. The institutions and relationships that surround systems also influence success and failure: local institutions like energy committees can help systems be more successful, while national and regional institutions such as Guatemala’s weak justice system and extensive organized crime networks contribute to failure. Beneficiary sense of “ownership” and monetary contributions to projects by beneficiaries are not contributors to system success, while accountability to donors and ongoing donor involvement are. The quality of the design and installed components of the physical system may have little bearing on system success.

Donors must be clear about their own and beneficiaries’ definitions of success, and must be willing to challenge received wisdom about what will lead to more and less successful projects. Defining success as a high rate of operable systems will tend to favor relatively wealthier beneficiaries, leading to questions of social justice and whether energy interventions are most appropriate to those living in extreme poverty. Further, physically interconnected energy systems such as microgrids can lead to stronger social and institutional connections than do the physically independent systems included in this research.

Readers: Dr. Emma Cervone, Dr. Benjamin F. Hobbs, Dr. Erica Schoenberger

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Chapter 1. Introduction

Distributed renewable energy systems can provide modern energy services to the rural poor in the developing world, improving their economic and human development opportunities while minimizing energy's environmental impact. However, efforts to operationalize this ideal have been fraught with failure by almost any definition.

Using solar electric energy in Guatemala as a case study, this research is a study of underlying assumptions about the success and failure of rural renewable energy systems: how success and failure are defined, by whom, and the contexts in which success and failure are considered. It also examines the technical, economic, institutional and social factors that contribute to these successes and failures in rural communities, based on a review of the literature and information from field work in Guatemala.

The outcome of this research is knowledge that can help us understand the outcomes of energy-related development interventions and guide future development programs in their decisions to help achieve outcomes that all stakeholders will consider successful.

1.1. Electricity in the developing world

"There is a clear relationship between energy and human capacity and an inevitable corollary – the availability of abundant electricity is a fundamental for development." (Briscoe, 1999)

Almost one third of the world's population currently lives without access to electricity (Acker and Kammen, 1996; Duke et al., 2002; WEHAB Working Group, 2002). Four out of five of these people live in rural areas of the developing world (UN-Energy, 2005). The potential for improvements in economic opportunity and quality of life are substantial when people have access to electric power (UN MDG's, 2000).

The demand for energy is rising fastest in the developing world (IEA, 2006), and the poorest populations benefit disproportionately from increased access to modern energy services. (UN-Energy, 2005) When rural areas gain access to electric power for the first time, whether to electrify an entire village or for a specific application, renewable electric power generation – including solar photovoltaic electric power production (PV), wind power generation, very small hydroelectric power production, and power production from biologically-based fuels – is sometimes appropriate. Decentralized renewable or fossil fuel-fired generation can be more reliable and cost-effective than extending the existing electric power grid over long distances or difficult terrain (Acker and Kammen, 1996; Chakrabarti and Chakrabarti, 2002; Huacuz, 2005). Compared to more traditional diesel-fired generators, renewables have the advantages of using locally available resources (sun, wind, flowing water), having relatively few local environmental externalities (air or noise pollution), having generally few maintenance requirements, and being modular so there is little wasted fuel or power generation capacity. More than 1.3 million solar home systems[1] alone have been installed in developing countries around the world (Nieuwenhout et al., 2001), in addition to the many other rural electrification applications.

It is known among professionals who work in rural development that rural energy systems are often not sustainable over long periods of time, and that many fail almost immediately or are not fully implemented (Nieuwenhout et al., 2001; Acker and Kammen, 1996; van Roekel et al., 2004). Though accurate statistics on the failure rate of rural renewable energy systems are unavailable, anecdotal evidence indicates failure rates as high as 90% in some cases.[2] Many rural development professionals have proposed various and sometimes conflicting reasons for these failures, but few have sought to test their hypotheses. The explanations proposed include issues of engineering, economics, geography, sociology and policy. This research is an effort to quantify and qualify several of the factors that predict and contribute to these

[1] A solar home system in the developing world generally includes a panel, a battery, often a charge controller, several lights and outlets to power a small radio or charge a cellular telephone. In this thesis, "solar home system" will exclusively refer to photovoltaic systems, and not thermal water heating systems.

[2] Failure rates of such projects are categorically poorly documented, and information tends to be anecdotal and approximated. I conducted an informal survey of rural wind power systems in Mauritania, West Africa in June, 2002. Approximately 80% of direct water pumping wind mills and 100% of wind-electric wind turbines (in total, approximately 90% of wind systems I observed) were not functional at the time of my visit.

successes and failures. Given these opportunities and benefits, why do rural renewable energy systems fail with such alarming frequency?

1.2. Research questions

My basic research question asks why renewable energy systems implemented in a rural development context fail. In my earliest work in international development, I saw the remarkable failure rates of donated projects and began asking why, from the self-interested perspective that I did not want projects in which I was involved to fail. People experienced in energy and development were unsurprised by the high failure rates that I observed, and many had their own answers to the question of why. I found these answers to be sometimes inconsistent between equally experienced development professionals. I also found that few of the people with whom I spoke had tested their hypotheses. I found little available literature on the topic, and the handbooks issued by development agencies on "best practices" seemed to rely on the same received wisdom and untested knowledge upon which development professionals seemed to rely.

I also found the information somehow inadequate. If the organizations that were espousing their own ideas as "best practices" were the same that experienced such high failure rates among their projects, I felt my question remained unanswered.

To more usefully answer the basic question, I rephrased it and chose a case to study: what factors contribute to donated rural stand-alone solar electric projects' success and lack of success in Guatemala? From this more focused but still very general question, the following specific – albeit closely interrelated – research questions and hypotheses emerged:

Hypothesis: *Higher economic value and greater practical utility to users lead to greater system success.* Basic economic theory, previous studies and conventional wisdom all suggest that users of a practical thing that helps them save or earn money will invest resources in its upkeep. Does this hypothesis hold true in the context of rural PV systems in Guatemala? Do solar home systems save users money over traditional energy sources, as suggested by previous research? Are there economic effects in the community beyond household energy cost savings? Specifically, is anyone earning money that they would not have earned absent the system, or is anyone losing money because the systems were donated? Beyond economically productive activities, to what uses do people put their systems? Do specific uses influence whether systems are successful or not?

Hypothesis: The institutions and relationships surrounding donated systems influence and are influenced by the presence of and circumstances surrounding the donation, and those institutions and relationships can influence system success.

A firmly entrenched belief in the development community is that user ownership of systems, and in particular ownership that is earned through a monetary or other contribution, is necessary for system success. This research poses two related questions: does beneficiary contribution relate to system success; and does legal or *de facto* user ownership of systems relate to system success? Many rural PV projects are implemented by donors or developers who then leave the community, without further or regular contact. Does maintaining a relationship with the donor matter for system success? What is the role of accountability in this relationship, if maintained? Does beneficiary involvement with the initiation, planning or implementation of the project influence overall system success? Many donor agencies help create maintenance or administrative entities to manage the projects, once the donor has left. Do these play a role in system success? Must they be legally established entities to be effective? The provision of technical and administrative training is considered by many to be critical to project success. However, the training provided is normally short and offered near the time of project implementation, without re-training later in the project life. Does this short training that is offered influence system success? Does the content or format of the training contribute to system success?

Hypothesis: Characteristics of communities, users and systems can influence system success. What characteristics of users or communities influence how successful systems are? Does the user's or community's approach to system maintenance influence system outcome? Previous work has yielded conflicting results about the effect of technical quality on system outcome. This research seeks to clarify whether high quality components, robust design and installation, and national codes and standards lead to better system outcomes, or whether lower cost of materials or installation leads to more success because systems are more easily maintained. Have local culture, religion, values, or physical environment been adversely affected by the introduction of novel energy technologies?

These hypotheses, and the relationships between them, are examined in more detail in Chapter 3, and in the relevant results chapters.

Questions of why solar energy projects are successful are predicated on a useful working definition of "success." As described in detail in Chapter 2, the *a priori* definition of success proposed for this research consisted only of whether a system was currently operational and whether users said they found it successful. This definition proved inadequate. The working definition that emerged as a result of this research included operability in a more general sense, user perception of system value and utility, and a characteristic here called *optimality*, which considered whether the system donated was the best fit for the environment and application.

1.3. Contribution of this research

This research is intended to contribute to the body of knowledge about electrification in rural development by expanding the understanding of the realities of development within the academic community, and by providing information that can contribute to greater project success among governments, donors and development organizations.

The conclusions of this research include results that challenge prevailing wisdom on several issues. Most importantly, this research fails to support the deeply-entrenched notions in the literature (Chapter 3) that "ownership" and user contribution to development projects are key to their success, and finds in fact that ownership may detract from outcomes that donors consider successful. Instead, this research suggests that accountability on the part of the beneficiary to the donor or another outside party for the state of repair of the system may result in greater system success. Such a finding, if confirmed by future studies, calls into question the paradigm under which donation-based development is often approached.

These results also call into question the utility of donated renewable energy systems as a means for poverty alleviation among the poorest beneficiaries. For those beneficiaries, other needs may supersede the need for electricity or they may be unable to overcome the short-term financial hurdles of ownership, maintenance or access in order to gain long-term economic benefit from the systems.

However, the results of this research support other key findings of previous research (Chapter 3). Among other conclusions, I find that ongoing donor involvement in communities after projects have been completed helps systems succeed. Most users of stand-alone PV systems see economic benefit by reducing real energy costs. However, this study finds that few opportunities to augment income are presented by these PV systems, which is also consistent with previous findings.

This study also finds that the insidious environmental and health impacts of lead from improperly-discarded lead-acid batteries are not adequately communicated to system users by project developers, resulting in the very serious potential for lead contamination. The lack of communication with beneficiaries about this risk was not noted in previous research.

1.4. Research setting and methodology

This research addresses many of the questions surrounding small renewable energy systems for rural electrification, but it is certainly not exhaustive. Many important topics are beyond the scope of this project. Specifically, the scope of the project is bounded as follows:

- *Guatemala.* While problems with rural electrification are ubiquitous in the developing world, the problems are not necessarily the same in all locations. This study looks exclusively at Guatemala.

- *Rural areas.* The energy-related challenges encountered by the urban poor may be very different than those encountered in rural areas. This research examines only rural energy users who are also beyond the reach of the national electric grid.
- *Solar photovoltaic electricity production (PV).* Many renewable energy sources may be used singly or in combination to generate electricity for rural consumers, and electricity is not the only form of energy needed or consumed by these populations. However, this study focuses solely on PV.
- *Stand-alone systems.* The energy systems included in this research are not physically connected to other energy sources and are restricted to serving the electricity needs of a single building. Physical interconnection of systems could affect outcomes due to technical, economic, institutional, social or other issues. Further, the success or lack thereof that was evaluated was the success of individual installations, leaving larger questions of programmatic success outside the scope of this research.
- *Donated systems.* All of the systems considered in this research were procured by their users under a donor model, not purchased in market-based transactions.[3]
- *Local context.* This research examines the environment, economy and society where the systems are installed. Thus the question of environmental impact is one of how the local environment is affected, not whether PV reduces carbon emissions on a lifecycle basis. The economic benefit or cost to the community is considered, to the exclusion of consideration of the influence of energy markets on the national economy. National and global influences on the community are considered (e.g., fuel price volatility or the influence of drug cartels), but the influences of the community on the nation or the world are outside the scope of this study.

Within these parameters, I examine the success and failure of rural stand-alone PV systems in Guatemala from the perspectives of community members in which these systems had been donated. The primary

[3] The causes of success and failure of systems acquired through market-based purchases may be very different from the causes of success and failure of donated systems. The latter is the subject of this research and future study is proposed of the former.

methods of data collection took the form of surveys and semi-structured interviews with community members and physical inspections of systems. Additional information was obtained from a review of published literature; from interviews with personnel of and project documents prepared by donor and development agencies; conversations with knowledgeable non-stakeholders; popular press; and personal observation. The data collected and analyzed included information that led to the development of a definition of success used for this research, technical, economic, institutional and social contributors to success, and observations of the effects of the donation of these systems.

1.5. Scope

This dissertation contains detailed descriptions of the background, methodology, data, analyses and results of this research. Chapter 2 includes a review of previous studies on this and related topics, and a detailed description of the hypotheses suggested by that work. In Chapter 3, I review the context of the study, including the background of the country of Guatemala and its current political state, and describe the methodology used to conduct this research. Chapter 4 describes the definition of success used, and the analysis that went into creating that decision. The subsequent three chapters include the analyses and conclusions of this research, divided into three sections: Economics and Utility (Chapter 5), Institutions and Relationships (Chapter 6) and Characteristics and Consequences (Chapter 7). Finally, I summarize my major conclusions and highlight areas of future research that have been suggested by the context, data and analyses of this study. Associated definitions, survey instruments and resultant data are found in the appendices.

Chapter 2. Defining Success

"... Something died when the light went away..."

Owner of a failed solar home system

This research focuses on the success and lack of success of stand-alone solar energy systems in Guatemala. To examine this topic, "success" must be defined. In this chapter, I examine "success" and create a working definition for purposes of this research.[4]

The broadest definition of success looks not the performance of a system, but at the effects on the people and environment in which it is located. Who is impacted intentionally? Why those people? Who is impacted unintentionally? What are other resulting costs and benefits?

The definition is inherently multicriterion in nature. There is no single metric since cost, reliability, convenience, social impact, aesthetics and a great many other criteria arguably must be included. The relative importance of each of these factors is subjective and will vary by stakeholder. To model the question in a decision analysis framework, it would be necessary to select the factors to be included, give weights to the relative importance of each, and set the definition of success based on these weighted factors. Must all reach a minimum level for the system to be considered successful? Can overwhelmingly positive outcomes for some factors make up for weaknesses in others?

This approach is not used to define success for this research, first because it relies very heavily on expert opinion. The first step, defining whether aesthetics or convenience or cost is included in the list of factors to consider, depends on an "expert" decision, and yet one that is inherently subjective. The expert must also decide what information is reliable and credible and how to weight the values of the *stakeholders* against one another. If a representative sample of project developers weights one factor very heavily but a sample

[4] Methodology referenced in this chapter is detailed in Chapter 4. Results referenced are tabulated in Appendix C.

of beneficiaries puts little weight on the same factor, the expert must decide how to account for these discrepancies in modeling success.

Second, I know of no “expert” in the field of renewable energy for rural electrification in Guatemala who is not also a stakeholder in the projects examined for this research. The experts are the current and former project developers. The model becomes tautological: as stakeholders, the experts choose factors and weights for the model, and then as experts agree with themselves as stakeholders.

As such, the definition of success for this research does not rely on expert opinion but is instead developed from the point of view of the beneficiaries. Are the systems successful for the beneficiaries themselves?

Looking at the success of a single stand-alone solar PV system, however success is defined, is a small part of this broader definition. At the outset of this research, I held the assumption that a higher percentage of successful systems translated to a more successful project and program outcome. However, this analysis suggests that the characteristics of a beneficiary that is most likely to be successful with a stand-alone PV system are also the characteristics of someone who has less need of the donation: if you can manage a donated system without substantial effort, you may have been able to purchase it yourself. Section 2.1 explores this idea further.

The “success” examined in this research is less that broader definition of success and instead defines success based on individual systems and users. My original hypothesis was that success was defined by a simple combination of whether a system was operable and whether its user believed it to be successful. This proved inadequate, as examined in the sections that follow.

The uncertainty in the definition of success in this context is compounded by the fact that the provision of a rural renewable energy system is rarely a goal unto itself. Solar home systems are intended to provide a household with better quality light that doesn't reduce indoor air quality. A PV water pumping system clearly exists to provide water. Renewables power rural health clinics, schools, churches, and community centers, but with the goal of helping those institutions achieve their missions rather than solely to provide power for its own sake.

In this chapter, I begin by considering whether the goal of a high percentage of operable systems is appropriate, or if some broader definition of success is warranted. In Section 2.2. I examine definitions of success found in the literature, both in the context of rural electrification and of analogous development scenarios, including a brief case study of a successful small hydroelectric project in Guatemala. Section 2.3. explores operability as a defining factor for successful systems and presents a case study of two stand-alone PV systems as evidence that system operability is neither a necessary nor a sufficient condition to define project success.

The important but confounding question of how beneficiaries themselves define success is addressed in Section 2.4. by analyses of the results of this study in the context of existing literature. Section 2.5. explores the concept of "optimality," and explains its role in completing the definition of success by examining user attitudes toward their systems. This chapter concludes with the working definition of success used in this research.

2.1. Are successful projects the right goal?

This research specifically addresses the success or failure of individual PV systems. In this section, I explain that this definition must be weighed against the fundamental goals of development projects. The underlying assumption has been that a greater number of successful systems is equivalent to a more successful program (and a better use of development funds). Collier (2008) suggests that this risk-averse approach to development may not be the most apt, and may in fact exclude those who are most in need of development aid. While he speaks of large-scale development projects for the poorest, stagnating nations (as compared to the poor but improving nations that make up the majority of the developing world), his conclusions might reasonably be extrapolated to communities within a developing country. It is possible to select the communities in which stand-alone solar energy systems are more likely to be successful on a project-by-project basis. These communities, however, may be those which are most likely to be able to develop with less outside assistance (due to level of income and other factors considered throughout this research). This may be true of relatively wealthier households or individuals within a poor community as well. As an example, delinquency rates are higher for IDB-financed publicly supported mortgages than they are for private-sector mortgages in the same locations (White and Bamberger, 2008). This is not evidence of programmatic failure compared to the private market; it is evidence that the public mortgages are intended for and benefit higher risk (poorer) borrowers. A lower failure rate could be attained by lending to people less in need of help. Similarly, as seen in this research and described in Chapter 5, exclusion of poor or marginalized individuals may boost the success rate of systems within a project, but at the cost of social equity and other explicit or implicit project goals.

As project developer, the desire to see projects succeed is clear. As someone interested in development in general, perhaps development efforts are best applied where projects are *less* likely to succeed: a single success among a myriad of failures in the most extreme poverty may do more to improve quality of life and reduce environmental impact than would many successes in more moderate circumstance. The appropriateness of a development agenda to specific circumstances is also important: sometimes projects are unsuccessful because beneficiaries need other things more.

The rate of success among systems installed under a particular program or project is a useful metric in comparing programs with like goals and beneficiaries but different implementation strategies. However, this success rate may be inadequate to assess how well a project meets stated or implicit poverty alleviation, improvement in quality of life or other development goals.

2.2. Project evaluation and project success: previous and analogous work

2.2.1. Evaluation and success

Systematic evaluations of policy instruments and interventions in international development are conspicuously absent. As in other fields that deal with developing countries, evaluation is complicated by the low availability and poor quality of data. Wealthy nations normally dictate the terms of evaluations and very often carry out evaluations based on their own priorities rather than based on the priorities of the targets of their evaluations.

A review of the literature suggests that there are few standard definitions of success, and it is often in fact undefined. Agencies may be motivated to judge their own projects as successful. There has been little focus on results- and impact-based evaluations of project success, but it is increasing (Naudet and Delarue, 2008). Overall and by nearly any measure, stand-alone PV systems in rural developing world applications have not been successful.

Billions of dollars have been poured into development projects absent even a “minimum standard of knowledge” of what works (Ruprah, 2008). Success rates cannot be quantified absent a relatively unambiguous definition of success. Most articles in the literature do not explicitly define “success,” and the definitions used by others vary widely. For example, data on system failure rates is notably absent from otherwise very informative reports on four communities in Guatemala (*Fundación Solar* 1, 2, 3 and 4, all 2003).

Sponsoring organizations or governments sometimes have motivation to declare a project successful without quantifying or concretely defining “success” (Ley, 2006). This has been suggested to me even by members of organizations proclaiming such successes (who would not like to be named). Even evaluating whether a project has had any impact is outside the mandate of many sponsoring institutions (Ruprah, 2008).

In this section, I explore prior definitions of success and means for evaluation that have been used in rural electrification as well as in analogous development interventions.

2.2.2. Evaluation and success in energy-related development

Following are a few of the published examples and "conventional wisdom" regarding the qualification and quantification of success in rural energy systems. Though they are few and sometimes inconsistent, these formed much of the basis for my *a priori* definition of system success. In this section, I present specific examples of projects evaluated as successful or unsuccessful, followed by more general discussion of the conventional wisdom and expert opinion often used in practice. In the subsequent subsection, I compare these to the criteria used for evaluation in other areas of development.

2.2.2.1 How successful are rural renewable energy systems?

However unclear the definition of failure might be, it is widely reported: One report states that sixty percent of solar battery charging systems in Thailand are not currently operational (Green, 2004). An earlier report states that one third of solar water pumping systems in Thailand are not operational (Kirtikara, 1997). Ninety percent of wind turbines in one region in Mauritania are not currently operational.[5] Forty four percent of solar home systems in Kenya are rated by their users as less than "functioning well" (van der Plas and Hankins, 1998). Forty-five percent of solar home systems were not functioning five years after implementation in a Fundacion *Solar study fro*m Guatemala (Nieuwenhout et al., 2001). A review of available literature found a range of failure rates among solar home systems from over ninety percent "non-operational" in Kiribati to twenty-three percent fully or partially non-operational in one study of Kenya (Nieuwenhout et al., 2001). After a single year, 70% of solar home systems implemented under a Brazilian program had failed (Ley, 2006). Even where success and failure are not explicitly defined, or when "success" is judged based on different criteria than "failure," failure rates are high.

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[5] See footnote 3, above.

2.2.2.2. Poverty before and after as a measure of success

Foster and Tre (2000) seek to show the correlations between poverty and access to energy. The study details extensively the use of a comparative methodology, looking at measures of poverty before and after an energy intervention has been implemented. Guatemala is used as a case study for this comparative methodology, but a single dataset is used and nothing to which to compare it is offered – and several of the data types emphasized as important in their methodology were found by them to be unavailable. Factual inconsistencies within the text make their data questionable. Their own inability to make use of their methodology (specifically failing to compare "before and after" data, and failing to collect data that they consider important) raise doubts about their conclusion that their methodology is an effective model to prescribe policy interventions in the energy sector and likely in the water sector as well.

2.2.2.3. Improvement in specific activities as a measure of success

On the island of Sagar Dweep in West Bengal, India, users of solar energy systems are reported to prefer electric power to other sources (e.g., kerosene lamps) because the light is brighter (Chakrabarti and Chakrabarti, 2002). The program that installed these solar energy systems is considered successful in four ways: it has improved education by allowing students to study longer at night; it has allowed shopkeepers and producers (e.g., weavers, betel leaf cultivators) to continue economic activity later at night; it has allowed people to "avail themselves of entertainment facilities" such as video houses; and it has allowed women to better do their household work. Improvements in specific activities can be a useful metric, but may not by themselves be an appropriate way to define success. For example, a medical intervention may use number of children vaccinated as a metric for the success of its program, but the number of vaccinations does not necessarily cause a decrease in childhood morbidity or mortality, which is more likely the goal of the intervention. However, looking at groups of activities in aggregate can be telling of the modes of success and failure of a project.

2.2.2.4. A "Table of Sustainability" to drive project success

Michael Ross, an engineer with Sandia National Laboratories in Albuquerque, New Mexico, is actively involved in implementing renewable energy projects internationally. Drawing upon his own personal experience and that of his colleagues, Ross proposes that there is a "Table of Sustainability" for any community owned project. This table is the foundation for system sustainability and is supported by three legs: robust design and quality components, proper operation and maintenance, and good governance and administration. "If any leg fails," explains Ross, "the table falls and sustainability slides right off. Education and knowledge within the community bind the table together."[6] While protocols and industry standards exist to define the first two legs, "good governance and administration" are seemingly tautologically defined for this proposed "Table of Sustainability:" Good governance is seen as necessary for project success, but project success is the evidence presented that governance has been good.

2.2.2.5. Meaningful sponsor involvement to drive project success

Woods (1998) proposed to qualify the reasons for success and failure of rural renewable energy systems in Nepal and Pakistan. While the insights of this study were valuable, only two variables were considered: the quality of the components installed and the quality of the ongoing support for their maintenance. Although the work implies that there are multiple factors that define the quality of the programs of support, the length of the commitment to support is the only characterization of these programs explicitly mentioned. This study offers no statistical analysis and merely comments on "higher" or "lower" probabilities of success without defining what is meant by success, but concludes that longer and more active involvement by donors correlates to higher probabilities of success.

Analysis at the National Renewable Energy Laboratory (NREL) by Taylor (1998) was based on the combined experiences of the NREL development experts. Taylor points to an ongoing commitment by the sponsoring agency as the most critical factor in the successes of projects. Additionally, success is greater

[6] Personal communication with Michael Ross of Sandia National Laboratories on 26 October, 2005.

for project implementation programs having an in-country partner (if the sponsoring agency is foreign) to facilitate communication across languages and cultures, sending appropriate price signals to end users, using valid planning and analysis tools and techniques, and connecting power projects to other development efforts. Projects must also use “tried and true” technologies, and be located in close enough proximity to one another to facilitate maintenance. While these insights are valuable from the points of view of those with broad experience in rural electrification, the study did not systematically test these hypotheses either among projects completed by NREL or among other projects. Further, the analyses presuppose that commercialization of the systems themselves is the end goal, and defines success relative to that goal only.

2.2.2.6. Stakeholder perception and success

Studies suggest that users are generally more satisfied with their systems if their expectations of the limits and abilities of their systems are reasonable and realistic (Nieuwenhout et al., 2001; Ley, 2006). Users complain that solar home systems do not provide sufficient power to meet their needs, particularly during rainy seasons, or are disappointed that they cannot afford sufficient PV for cooking or ironing; this dissatisfaction is evidence of a failure to set realistic expectations before installation.[7] It is evidence of the desire for expanded systems, not dissatisfaction with the system itself. This theme of “managing expectations” was reiterated often by project developers in formal and informal conversations that took place during the course of this research.

The success of solar home systems seems to enable the adaptation of other renewable energy technologies such as biogas systems and solar box cookers, which was also observed in this study (see Chapter 5). However, when projects fail, confidence in the technology may be lost – even when the failure was due to the implementation process rather than the technology itself (Ley, 2006). This loss of confidence may be seen in users, sponsoring organizations, governments or the media.

[7]Source for this paragraph is (Acker and Kammen, 1996) except where otherwise noted.

The media sometimes presents subjective or inaccurate information about proposed projects (especially large, government-sponsored projects), leading to unreasonable expectations by the recipients.[8] Media reports that distort or over-simplify the development process can lead future projects to fail if planners rely on those reports for guidance. These reports often lack adequate context and present only the "photo op" rather than the complicated issues that are involved. The scientific literature may present the same problems, and may be relied upon more heavily than mass media by the development community and therefore cause more damage if inaccurate.

2.2.2.7. Weaknesses in planning for evaluation

Traditional project planning has not included the design *ex ante* of project or program evaluations, so baseline data to which to compare outcomes have rarely been available (White and Bamberger, 2008; Ruprah, 2008). Thus even the best intentions of honestly evaluating "success" are often defeated by the lack of anything to which to compare. Most available literature on project success deals only with the first one to two years after implementation, which may give little insight on the long-term sustainability of the projects (Nieuwenhout et al., 2001) and may make projects seem to have a better success rate, though that part of the evaluation process is improving (White and Bamberger, 2008; Naudet and Delarue, 2008).

2.2.2.8. Biases in evaluating success

There are many potential positive biases in assessing project or performance success. The frequent lack of a control group or baseline data to which to compare (Ruprah, 2008) means that any improvement in outcome can be attributed to a project, whether it is directly related or not (White and Bamberger, 2008). Failed projects may be excluded from evaluation samples not with the deliberate intention of skewing a sample, but because a project with a known outcome may be perceived as not adding information to an evaluation (White and Bamberger, 2008).

[8] Source for this paragraph is (Ley, 2006).

Projects that are selected for evaluation may over-represent the success of a program since evaluation samples normally include projects that are easily accessible both administratively (listed on maps or project registers) and physically (reachable by evaluators in a reasonable amount of time) (White and Bamberger, 2008), especially focusing on pilot projects (Taylor, 1998). This evaluation selection bias may exclude projects that are perhaps most likely to fail, including those owned by marginalized populations or in very remote locations (White and Bamberger, 2008).

Participant selection may bias reports of project success rate. Characteristics of beneficiaries who are most likely to be selected often correlate to characteristics of those most likely to successfully maintain projects (White and Bamberger, 2008; Naudet and Delarue, 2008). While this may not skew the reported success rate of a particular program or group of projects, it would overstate the likelihood of success were the project replicated and expanded to a less selective group.

Project developers or the consultants they hire may be motivated to rate their own projects as successful or list fundamental problems as only recommendations for improvement in order to secure future funding or contracts (White and Bamberger, 2008). White et al. (2008) suggest that reports of this deliberate or borderline deceptive bias are "anecdotal" and that most organizations welcome negative feedback; I am less dismissive of this phenomenon because of reports from project evaluators (who wish to remain nameless) who have found themselves pressured to report success where there was failure or to cast marginal results in a positive light.

Success, while poorly defined, has remained elusive in energy-related development projects. Poverty alleviation has been used as a measure of success, as have improvements in specific activities. Other measures of success also rely on outside opinion, and some become tautological, claiming that project goals are met because a project is successful but defining success by meeting project goals. Few past studies have considered beneficiary perspective in concluding that a project is successful, but those that have note that these perspectives are more positive when beneficiary expectations are managed. Project developers normally evaluate or hire evaluators for their own projects, which is one factor that may lead to overstatement of success rates. Success is often not well defined because resources are not *a priori* committed for project evaluation so evaluations are planned *ex post facto*.

Success can be evaluated in analogous situations or technologies implemented for international development, which may offer further insight into appropriate definitions of success in donated PV systems.

2.2.3. Evaluation and success in water, sanitation and agriculture development

As in rural electrification, a dearth of studies of the success of development interventions exists for other sectors of the rural economy (Berti et al., 2004; Fewtrell et al., 2005; Curtis and Carncross, 2003) and many existing studies are poorly conducted or reported. Publication, reporting and selection bias may overstate the effectiveness of some interventions; this same bias may be present in rural electrification studies, although it is not dealt with explicitly in the literature I have found.

Water, sanitation and hygiene interventions in developing world applications are viewed as largely successful in some studies (Fewtrell et al., 2005), but others suggest that these interventions also suffer high failure rates. Among these interventions, the definition of success is necessarily different. An improvement in health outcome to any degree is a success in the latter case, where an energy system may not be able to succeed incrementally: it works or it doesn’t.

As with energy, other interventions are also frequently studied only during or shortly after implementation, leaving serious questions about the long-term effectiveness of the projects (Fewtrell et al., 2005).

Several agricultural intervention studies were conducted long after implementation – between four and thirty years later (Berti et al., 2004). Just over half of projects studied had some long-term benefit (Berti et al., 2004). Counter-intuitively, among those, fewer than half of interventions that increased users' incomes had a positive long-term effect on nutrition, as the increased produce was sold rather than consumed and resultant income was not necessarily spent on more or better food of other types (Berti et al., 2004).

Research suggests that water and agriculture studies suffer shortcomings in their evaluation processes and definitions of success as well, as described below. Rather than considering the population at large, many studies on water, sanitation and hygiene consider only the impacts on small children (Fewtrell et al., 2005) and many agricultural interventions focus solely on women (Berti et al., 2004). Examining only a part of the population may omit negative or positive impacts on the rest of the community, in studies of energy as well as studies of water or sanitation.

Studies on improved water supply often neglect the effects of possible increases in water use due to the water intervention (Fewtrell et al., 2005). Many studies of agriculture interventions, however, acknowledge their inabilities to identify the impacts of nutrition education, since it is never provided without additional, concurrent intervention activities (Berti et al., 2004). Though the outcome is the same (no new information is gained), the acknowledgement of the redundant or non-informing variable is important.

Many analogies can be drawn between energy and water interventions in developing countries, and as such, lessons learned from these projects may be applicable to energy projects as well. However, key differences remain that make the analogy imperfect.

Care must also be used in defining success among small-scale agricultural interventions. Many agricultural interventions increase food production, but do not necessarily improve health or nutrition of household members due to a lack of consideration of “cultural, economic and social conditioning” factors (Berti et al., 2004).

“Successful” intervention may also be a proverbial double-edged sword. Water supply interventions that decrease the surface pathogens consumed by users have been known to increase arsenic exposure and poisoning (Fewtrell et al., 2005). Agricultural interventions that increase food supply at the expense of other tasks – such as childcare – may actually worsen childhood morbidity or mortality (Berti et al., 2004). Such serious, negative consequences were not considered in the rural electrification literature I found. It is not *a priori* evident that such potential consequences are absent or present.

Two important lessons can be learned from an examination of the literature on water in development, including sanitation and irrigation. The first is that cultural, economic and environmental contexts must be adequately considered for projects to succeed. The second is that goals must be defined in order to judge whether they have been met successfully.

Successful water and sanitation interventions require that technical, economic, and cultural issues be given appropriate consideration, and often require a variety of expertise to implement optimally (Fewtrell et al., 2005). Interventions such as hand washing that require the modification of human behavior can only be successful if they are informed by an understanding of “what motivates, facilitates, and hinders” behaviors (Curtis and Carncross, 2003). Improvement in the long term success of agricultural interventions requires expertise from several disciplines: nutritionists, agricultural scientists and social scientists (Berti et al., 2004). Though the analogy between these development interventions and rural electrification is imperfect, they suggest a significant value to including non-technical issues in the planning and evaluation of stand-alone PV projects.

2.2.4. Success and evaluation in microfinance

Microfinance as a means for development is less directly analogous to energy in development than is water. However, the initial purchase (if not donated) and ongoing maintenance costs of the stand-alone PV systems that are the subject of this research are capital intensive relative to the incomes of the beneficiaries. Thus understanding what succeeds and fails in microfinance schemes – and how success is defined – can point to potential causes of success or failure based on the economic aspects of these projects.

Investment by development agencies in microfinance programs has far outpaced research on their effectiveness in poverty alleviation (Naudet and Delarue, 2008). Field research on specific microfinance programs is only now beginning.[9] However, foreign investment in microfinance in 2006 was approximately $4 billion – triple what it had been in 2004. Some are for-profit companies looking to tap into the "fortune at the bottom of the pyramid," others are altruistically driven groups looking to improve the lives of the poor, and some microfinanciers are driven by both, looking for opportunities to make money while helping the poor rather than taking advantage of them.

Microfinance programs are generally viewed as successful if they are economically sustainable: the rates of repayments of loans and interest are sufficient to cover program costs above and beyond any subsidy that may exist. While promising, anecdotal reports of the success of microcredit programs should not be viewed as unqualified evidence of their success, even as the need for microfinancing is ever more apparent. Please see Chapter 5 for further discussion of the role of microfinance in rural PV dissemination.

Microfinance as a means for development suffers the same lack of quantitative evidence of success as does energy in development. One conclusion of this research is that users cannot sustain that for which they cannot pay. Seeking opportunities for microfinance and evaluating the effectiveness of these opportunities is beyond the scope of this research, but is necessary for the sustainability of rural stand-alone PV systems.

[9] Source for this paragraph is (Collins et al., 2009) except where otherwise noted.

2.2.5. Success in an analogous situation: perceptions of a small hydro project

The following anecdote illustrates some of the complexities of analyzing the success of a rural renewable energy project.

Six small hydroelectric plants were donated to municipalities in Guatemala around 1994 or 1995. According to the office of one municipality, theirs was the only one of the six still in operation in 2008, at the time of our interview. They were asked why theirs still worked when the others failed, and what differentiated them.

The response of the two employees of the municipality was in part about money. They said that they recognized the benefits of having the hydro, and as such were willing to invest in the (mostly minor) maintenance and repair that had been required since its installation. The other communities either did not recognize the benefits that the hydro brought them, or more likely did not find them worth the money to repair. There is money to be earned by having electricity, but that money must be reinvested in the electricity source.

Their reasoning is clear, and may be analogous to the same issues that differentiate successful from failed stand-alone PV systems, but there are several important distinctions. First is level of education. The men who gave this answer seemed to be highly educated, with one of them having completed college. In contrast, most users of stand-alone PV in this study had very low levels of education. The second difference is that overseeing the system was a part of their job. They had a direct and unambiguous financial interest in keeping the hydro running in order to keep themselves employed. The third is level of poverty. The municipality where the hydro is located is neither as rural nor as poor as most of the communities included in this study, although there are some very poor agrarian households within the territory covered by the hydro. People in general did not use all of their available resources to pay for basic necessities like food and medicine; they had enough income to work beyond the immediate. The community had maintained roads and the national electric grid reached it. And finally, the hydro plant is common property rather than the property of each individual. It is managed centrally on behalf of everyone in the municipality. Both the costs (in the form of taxes, if necessary, although the hydro was generally a net income source to the municipality) and the benefits (in the form of development opportunities, especially water and water management projects, and possibly reduced local taxes) were shared among all. The cash flow burden was also shared communally, with public coffers available to make purchases (or municipal tax base available to guarantee loans), so no individual household was compelled to raise a large sum of money alone.

The basic conclusion that the men from the municipality reached, that they were successful where others failed because they were responsible enough to leverage the benefits to offset the costs, is reasonable on a fundamental level. However, the claim of superior understanding of the benefits or responsibility in maintenance also comes from the successful party itself, and may reflect a desire to believe in their own superior knowledge or skill rather than superior luck or circumstances beyond their control, which may also be the case if, for example, the other municipalities in the program were much poorer.

The analogy that one household with a solar home system keeps it operable while a neighbor does not because only one is responsible enough to leverage the benefits (in reduced lighting costs, for example) is obvious, but fails dramatically in considering the factors that may enable one household to "be responsible" while a neighbor cannot make the same financial arrangements or attain the level of technical expertise necessary.

2.2.6. Conclusions concerning project evaluation and success

Although the literature on success and evaluation of energy projects and analogous development interventions is relatively scarce, many lessons can be learned. These ideas are incorporated into the definition of success used in this research, as well as my *a priori* hypotheses on the causes of success and failure.

2.3. Operability

Based on the above review of existing literature and selected anecdotes, system operability and user perceptions are chosen *a priori* as factors to define the success of a stand-alone PV system included in this study. The following sections examine the shortcomings of those two factors as originally defined, and add the criterion of "optimality," as defined below, to the definition of success used in this research.

Where projects have been relatively successful, technical reliability is among the strongest drivers of the expansion of the use of renewable energy systems (Acker and Kammen, 1996). The definition of operability used in this study specifically does not require that the system be used for its originally-intended purpose to be considered operable. For example, solar panels may have been provided for a lighting application. If they are instead being used successfully to power a water pump, the system is considered operable. Further, the operability criteria for success are considered to be met for a system that is not functioning at the time of inspection but concrete steps are being taken to repair or replace it. For example, a PV-powered vaccine refrigeration system in one community was not functioning, but the refrigerator's compressor had been removed and sent to the capital to be repaired, as it had been when it had broken previously. This is considered a successful system based on these operability criteria. And finally, a system is not considered "inoperable" if it has been removed because its use was intended to be temporary and it had been replaced with a permanent system. See Section 2.3.1. for a specific example of a system that, while no longer operating, is not considered "inoperable" when judging its success in these analyses.

System reliability or degree of operability can be assessed easily if operators have kept logs of system events. However, the system users in this study include those with low levels of literacy and little or no motivation to keep such logs; among PV systems, none were encountered. One-time inspections yield little information about the operability of a system. Measuring battery voltage can indicate if a battery is over-charged or at a low state of charge, but neither necessarily means that a system is inoperable or gives a measure of the degree of degradation of system performance. A battery at a low state of charge may simply mean that the weather has been cloudy or that the battery was drained with the previous evening's lighting and has not yet recharged during the day. Therefore, if system owners considered themselves to be able to use the system, the system is considered operable.

2.3.1. Success and operability – the strange case of Chel

This section reviews the case study of the community of Chel to critically examine the measure of "operability" used in this research. I had initially set the current functioning of a system as a prerequisite for calling it operable, and consequently successful. Anecdotally using Chel and surrounding communities, I must reconsider whether it is a necessary condition for success – how can a non-functioning system be successful while a functioning one is not?

2.3.2. Chel background

Chel is an indigenous, mostly Ixil community, according to people who live there. The Ixil have lived in the area for at least 1400 years.[10] The area is ethnically homogenous and geographically isolated by surrounding mountains. The Ixil are poor and live traditional Mayan lifestyles, even compared to other rural indigenous people throughout Guatemala.

In Chel, people say they didn't take sides during the civil war, but all the young men were unofficially but forcibly conscripted to one side or another. A man I know there, *Don Exito* (not his real name, like all names reported in this research), served as a troop commander for the rebels when he was only sixteen years old.

[10] Source for this paragraph is (Stoll, 1993) except where otherwise noted.

Civil war violence was disproportionately directed at the indigenous communities (Grandin, 2005), and the Ixil people suffered worse than most. The army "shot, hacked, or burned to death thousands of unarmed men, women, and children" (Stoll, 1993).

Chel lies in the rural Western Highlands of Guatemala, in the Department of El Quiché, in an area that came to be known as the Ixil Triangle, which is among the areas worst hit by the civil war violence (Warren, 1998; Manz, 1988). The army "restored peace" in the area by executing nearly all people were accused of being resisters, leaving behind only those who were unwilling or unable to fight, as detailed in Chapter 3. Unlike in other indigenous areas, the army recognized that the support of the Ixil for the rebels came in part at least from an empathy shown by the insurgency for Ixil culture, language, and the everyday struggles of the people (Manz, 1988), while attempts at *ladinoization* (integration into mainstream Guatemalan Ladino culture) or *castellanezation* (imposition of the Spanish language) of Ixil people had been failing for 400 years (Manz, 1988) – the Spanish empire had conquered the area in 1530, but few outsiders lived there before the 20th century (Stoll, 1993).

General Efraín Ríos Montt is ambiguously viewed as the one who brought peace to the Ixil area and as the general who oversaw massacres of Ixil non-combatants (Stoll, 1993). He was unambiguously in command when the worst violence against Ixil people was committed (Stoll, 1993), but was also the force that systematized the violence from random, reactionary murder to predictable – and thereby often avoidable – killing as a consequence to particular actions (Stoll, 1993).[11]

The brutality against the Ixil people included a massacre of about 100 people peacefully demonstrating in Chel – with women and children at the front of the line ("non-combatants" is the more modern term, since some women and children fight while some men do not, but the community deliberately put children and

[11] In 2013, Ríos Montt was tried and convicted of genocide and crimes against humanity; the Constitutional Court of Guatemala overturned the conviction and ordered a new trial. At the time of this writing, the case is still unresolved, according to various news sources.

their mothers at the front of the demonstration).[12] Soldiers dumped the bodies over a bridge and into the river that runs through the community. People there talk of the river literally running red with blood. But Chel was no longer a combat zone after the massacre, so some people in the area view the government troops as having brought peace to the area.

When the peace accords were written in 1996, the government of Guatemala promised a great deal of reparation to the Mayan communities who were least active in the resistance but suffered the greatest loss of life, mostly at the hands of government troops and paramilitaries – though the rebels are not blameless. Chel had a hydroelectric power project on the drawing board at this point (described below). The NGO with the local presence suggested that the peace accords played some part in helping the Chel electrification project along (it was initiated after the massacre but before the peace accords). The government of the United States, through both USAID and DOE, put far more money into the project than the Guatemalan government did, according to a developer who worked on the project on behalf of DOE. But the national government of Guatemala did make financial contribution to the project and has been nominally supportive, in keeping with the peace accords

2.3.3. Solar for phones in Chel

A Guatemalan NGO worked with the adjoining communities of Chel, Las Flores, and Xesaí (hereafter referred to in aggregate as "Chel" for simplicity) for over ten years (Blanco Verdugo Ingenieria, 2001) to bring the project to fruition. The stated goal of their interaction was to bring electricity to the people of these three communities.[13] While the initial idea had been the use of solar panels, the community and the NGO agreed early in their discussions that a small hydroelectric project on a river bordered by all three communities would serve their needs better – the same river into which the bodies of the massacre victims had been dumped.

[12]The massacre is briefly documented in (Stoll, 1993), but the details contained here are from "off the record" conversations with community members and development organizations that have had a long presence in Chel. Both the impression of the massacre and the persistent discomfort in speaking of it are conveyed strongly, even if details of dates and numbers of casualties are imprecise.

[13] Details of this project are from interviews with community members, unless specifically noted otherwise.

The relationship between the NGO and the communities was much more complicated than I am presenting here. Initial trust between the communities and the NGO, and between and within the communities, was very low. They worked together for years, with an NGO employee originally from a nearby community living in Chel, to help establish the credibility of the NGO, train people from the communities in the administration and maintenance of the project, and to see that all people were equitably represented. The end result was a hydro project that is largely successful (by almost any definition) in that it is technically operable, favored by its beneficiaries, administered in such a way that it pays for itself without subsidy, and is going to expand to provide electricity to other nearby communities because it has excess capacity. Although this research is not a study of the success of hydro projects, the process of creating the hydro involved the use of a PV system that is noteworthy.

Even a “micro” hydroelectric project requires significant civil works, including a dam, entrenched pipe, a building to house machinery and electronics, and poles and wires to carry electricity from the generators to the users. Chel was, at the initiation of the project, a remote and isolated community. It lacked roads, telecommunications, and electricity of any sort. It was only accessible by foot because only a weak suspension bridge connected it to the nearest roads, still miles from the communities, and the bridge would not have held the weight of a car. Members of the communities were enlisted to help with the construction of roads to enable the project to start, and a pickup truck was brought to Chel (it was dragged across a shallow point in the river during the dry season and was made operable again after it dried). Roads solved only part of the problem: there was no way to communicate with the communities except by physically visiting them.

To solve this problem, the NGO and the communities (who had by this point formed the *Asociasión Hidroeléctrica Chelense*, the association that governs the project and represents the communities’ interests in the project to the NGO and other outside parties) decided to install a solar-powered satellite phone (cell phone service was not available at that time). I was given conflicting reports of whether the NGO or the association paid the initial costs of the phone and its energy system, but I believe it was the NGO since the cost of the system would have been prohibitive as the association didn't yet have any income. Since the phone was used only occasionally for project-specific business, community members took an interest in using it for personal matters. The association saw this as a potential source of income and began charging for use of the phone. In time, they expanded the system to include two telephones and (according to one source) a fax machine.

Throughout and after the long and labor-intensive process of completing the hydroelectric project, the association continued to rent the phone on a fee-per-minute basis. The association benefited in having the additional revenue source, especially when people were newly connected to their new electric microgrid and unused to paying monthly electric bills. The communities benefited from having access to telecommunications services that were previously unavailable.

However, "recently"[14] on a nearby river, construction began on a much larger hydroelectric plant that will be connected to the national electric grid. With the influx of workers and managers to the area, two of the country's three cell phone companies constructed cell phone towers in the area. Additionally, the large construction company replaced the frail suspension bridge with a concrete bridge designed to handle even large truck traffic. The result was that cell phones became useful and readily available in Chel. Interest in the satellite phones quickly evaporated, and the association closed that part of its business.

When I asked association members what had become of the panel or panels that had powered the phones, they did not have ready answers. A few said the NGO had taken them for other purposes, but most simply had no idea. Whatever happened to them, clearly they are not functioning in their originally-intended capacity.

[14] Community members did not know even approximate dates.

Definitionally, I hypothesized that I should consider missing panels as not operational, whether they were stolen or sold or the owners don't know what happened to them. And as "operability" is a necessary but not sufficient condition for my definition of success, they must be considered unsuccessful projects. However, the panels were replaced by something the community found more useful, perhaps suggesting they were not the right thing to install in the first place. They went a long way towards enabling their replacement to happen. Solar panels, with their high capital costs and 20 to 30 year lifespans, are not generally good candidates for short-term use. Because I have to consider the now non-functioning solar-powered satellite phones represented a successful donated PV project in rural Guatemala, the "operability" criterion for project success has been broadened to include systems that operated when needed and then were removed at the end of their intended period of use.

2.3.4. Solar for home and business

The dramatic changes in Chel since the commissioning of the hydroelectric project, the opening of the bridge, and the arrival of cellular phone service are nowhere more evident than in the explosion of businesses in the town. Services that were unheard of or not needed previously (such as the photocopier, the pharmacy, or the tire repair business) now exist, and existing enterprises such as the bakery or the *tienda* now have ample competition from others in the same line of business, complete with refrigerators and lights at night. A young couple moved into Chel once these changes were underway and opened the photocopy business, with an odds-and-ends shop to draw additional customers. They installed a PV panel on their roof, despite the fact that their home/store building was connected to the (highly unreliable) hydroelectric microgrid. Because this panel was not donated to the household, the system is not within the scope of my study. But out of curiosity, I asked to inspect the system and interview the couple anyway. They had bought the panel second-hand in the informal economy, and a physical inspection of it quickly showed it to be of Mexican origin, and of the same make as panels that were donated to households in an infamously unsuccessful rural electrification project in southern Mexico (see section 3.3 for further information about the Mexican project). These panels were given to households without any instruction on what to do with them, so many of them were immediately sold. The have been reportedly seen as far south as Panama. As such, it is my (unsubstantiated) conclusion that the panel I saw was, in fact, originally donated as part of the Mexican electrification program. The panel functioned well, was well maintained, and the couple was very pleased to have it as back-up power, needed a minimum of twice daily.

The originally-intended beneficiary either sold it and opted to go without electric light, or it was stolen and the beneficiary was left in the dark. That household would have done as well or better if the government of Mexico had just handed them cash; the goal of household electrification (with the health, education, and communications benefits it brings) is not met. In this case, I see a donated PV panel that is functioning, but still I cannot consider it a successful project within the scope of this study.

The examples of the solar phones and the photocopy business in Chel show that the seemingly straightforward criterion of operability is neither universally necessary nor sufficient to define project success or failure. Functioning but not serving the intended beneficiary cannot be considered success, while not functioning because of planned obsolescence cannot be considered failure. However, success intuitively relies in some form on operability: a PV panel that never produced usable electricity is not a success to donor or beneficiary.

In this research, I consider "operability" to suggest that a system is operating generally as it was planned to operate. If a system was removed because its use was intended to be temporary, it was not inoperable due to any failure and as such is considered "operable," as is the case in Chel. Since 100% reliability cannot reasonably be expected from any technology, systems may be found inoperable at a given moment because they are under repair, but this does not suggest failure from an operability perspective. Maintenance enables the continued operation of the system. Thus, for a system included in this research to meet an "operability" criterion of success, it must meet one of three conditions:

1. it was producing usable electricity on the day of the interview or inspection;

2. it was not working, but concrete steps were being taken to repair it in the near future (for example, an organization responsible for system repair had been notified or a missing component was on order); or
3. it had been removed or abandoned because it was intended to serve temporarily until another electricity supply (such as the national electric grid or a microgrid connected to a small hydroelectric project) was implemented.

2.4. User perceptions

The *a priori* definition of success that included user-reported perceptions of the straightforward question, "is this a success for you" suffered shortfalls, just as the straightforward criterion of operability did. These shortfalls and the expanded considerations of user perceptions are included below.

2.4.1. User perception of success

Stakeholders' own understandings are often more effectively used to judge project success than expert opinion since the "expert" often lacks detailed local knowledge both about the physical system and the community (Fraser et al., 2006). An appropriate stakeholder group might be a sponsoring organization. However, as discussed above, donors and developers often do not have clear definitions of success themselves.

The perception of success within one stakeholder group can be very different than the perception of another. The goals of a donor may be different from those of community members. This is not intended to be a study of whether the donor's ultimate objectives of rural electrification are met – such as improved health, education, or income opportunities – but instead a study of whether the intermediate objective of providing electricity – for any reason – has been met (Fisher et al., 2002). Specifically, these analyses focuses on output: whether the service is available for use and whether people are using it (Bertrand et al., 2004). Less focus is given to evaluation of the programs under which these systems were implemented.

The focus of this research is on the impacts of renewable energy systems in rural communities. It is the users' or beneficiaries' perceptions of success, not the donors,' that are being considered. Community perception has been used in other studies as a measure of project success (Chakrabarti and Chakrabarti, 2002; Nieuwenhout et al., 2001; Acker and Kammen, 1996; Ley, 2006). What are people's expectations of their system, and how well does the system meet them? How do current expectations differ from the original expectations people had when the project was proposed or installed? How do they define the "success" of development projects in general, and this project specifically? However, the literature does not discuss how to gauge this perception of success when direct answers to the question do not yield useful information, as discussed below.

When users were asked whether they felt their projects were successful, the near-universal answer (94% of respondents) was "yes," and 6% of respondents described it as "more or less" successful.[15] Only one respondent said no, that the project was not a success.

There are several potential explanations for this counterintuitive response about some systems that had not functioned in years. As a foreigner asking about solar energy systems, I was perceived as a potential donor, despite having said that I was not. In the face of a potential donor, people may not want to seem ungrateful by describing previous donations as failures. Similar numbers of people answered affirmatively when asked if the project met their expectations.

When asked how they defined success and what might constitute an unsuccessful project, answers differed. Some responded with the benefits it had brought to them personally: they found the light useful or important. Some spoke of the specific benefits they associated with having PV lighting, such as reduced

[15]See Chapter 4 for survey details.

energy costs, children's ability to study later at night, and improved quality of light in the home. Most, but not all of these respondents had systems that were functioning at the time of the interview.

Another category of responses was that any donation or development project was a success. People *had* benefited, even if they were not still benefiting, so the project was counted as successful.

Some respondents, largely those with systems that were not functioning on the day of the interview, wavered on their definitive answer of "yes." They made comments like "it was good while it lasted" and "there is no system maintenance so there is no sustainability." One woman said her system was successful to her personally because she could afford to replace her battery, but not for others who couldn't afford a battery and expected the donor to replace it for them (an expectation inconsistent with that specific donation program).

Notably, the only two people who answered "no" unqualifiedly to the question of whether the project met their *expectations* had systems that were functioning on the day of the interviews. One said he was paying more for lighting with the solar home systems than he had previously; the other said that the community had expected panels of greater capacity.

A "successful" system, however, was not synonymously one that provided value to the user, nor was an unsuccessful system necessarily one that failed to provide value. The subsequent section examines the concept of value and user's perceptions thereof.

2.4.2. User perception of value

The "value" or "usefulness" of a project could be judged by a comparison of the village economic and social conditions with the project against a counterfactual "without" project condition. However, this definition of success is impractical to implement. This is because construction of such counterfactuals would either have to rely on outside "expert" opinion of the conditions in a community, which may not adequately account for beneficiaries' sense of value, or upon a statistical analysis of a large enough number of communities so that the effect of projects can be statistically controlled for, which is not feasible due to resource constraints, data availability and political instability in the regions included in this study (see Chapter 3 for details).

Instead, the end users themselves were asked to be the judges of the degree to which the project is important to meeting their needs. Where a community member surveyed reported that the project has not been important or valued, the project is not considered a success regardless of its operating condition.

2.4.3. Users in their own words

Specific responses and trends within responses are used to define both what constitutes a successful system and what does not. Several words and themes were recurrent, some of which are more easily directly translated from the language in which they were given than others. Below are several of these themes, and inferences as to the reasons for them.

Different words used in different locations may simply be colloquialisms: people tend to talk as their neighbors talk. However, people have many ways of describing the same thing, and word choice may be meaningful. Nonetheless, analysis of the words users spoke is limited because I am not fluent enough in Spanish to appreciate all the subtleties of the language. However, some words and the sentiments behind them were clear. In the following subsections, I describe five specific words or phrases and the meanings ascribed to them.

2.4.3.1. Bonito, bueno, and uts

In talking about success, *bueno* (good) and *bonito* (pretty or nice) were among the most common words used. These are both insubstantial words that convey satisfaction without strong enthusiasm. They tell more of respondents' reluctance to commit to a point of view during interviews than they tell of the success or failure of systems, as described below.

Mayan Q'eqchi' was spoken in twenty-nine of the sixty-five communities and sites visited during the course of this research.[16] Most interview subjects in these communities spoke predominantly Spanish, some spoke predominantly Q'eqchi', but nearly all used some hybridization of the two. I am limited in the analysis I can do of the words of predominantly Q'eqchi' speakers, since I must rely on the interpretation of a hired translator in cases where the interview subject could not answer questions in Spanish. However, one word I know is *uts*.

Among Qéqchi' communities, even respondents who speak Spanish often used the Q'eqchi' word *uts*. Literally translated, *uts* by itself means "well done" or "a good thing," according to Guatemalans who speak both Q'eqchi' and Spanish, but its meanings in use are myriad. It is used in response to the question "how are you?" as one example. Another example is that when water is described as *uts*, it means the water is potable. In response to questions about the success of a solar energy system or how it has met or failed to meet expectations, it means the same as *bueno* or *bonito*: it's nice.

2.4.3.2. Anything donated is a benefit

A common attitude among respondents in this study was "anything donated is good." People considered their PV systems successful even when they had quickly stopped providing value – or considered projects successful even when they themselves had been excluded – because *anyone* in the community benefited for *any* period of time. People spoke specifically of *benefit*. "I benefited for a little while," and "other people

[16] Not all are included in the analyzed data because some did not meet the criteria for project selection.

are benefiting," were common refrains when explaining why a seemingly unsuccessful project (from my perspective) was considered a success to them. "The light benefits us" and "having the project is a benefit" were things said by those with functioning systems.

Differences are found between Ladino and indigenous communities, as discussed in Chapter 7. *Benefit* was a word used in indigenous communities, but little or not at all in Ladino communities. In Spanish as well as in English, "benefit" can be used to describe a good outcome from a thing: we *benefit* from having light. But it can also be used as a noun to describe an entitlement: Social Security is a government-provided *benefit* in the U.S. The Peace Accords signed to end the civil war in Guatemala promised such benefits as development projects and education to the indigenous communities, but not to Ladino communities because they were not affected by the war in the same way. Although donated PV systems were not described as "Government benefits," the term *benefit* implies a relationship between user and government or other donor. There is a sense of entitlement – people feel entitled to the benefits owed or promised to them – but also little sense of control. People have little control over what benefits are offered to them and when they will receive them.

The idea that "anything donated is good" was also evident in comments about training, in which some respondents expressed happiness to get training on any topic (see Chapter 6). People find a way to derive value from what is offered to them, and seem to either be more successful at or have more confidence in their ability to do this than to decide independently what they need and then navigate an enormous and seemingly arbitrary web of development projects and organizations to see if they can obtain it.

The logic behind this approach is solid. The values of community members do not necessarily correspond to the values of developers and donors. Many women interviewed for this study would like to have enough electric power to run blenders (something solar home systems are not designed to do). While blenders no doubt make kitchen work easier for women and allow them more time for other activities, whether productive or of any other sort, expending critical community resources to search for a donor to provide blenders and the electricity to power them would be futile. I have found no evidence of any blender donation programs having ever existed in Guatemala. A better use of time and energy would be to work with the most available donor to obtain whatever was being offered, and then find the best way to take advantage of that.

2.3.4.3. "We can complain, we can demand"

A user of a microhydroelectric energy system in rural Guatemala said of the hydro, "It is successful because we can complain." The hydro has a local governing body that represents the users and is answerable to them. In this indigenous community, among the most severely impacted by the civil war, the user described his project as successful because he felt safe to state a grievance and had the expectation that he would be heard.

Analogously, the user of a solar home system in an indigenous community nearby who was part of a strong system management organization described success using the word "demand." "We can demand and (the management organization) will have to comply."

Thus being part of a community that collectively manages renewable energy systems may empower people to act within institutions, while being the autonomous owner of a solar home system paradoxically may be less empowering. Rural energy systems can lead individuals to act politically on their own behalf, and to view the energy system as successful because of their own success within the institution built around it (see Chapter 6).

2.3.4.4. "What we achieved"

Among users of communally owned systems, several respondents talked about the success of a project as their own or their community's success. Even among projects that were not functioning, they talked about their own accomplishment: we achieved this project; we met our goal; this was our objective and we obtained it. Unlike those who see anything donated as a success, this group saw success in what *they* did more than what was done for them.

2.3.4.5. Advancement, progress, development

Contrary to my previously-held assumption, concepts of development and advancement were rarely suggested to be part of success. The few who brought the ideas into the conversation fit no particular description: two were users of collective systems, three were users of autonomous systems. Two were among the richest people included in this study, one was among the poorest.

The *products* of "development" were mentioned by many: we have light, health is improved, and children can study. But being more developed was not itself a theme that emerged from respondents as a measure of success.

Users' perceptions of success are most meaningfully derived from their own words. Simple "yes" or "no" questions do not yield much information, but allowing users to express themselves gives insight into their thoughts on what success means to them. System users had understandings of system success that did not necessarily correspond to what developers might see as success; independently of labeling a system as "successful" or "unsuccessful," systems brought value to users to varying degrees; and the words users chose to express their sentiments about and towards their systems and the programs that brought them are at times more telling than their answers to questions phrased in the words I chose.

2.5. Optimality

A final question of success is whether users consider PV to be the best solution for their energy needs. Do they want solar energy enough that they would choose it over other energy sources? If the system were damaged or destroyed, would they wish to replace it with another solar energy system, return to using traditional energy sources, or replace it with a different energy system entirely? The question specifically did not ask whether respondents had the resources to obtain any of these sources, but simply what they would choose if they could. Systems are not considered fully successful if users would choose an energy source other than PV.

Some users have complained that solar home systems do not provide sufficient power to meet their needs (Acker and Kammen, 1996). Though this dissatisfaction is evidence of the desire for expanded systems, not dissatisfaction with the system itself (Acker and Kammen, 1996), it is another example of a community perceiving a project that is technically operable as having little value. In this research, users who wish for *more* solar power are not necessarily considered to have unsuccessful systems unless they stated explicitly that the project failed to meet their expectations or wasn't successful. On the other hand, users who express a desire for something *other* than solar are expressing dissatisfaction with the technology to the degree that it is not sustainable: they will switch if they can. Thus users who express a desire for a different form of power are not considered to have successful systems, regardless of the operating state of the hardware itself.

These systems are not considered "successful" because they fail to meet users' needs, even though from a developer's perspective some might be considered among the most successful projects included in this study. Relatively affluent beneficiaries with systems in good repair who are pleased with the utility that the system provides within its capabilities may be dissatisfied with and limited by system capacity constraints. For purposes of this study, "better than nothing" is not sufficient to call a system successful. Successful systems are those that users would choose.

2.6. Working definition of success

A uniform definition of success is useful for analysis. The originally hypothesized definition of success, a system that is technically operable and considered successful by users or owners, is inadequate as described above: systems that are inoperable because they are being maintained or have served their intended purpose are not necessarily failures, and users' near-ubiquitous response that systems are successful when asked explicitly does not imply near-ubiquitous success.

For this research, I have created an ontological definition of success (Goertz, 2006). That is, rather than *a priori* choosing characteristics to create an "if and only if" definition of success, the characteristics of the systems are examined first and success is defined based on these characteristics.

Thus for this research, several criteria emerged as useful to define success. A system is counted as successful if it meets the following criteria:

- The system was functioning on the day of the interview, or concrete steps were being taken to have it repaired in the foreseeable future, or it was removed because its use was intended to be temporary until another energy source (typically an electric grid) replaced it. Operability was an *a priori* part of the definition, but that technically inoperable systems could also be successful emerged as a part of this research;
- The user considers it successful, feels that it has met his or her expectations, and finds it important in daily life or for specific events. The hypothesis that users could simply be asked whether a system was successful proved inadequate, and other measures of satisfaction and utility give more depth and meaning to user responses.
- Assuming the resources were available, the user would not choose a different energy source if the PV system were (or had been) lost or damaged. A system may be tolerable to users in that it functions and is consistent with what they were promised upon installation, but willingness to trade it for a "better" alternative suggests that it is sub-optimal and does not meet the user's needs. A system need not be operable to be optimal; if users would gladly go back to using PV if they could afford to, then it was an optimal solution.

This is not a rigid "if and only if" definition, but rather a set of characteristics that do not define success singly, but when taken in aggregate show that the user is getting long-term benefit from the system. It is, however, a noncompensatory definition: failure in any of the three categories is sufficient to call the system a failure.

Notably, these criteria for success do not capture all possible failures. I would find it difficult to describe as successful any development intervention that makes users' situations worse than they would be without the intervention – even if it operates as designed, users perceive the project as successful, and would not choose to replace it with something different. The provision of a tube well that turns out to be contaminated with arsenic (Hoque et al., 2006) may meet these criteria for success, but if arsenic contamination in wells poses greater risk than organic contamination in the surface water that the well replaced, I could not consider the project "successful." While quantifying such risks in the case of rural electrification – and in particular quantifying the risks of the *absence* of rural electrification so the comparison could be validly made – is beyond the scope of this study, many factors not included in the original hypotheses and research questions are considered qualitatively in these analyses.

2.7. Conclusions

Success is defined narrowly for this research to relate specifically to individual systems and projects. The success of development aid in general and the process by which such success is evaluated are not examined further in this study, though they leave many questions unanswered.

The definition of success built in this chapter, with its components of operability, user perception, and optimality, is the definition used throughout this research. Though the factors that lead to each success criterion being met or unmet vary and are examined qualitatively, quantitative conclusions and comparisons depend only on one question: based on this definition, is the system a success?

Chapter 3. Context, literature review and hypotheses

In this chapter, I introduce the contexts in which this research takes place. I also discuss the hypotheses and research questions explored in this research, and review existing literature from which these hypotheses were developed.

The idea of context is broad and I consider only a few specific aspects. This study includes communities, institutions and equipment that have been involved in or resulted from development aid programs. As such, I define the concepts of "development" and "aid," and briefly discuss the histories, motivations, success and failures of programs and individuals involved. This thesis does not address the overarching questions of whether development aid accomplishes its goals or the degree to which outcomes are beneficial to donors or intended beneficiaries. However, the results of this study must be understood in the context of this donor-beneficiary model.

The second aspect of context addressed in this chapter relates to energy. This study focuses on a specific type of energy system – photovoltaic electricity production in physically independent systems – in a specific application – rural electrification to meet development goals. Section 3.2 of this chapter briefly describes the human and economic development benefits derived from modern energy sources in general and from PV systems specifically.

Sections 3.3 and 3.4 then address the context of the country of Guatemala: why it was chosen, Guatemala's history and current geopolitical environment, and the potential influence of these on the outcomes of this research.

The remainder of this chapter reviews existing literature on the application of renewable energy in rural development and describes the hypotheses and research questions I derive from this literature, and highlights areas where this research may contribute to it. These hypotheses and research questions are grouped generally into three categories: economics & utility, institutions & relationships, and characteristics & consequences. These categories are subsequently divided further into sub-sections, addressing particular aspects of each category. These are described in detail in the appropriate sections below. This categorization is for convenience, and should not be interpreted to mean that all hypotheses will fit neatly into a single category. Physical systems are shaped by institutional arrangements, which in turn take shape as a result of the characteristics of the donors and beneficiaries involved. These and many other interrelationships are addressed in this chapter and throughout this document, although the general categorization remains.

This review of existing literature shows that, while much is known about the use of renewable energy in rural electrification, much is also uncertain and existing information is sometimes contradictory. This research attempts to answer just a few of the many questions on the success and failure of rural electrification using photovoltaics, and ultimately raises many more questions yet to be addressed.

3.1. Context: International development and the concept of aid

All research takes place in context. Contexts relevant to this research include the international aid and development paradigms, and the history and culture of Guatemala. In this section, I consider concepts of aid, development and "sustainability." In subsection 3.1.1, I consider the concept of "sustainability" and the limits of its applicability in this research. Sections 3.1.2 and 3.1.3 discuss the topics of international aid and international development. Subsection 3.1.4 considers the motivations of donors who participate in aid-based development and potential effects of those motivations on system outcomes. Finally, subsection 3.1.5 considers critically the ways in which international aid has succeeded and failed.

3.1.1. Sustainable development and "sustainability"

Rural electrification can be broadly categorized as "development" and using renewable resources such as solar energy as a means for electrification often is called "sustainable development." Some would call the term sustainable development oxymoronic: development (growth, increased use of resources) is inherently unsustainable in a world of finite resources. In contrast, others would call the term redundant. Maren (Maren, 1997) succinctly says "if it's not sustainable, it's not development."

Although this work deals with what may be considered an environmentally more sustainable technology (solar panels versus diesel generators or extension of a fossil fuel-powered national electric grid), broad claims about the sustainability of any technology are specifically excluded. Lifecycle impacts of the panels themselves, lead contamination from improper battery disposal, reduced dependence on petroleum-based fuel sources like kerosene, and other positive and negative environmental or fossil fuel related impacts of these systems will not be considered.

Defining all the necessary and sufficient characteristics for an energy system to be considered "sustainable" is a significant task, fraught with controversy, and beyond the scope of this research. Here I merely postulate that a rural electrification system must be considered "unsustainable" unless its users can expect to have electricity into the indefinite future, just as their urban counterparts can. While a system that continues to work or will be replaced is only one necessary (though not sufficient) condition of sustainability, it is the only condition of sustainability considered in this research.

3.1.2. International aid

Indisputably, some people and nations in the world have much "more" than others: more wealth and economic opportunity; better access to health care and education; more freedom of speech, movement, and organization; better natural and built environments; longer life expectancy and better overall quality of life. The distinction between the "haves" and the "have nots" (and the "in-betweens") can be made along many lines. The World Bank distinguishes between low, lower-middle, upper middle, and high income countries, while noting that "classification by income does not necessarily reflect development status" (Saghir, 2001). The United Nations Development Programme uses a continuous "Human Development Index" to rate countries based on income and quality of life criteria (UNDP, 2013). Some divide nations as OECD members or non-members. There can be said to be a "North/South" divide. Economist Paul Collier divides the world into three groups: a small group of rich nations, a large group of developing nations, and a small group of nations that are categorically failing to develop (Collier, 2007). Some nations and individuals choose to become donors to others. Some choose to be beneficiaries by accepting what donors offer. Many are both.

Approaches to aid (among them charity, development, social justice, discussed in this section) depend upon the perceived agency of the beneficiaries (Farmer, 2005), where "charity" may imply that beneficiaries are inferior and powerless victims of circumstance, "development" that beneficiaries can overcome their circumstances with the right tools, and "social justice" that circumstances must be change to empower beneficiaries. There is little discussion about the ability of those living in poverty or extreme poverty to survive or even prosper absent such aid or outside help in development (Collins et al., 2009), though it is an area that merits study.

Regardless of the type of aid, the relationship between donor and beneficiary is complex. The current system of international aid for relief and development has many failings, despite what I believe to be the best intentions of most people who are involved. The low success rate of the donated solar energy systems considered in these analyses may be strongly affected by the success of donation as a model for aid. Although members of beneficiary communities included in this study were asked about their impressions of and interactions with project donors, this work is not a comprehensive empirical study of the donor/beneficiary relationship. However, these results exist within the context of the donor model, which is explored in further detail in this section.

3.1.3. International aid for development

This work focuses predominantly on what I call "development aid," which I define to include donation or subsidy to projects or programs with goals of long-term benefits. The individuals and communities I studied are the recipients of donated or partially donated solar photovoltaic systems. The systems in this study are not portable, but are intended to be long-term investments in infrastructure. If a road washes out during a storm or becomes impassible because of lack of grading and other maintenance, it does not imply that the road was intended to be temporary. Similarly, I assume “permanently” installed PV systems are intended for long-term use, whether or not they are usable in the long term.

“Development” has many definitions. “Persuading everyone to behave decently to each other because the society is so fragile is a worthy goal, but it may be more straightforward just to make the societies less fragile, which means developing their economies,” argues Collier (Collier, 2007) . Sustained economic growth, improved long-term quality of life, or both are generally the intended results of “development.” Economic growth in a county is said to benefit the poor as well as the rich (Dollar and Kraay, 2002; Collier, 2007), with incomes in the poorest quintile appearing to rise proportionally with a country’s median income (Dollar and Kraay, 2002). International aid to the poorest countries contributes to their overall economic growth (Collier, 2007). As such, most international aid should help the poorest people in beneficiary countries, subject to conditions including rule of law (Dollar and Kraay, 2002), accountability of government officials (Collier, 2007), and others. These conclusions are arguable: development is sometimes achieved on a national scale at the expense of the nation’s poor (Farmer, 2005), as when small farmers are left landless when a dam is built for hydroelectric power. In Central America, countries are generally on track to meet their UN Millennium Development Goals in urban areas, but are failing dramatically among the rural poor (United Nations, 2011). It can be said that many international development programs have the *intention* of producing economic growth opportunities among the poor (either to reduce inequity between rich and poor or to raise the standard of living of entire populations), whether as an end unto itself (Collier, 2007) or as part of a larger concept of quality of life (Farmer, 2005). “Who would argue with the proposition that a robust economy is preferable to handouts?” (Farmer, 2005). Aid programs with goals such as health or education may be called “photogenic” (Collier, 2007) or “starry-eyed” (Farmer, 2005) by those advocating a purely growth-oriented strategy, despite that higher levels of education are often considered prerequisite (or at least contributing) to economic growth (Collier, 2007) and basic physical health is inarguably necessary for the unskilled laborers who are a key input to a growing economy.

Development aid under a donor model consists of the processes and institutions involved in pursuing greater economic opportunity or quality of life for beneficiaries, using (at least in part) resources from a donor or group of donors who perceive themselves to have an economic or quality of life advantage over the beneficiaries and to be in possession of the knowledge necessary to bring the beneficiaries' economic and quality of life conditions closer to their own.

3.1.4. Donor motivation

Decisions to provide aid to specific countries are often politically driven or driven by the economic needs of the donor country rather than the beneficiary country. Aid might be seen as a means to extend a donor country's influence over the beneficiary country without acquiring the responsibilities and international disrepute that are a part of explicit colonialism. For example, family planning efforts have been carried out in locations with some of the world's lowest population densities but rich mineral deposits (Galeano, 1973), illustrating the use of aid to lessen competition for scarce resources. A delivery of emergency relief to Japan after a 1990 earthquake included 12,000 bras (Maren, 1997), illustrating aid being used as a means to soak up surplus goods that cannot be profitably sold in the donor country rather than to meet a beneficiary's need. The U.S. Government's significant involvement in foreign aid began with this objective in mind: the Agricultural Trade Development and Assistance Act of 1954 explicitly states its intention as finding markets for excess U.S. farm products and opening future markets for the same and furthering U.S. foreign policy objectives, while simultaneously helping to feed those people living in needy countries (Maren, 1997). Prototype programs before this act also emphasized the absorption of excess agricultural products and the expansion of markets as goals, alongside feeding hungry people (Maren, 1997). Since the end of the Cold War, the opening of markets to free trade is a frequent, fairly direct goal of many international aid programs, pursued by donors even at the price of helping to secure the position of dictators or other repressive heads of state in beneficiary countries (Farmer, 2005).

Discrepancies between what is wanted by beneficiaries and what is provided by donors can be attributed to self-serving economic or political agendas, as above, but are sometimes the result of misunderstanding of or disagreement about beneficiaries' needs. At the World Summit on the Information Society held in Tunisia in 2005, potential beneficiary countries questioned the need for computers to be donated to children living in extreme poverty when the One Laptop Per Child program was discussed (Smith, 2005). Participant Marthe Dansokho from Cameroon stated "What is needed is clean water and real schools" (Smith, 2005) . Another participant asked "What use is that computer for your children who don't have a doctor within walking distance?" (Smith, 2005). But the sincere desire to reduce the disadvantages caused by the so-called "digital divide" may have led many people from wealthier countries to see giving computers to poor children as a very positive step.

In another example of donors' incomplete understanding of beneficiaries' needs described by Paul Framer (Farmer, 2005), patient non-compliance with free tuberculosis treatment in Haiti was initially ascribed by some health professionals to patients' beliefs that witchcraft caused the illness, making drugs and medical treatment useless. In fact, poverty made compliance with treatment impossible for some. Many patients did not have time to come to clinics for treatment because they were working to keep their families from starving, whether they believed sorcery played a role in their illness or not. People could not sleep away from others to avoid infecting them when the entire family shared a single-room hut. Patients were non-compliant with doctors' orders to eat well because they had insufficient food. In this case, "free" was still too expensive, and the donor initially did not understand this.

As another example of donor motivation, aid may be used politically to improve the image of one country or organization, or to embarrass another. During a time when Venezuelan President Hugo Chavez and then-U.S. President George W. Bush had a clearly adversarial relationship, the Venezuelan government opted to provide assistance in paying for heating oil to poor families in the U.S. at the same time the U.S. federal government was cutting its domestic heating oil assistance program (Ekstrom, 2008). Reportedly in response to falling oil prices and in an effort to maintain its hard currency reserves, Venezuela suspended the program four years later in January, 2009 (Romero, 2009). In the same month, U.S. President George W. Bush was replaced by incoming President Barack Obama (Zeleny and Stolberg, 2009).

Political favoritism or attempts to influence political opinions are also motivations for providing aid. Members of one community included in this study received replacement batteries for their solar home systems from a political candidate immediately before an election.[17] Communities in another district benefited from a government solar panel program despite that they had already benefited from a private program, in explicit violation of government program policy (an employee in the government program later insisted that no such double donations existed). Community members acknowledged that their representative at the time of the government installation was politically powerful in Guatemala City without directly drawing the link between his influence and their "unorthodox" participation in the government program. These cases are explored in more detail below.

In my experience, most individuals who are involved as donors in any capacity have genuinely altruistic goals. However, there are many options for states, organizations, and individuals to become donors, and motivations for involvement in specific groups, locations, or types of projects vary considerably. The noble goal of feeding the hungry can be linked easily to a state's political goal of opening new markets for its goods. Students' genuine desires to improve infrastructure for those less fortunate may be leveraged to improve their résumés at the same time. Without second-guessing the good intentions that drive people to participate in donation-based development projects, their motivations for choosing their methods of involvement clearly impact who benefits and in what way.

3.1.5. The success and failure of aid

Donor and development agencies and organizations, whether public or private, are generally expected to define the criteria for success of their projects, and self-evaluate and report on this success, with evaluation and reporting often carried out by people who will themselves be judged professionally by the success of their projects.[18] The U.S. government, which frequently awards contracts to these organizations, relies heavily or entirely on their self-reported success to justify the award of future contracts. In some cases,

[17] Details of the case studies mentioned here are found in Chapter 6.

[18] Source for this paragraph is (Maren, 1997) except where otherwise noted.

USAID may also lack the means to successfully evaluate its own programs. The U.S. General Accounting Office noted in a 1993 report that USAID had no system to assess whether donated food in fact meets the goal of improving the "food security" of the beneficiary country (quoted in Maren, 1997). Specific examples of project developers' evaluations of success in energy development are found in Chapter 2, Defining Success.

International aid may take the form of "budget support," which is merely a cash inflow into an existing government budget.[19] The effectiveness of this type of aid is highly dependent upon the recipient government being "reasonable" in how it is spent; the more corruption there is – or the further apart the donor and recipient governments are in their goals – the less aid this money will bring to the intended recipients. Further, in the poorest countries, large amounts of aid money increase the statistical likelihood that a coup will take place.

Project-specific aid is more relevant to these analyses, but it too faces many potential pitfalls. Beneficiaries seem unlikely to reject anything offered for free or nearly free, regardless of their need for it. In response to this, "participatory development" was a practice attempted by some project developers. Its intention was nominally to work with beneficiaries to assess their needs, but in some cases became more of a consensus-building exercise in which donors sought to convince beneficiaries that they needed what the donor was offering (Maren, 1997).

Aid agencies are not generally coordinated with one another and conflicting goals can place them at odds with one another (Collier, 2007; Maren, 1997), perhaps negating each other's work. Further, logistics are an enormous challenge to project-specific aid, and may take up more time than the actual development work (Maren, 1997), creating a huge drain on available resources. And creating infrastructure or implementing hardware does not necessarily provide benefit. "Any engineer can construct an irrigation system, but using the system to grow food is another matter altogether" (Maren, 1997).

[19] Source for this paragraph is (Collier, 2007) except where otherwise noted.

Aid can create unintended incentives for beneficiaries. People spend their energies getting access to what donors are offering rather than working towards self-sufficiency (Maren, 1997). "The donors are amateurs. The recipients are professionals," notes Maren. Once the stream of aid stops, "professional" recipients may be left with a skill set that is no longer useful and no other means of supporting themselves.

Aid itself can be the source of conflict (Farmer, 2005), with corrupt officials skimming off (or dipping deeply into) donated resources, populations being gathered together by promises of aid and then resettled according to a government's plan, and tensions being created or heightened between recipients and non-recipients, as in the case of refugees who get aid while the poor of their host countries do not (Maren, 1997).

Donations distort local prices, at times ruining local businesses by undercutting their prices (often to zero).[20] This can have disastrous long-term impacts on a beneficiary country's economy if those previously producing or importing the commodity being donated are forced permanently out of business; when the aid is no longer available, the means and markets needed to fulfill the demand no longer exist.

Contrarily, in some circumstances (including the case of solar PV systems) donors may also build beneficiary countries' markets by creating demand for a commodity to be purchased locally, providing needed training in a novel technology, and creating the demonstration projects that work as proof of concept for people who may later purchase systems themselves (Acker and Kammen, 1996). However, the risk of undercutting local prices (thereby threatening emerging markets) remains, even when local vendors are used, if beneficiaries sell their systems at below-market prices (Corsair and Ley, 2008). The positive and negative influences of donors on solar PV markets in rural developing world applications are discussed in greater detail in Chapter 5.

[20] Source for this paragraph is (Maren, 1997) except where otherwise noted.

Donors' impacts on development in beneficiary countries varies greatly, and may have unintended consequences and create perverse incentives. The questions of whether or to what degree rural stand-alone PV systems in Guatemala succeed or fail because they are donated under development models that don't work, and whether donation bolsters or impedes local Guatemalan PV markets are not answered in this study. Donated systems are not compared to systems obtained through market or other models. However, the observed differences in success between programs in which donors remain involved and those in which donors leave suggests that some donation models are more suitable to PV for rural electrification in Guatemala than others.

3.1.6. Conclusions concerning the contexts of international development and aid

Although development aid is not the subject of this research, the stand-alone solar electric systems included in this research are donated under a development-based aid paradigm, and must be understood in that context. The level of development of a country and the aims of the process of development can be defined in many ways, but most center on economic opportunity and quality of life. Donor nations, organizations and individuals can have self-serving as well as altruistic motivations and intentions, and may consider their actions to be anything from helping the helpless to empowering people to overcome adverse circumstances to changing the underlying circumstances that cause them to need aid in the first place. In the following section, I consider Guatemala and electrification in Guatemala within this context of aid and development.

3.2. Context: Electricity in Guatemala

Guatemala, and specifically rural electrification in Guatemala, is a part of the context of this research. In this section, I explore briefly the rationale for electrification, and the history and culture of Guatemala. This section provides the background against which my hypotheses and research questions are framed in section 3.5

3.2.1. The need for and advantages of renewable energy

The provision of modern energy sources such as electricity is a goal of some development programs. In this section, I examine the rationale for including modern energy as part of a development paradigm, and the particular advantages of including renewable electric power generation.

3.2.2. The need for electricity

Energy is not an end unto itself: it is a means for achieving other goals. In the U.S., modern energy sources are the basis for our quality of life and economic opportunity. Potable water, our food system, medicine, homes, commerce, and industry all depend on the availability of inexpensive energy. Electricity provision has not always been an explicit goal of broader development agendas (Cherni and Hill, 2009} and important goal sets such as the United Nations Millennium Development Goals (MDG's) omit quantifiable or qualifiable electrification targets (UN MDG's, 2000).

In developing countries in rural areas, most of the energy consumed is traditional biomass: firewood, crop residue, dung, and other easily available combustibles (Saghir, 2005; Casillas and Kammen, 2010). These are normally burned in open fireplaces. In addition, many people have access to and use candles and gas or kerosene lanterns, and some rely on wooden torches. The potential for improvements in economic opportunity and quality of life are substantial when people have access to electric power (UN MDG's, 2000; Saghir, 2005), and the provision of modern energy sources can contribute substantially to other development goals (Saghir, 2005; Rady, 1992; Chakrabarti and Chakrabarti, 2002). However, electrification does not by itself bring about these outcomes if other fundamental needs remain unmet (Casillas and Kammen, 2010).

About 1.5 billion people in the world lack access to electricity (Legros, 2009) and electrification in rural developing world locations is particularly low (Rady, 1992; Barnes and Foley, 2004). Extending the electric grid to rural locations is often infeasible because of the high cost (Grimshaw and Lewis, 2010; Soto et al., 2012; Wiens, 2011), or the demand density is so low that a grid system is technically infeasible (Rady, 1992), or is undesirable because grid electricity in remote locations is so unreliable (Acker and

Kammen, 1996; Chakrabarti and Chakrabarti, 2002) . That a community is connected to the grid is by no means an indication that all or even most of the households have electricity (Ailawadi et al., 2006; Rady, 1992) , although the location is then considered to be "electrified" for government reporting purposes, as I also observed in Guatemala.

3.2.3 Rural electrification using solar photovoltaics

Small-scale renewable energy can offer advantages in development projects. Solar photovoltaics offer the technical advantage of being "scalable" (Breyer, 2010; Acker and Kammen, 1996); that is, regardless of amount of power needed, a system can be created that is very nearly ideally sized. Suites of intermittent renewable energy sources – or renewables in combination with diesel generators – may be the best approach to rural electrification near the equator, making photovoltaics particularly suitable (de Jong et al., 2013; Alazraque-Cherni, 2008; Mostofi and Shayeghi, 2012; Tanoto, 2011). A disadvantage to PV in many developing countries near the equator is that they are frequently hot, and high temperature lowers the efficiency of PV (Skoplaki and Palyvos, 2012; Chow, 2010), which lessens the advantage of greater insolation.

Intermittency can be an issue with renewable energy sources if highly reliable power is demanded. The sun, wind and flowing water may or may not provide maximum available energy when maximum power is needed. Providing very highly reliable power can cause large increases in the cost of stand-alone renewable energy systems (Corsair, 2005). However, the degree of reliability demanded in rural developing world applications is arguably lower than that which is needed for more "advanced" societies that depend upon electricity to meet basic needs.[21]

Beyond the reach of the national electric grid in rural Guatemala, I observed home lighting produced from kerosene lanterns, candles, flashlights, and torches made from *ocote*, a resin-rich pine found readily in

[21] For example, water provision in developed countries generally requires electric pumps; a loss of electricity means a loss of water and viable alternative sources are few. In contrast, in a location that water is drawn from a well by hand, an interruption in electricity supply has no bearing on water supply.

Guatemala, and sometimes provided by electric lights powered by car batteries that are re-charged by vehicles or in grid-connected communities.

Solar photovoltaic electricity production can be used for lighting and other small applications in rural locations. Its use has numerous advantages over traditional energy sources or local diesel generators. Users of solar home systems with whom I spoke found the quality of light to be better than that from combustion sources, and some expressed appreciation for the improvement in indoor air quality. *Ocote* produces a particularly egregious amount of smoke and poor lighting quality, according to those who had used it for lighting.[22]

Energy consumption is generally lower in rural, developing world environments than in urban environments in the same countries or in developed countries (Bazilian et al., 2011; Grimshaw and Lewis, 2010; Rady, 1992), and Guatemala is not exceptional in that regard. Solar photovoltaic panels are very modular and systems can be sized to meet the small needs of rural households.

Although photovoltaics have high up-front capital costs, PV can be most cost-effective means of energy production in remote applications, under some conditions (Casillas and Kamen, 2011; Chakrabarti and Chakrabarti, 2002), especially because the cost of transmission from centralized power plants can be high. Even micro-grids that link buildings in a single community to a centralized micro-hydroelectric or diesel plant have substantial costs. A particularly noteworthy example of the cost of micro-grids comes from the northern highlands of Guatemala: a small hydroelectric plant was installed to power three geographically close communities. These communities were not accessible by road, so all equipment and supplies had to be carried in by hand, and the community members were expected to provide all unskilled labor for the project, including transporting materials. Ten years after the inception of the project, every community member with whom I spoke about their personal contribution to the power system mentioned that they or their husbands helped carry the power poles from the end of the road, seven miles to the community.

[22] See Chapter 5 for details.

Though this was not a monetary cost, it was the only cost unanimously remembered by the contributors, and was viewed by them as substantial. See Chapter 2 for more details about this community.

A particular economic advantage to PV over diesel generators is insulation from fuel price volatility. In interviews conducted in the later part of 2008, most people who used diesel or gasoline in any capacity complained of the unexpectedly high prices during the much of that year.

PV has the advantages of being environmentally benign on a local level (it creates no air or noise pollution in the location of use, and can be installed without the damage that can be caused by clearing rights-of-way for power lines). From a global perspective, once installed, PV does not contribute to climate change and does not rely upon exhaustible fossil fuels that must be imported and are therefore subject to disruption and price volatility due to events very far removed from the final energy users in the remote communities in Guatemala.

Thus, quality of life and economic opportunities in rural areas are improved with the provision of modern energy sources. Photovoltaic electricity can offer both cost and environmental benefits over alternative means of providing electricity.

3.3. Why Guatemala?

Problems of rural electrification are ubiquitous. More and less developed countries alike have rural populations without access to national electric grids, or whose access is unreliable. Problems with solar energy in rural electrification projects are also broadly reported, as detailed in Chapter 2.

In this way, Guatemala, the country chosen for this study, is not unique. Further, the solar energy projects within Guatemala that are included in this study share characteristics with many other solar energy projects within Guatemala, Latin America, and the developing world in general.

However, every nation has its own cultural and geopolitical environments that form the context in which electrification projects are undertaken. While it is fair to say that Guatemala, like other developing countries, experiences problems with solar energy in rural electrification, this study does not presume to present evidence that these problems are *the same* as problems encountered in other countries, nor even that the specific projects and areas studied are necessarily representative of those found in Guatemala as a whole. The results of this study may be a useful starting place for examining analogous systems, locations and environments.

Thus the country of Guatemala and the projects and programs within the country were not chosen to be representative, but were instead chosen as a starting point against which to compare future and analogous studies. The country was chosen in large part to minimize demands on the constrained time and monetary resources of the research. Familiarity with the language, acquaintance with people and organizations working on electrification and development in the country, proximity to the home research institution, and relative political stability at the outset of the study were all factors that made Guatemala a favorable choice. Analogously, solar projects within Guatemala were chosen based on information available about them outside the communities, safety and stability of the departments in which they were located, and reasonable accessibility. Details of site selection are found in section 4.4.1, below.

All results must be understood within the context of Guatemala as a country with a difficult physical geography that has played a significant role in its turbulent history and diversity of population. This research is not an analysis of a technology isolated in a laboratory, but tells the story of energy as a basic need of Guatemala's rural poor, and solar photovoltaic electricity production as a resource to meet that need.

3.4. Rural electrification in Guatemala, in context

In Guatemala, many organizations have installed PV as part of solar home systems and other small stand-alone applications. Although some programs have succeeded, the technology cannot be said to categorically be a success. This research examines the differentiating factors between systems that succeed and those that fail. What exactly constitutes "success" is discussed in Chapter 2.

As described in this section, Guatemala has suffered near continuous warfare and violence since the time of the Conquistadores. A 30-year civil war ended in 1996, after having killed or displaced huge segments of the population. The indigenous Mayans who make up half of Guatemala's population suffered the most loss of both life and property during the civil war, and have been left with low levels of education and little trust for the government or other "outsiders," as explained below. Currently, although no active *political* strife dominates the Guatemalan landscape (isolated political assassinations continue to take place, but they are targeted and have not led to much civil unrest), it is at risk of failing as a state as more and more territory is controlled by drug cartels and other organized crime.

This study focuses on those systems located in areas that were governed by rule of law at the time of the study, though some areas were marginal and several have fallen to *narco* control since. In Section 3.4.1, I briefly describe the history and culture of Guatemala. Section 3.4.2 highlights the lasting impact of the recent civil war on the current political and social environments in Guatemala. Finally, Section 3.4.3 briefly describes the current opportunities and challenges in a country that has come increasingly under the influence of organized crime.

The findings of this study may shed light on the analogous successes and failures in other locations, but these findings must be understood in a context that is uniquely Guatemalan.

3.4.1. Guatemala background

"We grow our corn; it is part of our culture," said Federico Franco, then-Vice Minister of Sustainable Development under the Ministry of Energy and Mines, "but we are a land of rivers and trees."[23]

[23] The statement was made at a press conference, as detailed below.

Franco’s statement is aptly descriptive of Guatemala. It is an agrarian society in which 50% of the population engages in some form of agriculture (U.S. Department of State, 2009 (2)). Corn is a cultural staple as well as a food staple in Guatemala, especially in rural areas. It is described as an “extremely sensitive commodit[y] in the public consciousness” (Tay, 2007). According to one coffee and rubber plantation owner (interviewed in August, 2006), the *peones* who work his land prefer to grow their own corn than to buy it, despite the fact that seed and fertilizer prices made it more expensive to grow than to buy at the time.

Franco’s statement also illustrates that Guatemala is a land in conflict, quite apart from the violent environment described in Section 3.4.3., below. The statement was made on 17 October, 2008, during a press conference about sustainable development. Leaders of rural communities who had not been invited to the press conference arrived to air their concerns; notably, they were concerned about their exclusion from discussions about development that involved them and the land that historically has been theirs. People in agrarian communities need land and water to produce food, and may find themselves in competition with both development and conservation efforts. According to interviews conducted during the timeframe of this study, the needs of farmers, pisciculturists, and other small water users are sometimes in conflict with the water needs of upstream hydroelectric power producers, and the voices of these small users are not always heard.

Guatemala is a country of approximately 14 million people (U.S. Department of State, 2009 (2)), the largest population of any country in Central America (CIA, 2009). It is bordered by El Salvador and Honduras to the south, and Belize (a contested territory (U.S. Department of State, 2009 (1))) and Mexico to the north (U.S. Department of State, 2009 (2)).

Approximately one half of Guatemala’s population is ethnically indigenous (Stoll, 1993), with estimates ranging from 40% to 65% (CIA, 2013; Plant, 1998). However, the indigenous populations should not be considered one homogenous culture. Indigenous communities may be differentiated from one another by language, clothing, religion, location, and history. Although Spanish is spoken throughout Guatemala, over twenty languages are officially recognized (U.S. Department of State, 2009 (2)), mostly (though not all) Mayan languages. Some of these have dialects distinctive enough that speakers of what is nominally the same language were seen to have had trouble understanding one another. Traditional attire (worn predominantly by women) in Mayan communities varies by region. In urban areas, where most people eschew traditional clothing and work in non-agrarian jobs, the distinction between Ladino and indigenous can be nebulous.

The Guatemalan people are poor, by almost any measure. Over half of Guatemalans live in poverty (CIA, 2013). In rural areas, the poverty rate is higher, around 70% (UN World Food Programme, 2010). Over 13% of Guatemalans live on less than $1/day (CIA, 2013), and Guatemala has one of the most unequal income distributions in the hemisphere (U.S. Department of State, 2009 (2)). Guatemala has the highest rate of chronic malnutrition in Latin America, and the fourth highest in the world (UN World Food Programme, 2010). The United Nations Human Development Index (HDI) assesses poverty using both economic and quality of life indicators (UNDP Human Development Reports, 2010). Guatemala's 2009 HDI score, while an improvement over previous years, remains the lowest in Latin America (UNDP Human Development Reports, 2010). Poverty and ethnicity are strongly correlated, with indigenous populations being notably poorer than their *Ladino* counterparts (CIA, 2013; Plant, 1998).

Despite their poverty, I have found Guatemalans (or *Chapines*, as they call themselves) to be both proud and generous. I was shown hospitality that surprised me both by the urban rich and the rural poor: from rides in helicopters to cups of coffee that meant someone in the household would do without. Several people spoke with pride about the Quetzal, their national bird, seeming to boast that it must live free. If it is caged it will die, suggesting that the people too will fight to the death for their freedom.

The earliest recorded history of people in the territory that is modern Guatemala is of the Mayan populations, some of whose descendants still live literally atop ruins of their ancestors' civilization.[24] Spanish conquest of Guatemala's lands began in the 1520's (although parts of it remained largely untouched by Spanish or *Ladino* influence until the 20th century; Stoll, 1993), and Spanish rule persisted until September 15, 1821 (CIA, 2013). For over one hundred years thereafter, Guatemala "passed through a series of dictatorships, insurgencies…, coups, and stretches of military rule" (U.S. Department of State, 2009 (2)) , including a coup enabled by the CIA that overthrew a short-lived but democratically elected government (Grandin, 2005) to the benefit and with the support of U.S.-based corporations like the United Fruit Company (Bowen, 1983). Out of these four and a half centuries of violence and oppression emerged what is called the Guatemalan Civil War.

The legacies left behind by Mayan, Colonial, and post-Colonial populations are certainly not limited to conflict. The ruins at Tikal are among the most significant archaeological finds of the Mayan people (Wiseman, 1998), and beautiful colonial architecture is found throughout the country. However, the outcome was none the less a civil war that cost between 100,000 (Grandin, 2005; CIA, 2009) and 200,000 lives (Roht Arriaza, 2008; Ball et al., 1999).[25]

3.4.2. The legacy of civil war

In December 1996, Guatemala emerged from its bloody, 36-years-long civil war (U.S. Department of State, 2009 (2)). Everyone interviewed for this study, which included only adults of at least 18 years, was school aged or older when the war ended. Although few chose to talk about it, I believe almost all remember and were affected by it.

The brutality of the killings, rapes, tortures, and desecration of sacred places committed by or on behalf of the state make the Guatemalan civil war among the most violent modern wars seen in the Western

[24] The above-mentioned 2006 interview took place on a coffee and rubber plantation (where the *Ladino patron* and indigenous *peones* currently live) that is constructed atop the ruins of an ancient Mayan city. The plantation owner has allowed archaeological excavation of some of the site.

[25] The wide disparity in values suggests that the reliability of one or more data sources may be questionable.

Hemisphere (Grandin, 2005), the specifics of which were little discussed by my informants and therefore will be included as a part of this work only if directly relevant. I find it sufficient to say that people interviewed in this study are closely akin to people who were long oppressed under a colonial regime, and who saw their countrymen slaughtered during the 1980's and 1990's.[26] The difference in the impact of the war on Mayan and *Ladino* people may account for some of the categorical differences in their responses. Those differences are discussed where relevant in subsequent chapters.

The indigenous people of Guatemala were more affected by civil war violence than their *Ladino* counterparts, and those in some departments were more affected than others. From colonial times to the 1970's, *Ladino*, elite, and government reaction to demands from rural Mayans typically has been to classify any protest gathering as a *motín de indios* (an Indian riot), and to react with force to suppress it.[27] The four decades long civil war did not, initially, deal differently with indigenous populations than its colonial antecedent. Starting in the early 1980's, the Guatemalan government and armed forces tactics changed from the use of violence as a reaction to specific events to a "scorched earth campaign" that left countless Mayans dead and over 400 villages destroyed. The campaign, begun in 1981, has been called genocide, a charge reinforced by staggering drops in population; national government estimates were nearly double the population that was measured by census or local health centers (Stoll, 1993). Notably, the number of indigenous Guatemalans killed is very uncertain, with Grandin (2004) claiming over 100,000, Roht Arriaza (2008) saying that "most" of 200,000 deaths attributed to the civil war were Mayans (Roht Arriaza, 2008), and Ball et al. specifically claiming that 83% of 200,000 murders were of indigenous people (Ball et al., 1999). Additionally, an estimated one million people were displaced (Manz, 1988; Stoll, 1993), either internally, or for approximately 200,000 people, to neighboring countries (predominantly the U.S. and Mexico) (Manz, 1988). The purpose of the intensity of the violence seems not merely to destroy a then-

[26] One of the best-known authors to write about the struggles of indigenous peoples in modern Guatemala is Nobel Prize-winning author Rigoberta Menchu. While her autobiography is categorically believed to be representative of the plight of rural Mayans in general, there are several parts of it which she herself admits can be said to be perhaps truer in spirit than they are in fact. As a story-teller who has illustrated the lives and deaths of Guatemala's indigenous populations, she contributes a great deal. However, I do not cite her work in this research because she attests as facts things that she now admits she knew were not factually accurate when she wrote them.

[27] Source for this paragraph is (Grandin, 2004) except where otherwise noted.

current insurgency and its support base, but to "eliminat(e) future capacity for opposition" (Manz, 1988, p 17).

Violence and atrocities committed during the Guatemalan civil war were not exclusively committed by the state and state-allied paramilitary forces; rebel forces committed similar acts of violence, but in far fewer numbers (Ball et al., 1999). This fact is not presented as a justification for atrocities committed by insurgents, but rather a justification for focusing on state-initiated violence and its impact on rural Mayan populations in this work.

The Guatemalan civil war was fought in a Cold War context, with most decisions and divisions based on Cold War political lines and priorities.[28] The war began after the 1954 U.S. intervention that led to the overthrow of the democratically-elected president Jacobo Arbenz. The fight to democratize the nation – to free itself of its colonial and dictatorial past – was undertaken originally by reformers on both sides, but ultimately gave way to political pressures to appease and appeal to the Soviet Union on the left and the U.S. on the right, largely leaving out the very marginalized populations that were the original targets of the reform. The name "communism" became something for or against which opposing groups could rally (and rally international support), for practical purposes eliminating the possibility of left/right coalitions working towards a common cause. However, a small sense of political agency began to manifest itself within the population in general, which was a threat to the established political and economic elite. The populace no longer accepted at face value the colonial-era sense of entitlement held by the ruling class.

The U.S. held ever-increasing influence throughout the Americas, and elites leveraged two U.S. goals to fortify themselves: the exclusion (local extinction?) of communism and the desire to secure U.S. access to markets and materials in the region (Grandin, 2005). Peasant and union movements came to be seen not as the democratization of the political sphere, but the incursion of communism. Democracy and development, which were seen to go hand in hand after World War II, were seen to be in conflict in Latin America as

[28] Source for this paragraph is (Grandin, 2004) except where otherwise noted.

attracting foreign capital for economic development increasingly required repressing peasant and labor classes (Grandin, 2005).

Guatemala, among many states in Latin America, eventually grew to a more democratic state that was more inclusive of the populace.[29] In 1963, the U.S. again decided that its democratically elected government was a threat and aided the military in successfully overthrowing the president. However, the power behind the movement was vested more in an ambitious middle class than in the military or traditional elite. The government's increasing political repression largely silenced the left's traditional leaders that garnered their power from the working class, and power shifted to rural (and mostly indigenous) people who worked clandestinely as an insurgency rather than within the existing political paradigm. "In thousands – perhaps hundreds of thousands – of cases… government violence targeting political action had the effect of isolating individual leaders, wrenching them out of their larger political and ethical universe" (Grandin, 2005). The government and paramilitaries began to treat all indigenous people as rebels.

This is the backdrop against which the history of post-war Guatemala is set: colonial oppression leading to imperial repression and repression by the existing elite. The Cold War drama played out in Guatemala, just as on the international stage, in Guatemala's case leading specifically to the wholesale slaughter of its indigenous peoples. It is my observation that the battles, both violent and political, the Mayans have fought have left them economically poor, poorly organized, distrustful of outsiders and even of their own neighbors, and reluctant to assert themselves publicly, either individually or as a group. For decades, the penalty for any action – not merely those in opposition to the government, but any action not initiated by the government – has been death. Specifically, between 1978 and 1980, the government sought to destroy legal popular grass roots movements by killing their leaders, leaving behind "a generation of dead or exiled… leaders" (Manz, 1988, P17). By 1983 when the rural areas were largely under military control, the population was left with many leaders dead and local institutions destroyed (Manz, 1988). People who

[29] Source for this paragraph is (Roht-Arriaza, 2008) except where otherwise noted.

challenged the government were frequently tortured or murdered, though wide-scale massacres largely stopped by this point (Manz, 1988).

Though this is in largest part no longer true (I have not heard rumors of peasants being disappeared by government or paramilitary forces, but high-profile political figures have continued to die under mysterious circumstances), the Peace Accords signed in 1996 seem to be interpreted by the indigenous with whom I spoke in the same context as the military rules that preceded them: the government said it would do a thing (perhaps install a small hydroelectric plant for a community), and the responsibility for not only building it but also for maintaining it falls on the shoulders of the government that agreed to it. Part of this expectation seems to come from an emergent sense of entitlement: after what the government did to us during the war, they owe this to us, and further, they agreed that they owe this to us. But part of this must come from the sense of paternalism that the government fostered during the civil war, as did colonial land owners before them. Effective self-determination is a skill set that has not been ignored but actively repressed for hundreds of years in the Mayan communities in Guatemala. Those who learn or are perhaps born with the sense that they have the power to significantly improve life for themselves and their families tend to select themselves out of village life by migrating to Guatemalan cities, to Mexico, or to the U.S. The local elites who do choose to remain in the communities tend not to wear traditional Mayan dress. Whether divorcing one's self from parents' traditions is a necessary condition for or a consequence of rising socioeconomic status is not the subject of this research. But the history of Guatemala from colonialism through the end of the civil war has done a great deal to shape rural indigenous communities.

Those who committed the war crimes and atrocities during the Guatemalan civil war have done so with near complete impunity, as described in this section.[30] The State still lacks either the will or the ability to investigate or prosecute past crimes by most of these powerful actors (Deibert, 2008). International criminal tribunals, whether the International Criminal Court or the specific tribunals, have been set up to prosecute "humanitarian law violations" by individuals untouchable by the justice systems in their own

[30] Source for this paragraph is (Roht Arriaza, 2008) except where otherwise noted.

countries. While these tribunals have had success in prosecuting individuals of crimes against humanity, they have done little or nothing to help build and strengthen states' legal institutions and abilities to prosecute their own criminals; a state with independent and strong legal institutions should cease to need outside institutions to prosecute violations of its own laws, regardless of the perpetrator.

Hybrid international and national courts have been established in Sierra Leon, Cambodia, East Timor, Kosovo, and, in 2006, Guatemala.[31] In theory, these hybrid courts will be better at building local legal capacities and aligning national laws and expectations with those of the international community, and, importantly, legitimizing the outcomes of legal proceedings in the eyes of the people being prosecuted and represented. They have met with mixed success.

Two hybrid approaches have been used in Guatemala to bring otherwise untouchable actors to justice. Guatemala, with the United Nations, established the *Comision Internacional Contra la Impunidad en Guatemala* (CICIG), translated as the Commission against Impunity in Guatemala, with the goal of aiding Guatemala to investigate and prosecute the current clandestine actors in Guatemalan courts (Roht Arriaza, 2008). Because of this structure and goal, CICIG can neither subpoena nor indict; local courts have legal authority, and CICIG can only work with their support (Deibert, 2008).[32]

Independently of CICIG, Guatemalan courts have worked simultaneously with courts in Spain and Belgium to prosecute war crimes (Roht Arriaza, 2008). Spanish law dictates that these war crimes can only be prosecuted in Spanish courts if the suspects have not been "convicted, found innocent, or pardoned abroad" (Roht Arriaza, 2008), ironically allowing trials in domestic kangaroo courts to cement suspects' impunity rather than weakening it, but even these sham trials largely have not taken place.

[31] Source for this paragraph is (Roht Arriaza, 2008) except where otherwise noted.

[32] On 12 January, 2010, the CICIG concluded that the murder of a prominent lawyer, blamed on the president of Guatemala and his wife, was orchestrated as a sophisticated assisted suicide by the lawyer himself. This finding is being called a cover-up by some Guatemalans, purportedly including some close to the accused president himself. The credibility of the CICIG and its long term effectiveness may depend upon the public's final acceptance of the finding. Though I know of no formal surveys, anecdotally some Guatemalans seem to view the outcome as the "business as usual" impunity with which their leaders operate.

However, hybrid tribunals and transnational prosecutions require the support of the domestic legal establishment in order to investigate crimes and to arrest and extradite defendants. Similarly to what has been seen in the Sudan, the former Yugoslavia, Nigeria, and Indonesia, Guatemala's judges, investigators, and prosecutors are widely subject to bribes and intimidation, and have not proved very effective in this regard (Roht Arriaza, 2008). Treaties signed by Guatemala explicitly state that crimes of this nature that are alleged abroad must be investigated and prosecuted domestically, if the country involved refuses to extradite (Roht Arriaza, 2008). Again, Guatemalan legal institutions have not done this (Roht Arriaza, 2008). The legacy of impunity continues.

The civil war left in its wake a culture of mistrust – not just of authority figures, the military and outsiders, but within communities and even families (Warren, 1998). Warren (1998) quotes an indigenous Guatemalan speaking of the war:

> *Some people would say, "How are you?" … They wanted to get something out of us. But we ignored this because it was not a good thing… You couldn't know who he would talk to. There were cases… where you couldn't talk with your own wife — if the wife sided with the guerrillas or with the army. If the children were with the guerrillas and the father with the army… Even among brothers, one wouldn't know if someone had been paid. Because money does all sorts of things…*

In May of 1978, government troops killed somewhere between thirty-five and several hundred (depending on the version of the story told) indigenous people who were protesting (or rioting, again depending upon the account) in the Mayan town of Panzós (Grandin, 2005). Grandin (2004, p.171) quotes a witness who lived downstream: "Every day… I dreamed that they were the same bodies that floated down the river. Even though I knew it wasn't possible, it was too awful to believe that each day the river brought new dead."

The rising generations are being shaped as much or more by a new oppressive order in Guatemala: drug cartels and organized crime. And each day from their compounds and airstrips, clandestine holding sheds and known drug warehouses, the rivers bring new dead.

3.4.3. Modern Guatemala

Modern Guatemala exists in an environment of "chronic political uncertainty" (Warren, 1998, p 3). The violence associated with the 2007 presidential elections, described as "the worst political violence since the end of the civil war," suggests that the decade succeeding the signing of the 1996 Peace Accords did little to stabilize the political sphere (Rosenberg, 2007). Dutch ambassador Teunis Kamper described modern Guatemala as "a paradise for organized crime" (Scholfield, 2008). Carlos Castresana, the UN-appointed head of the CICIG, resigned his post on 7 June, 2010, stating that the Guatemalan government lacks the political will to reform its justice system and accusing top government officials of ties to organized crime (*La Prensa Libre*, 2010). The civil war is over, but people continue to live in fear of violence and corruption (Abom, 2004).

The impunity with which war crimes were committed continues with other crime in modern Guatemala. Many of the same people in power during the civil war continue to exercise clandestine (and sometimes overt) control over many of the country's current political and economic circumstances, both legitimate and criminal (Deibert, 2008; Roht Arriaza, 2008). As an example, General Efraín Ríos Montt was president of Guatemala in 1982 and 1983 when the civil-war era genocide and massacres of indigenous non-combatants were at their worst, was elected in May 2007 to the Guatemalan congress (GHRC, 2007). He was formally accused of genocide in 2011 (McDonald, 2013) and was tried for the crime in 2013 (Castillo and Salay, 2013). All though he was convicted, his conviction was overturned by the Constitutional Court of Guatemala and he is at the time of this writing awaiting re-trial (Castillo and Salay, 2013).

Guatemala has long been known as a transit point for cocaine moving from South America to the U.S. (New York Times, 2009). Drug *capos* and their subordinates have been known to influence local and sometimes national elections by killing off or intimidating rival candidates for office to ensure their own candidates are elected (Rosenberg, 2007). Profits from drug trafficking are high and the costs of bribing officials are low, creating an environment in which it is advantageous for cartels to operate and giving them incentive (and ability) to further manipulate the political environment to meet their needs (Keefer and Loayza, 2010).

The State lacks either the will or the ability (or both) to investigate or prosecute current or past crimes by these powerful actors (Roht Arriaza, 2008; Deibert, 2008; New York Times, 2009). The prosecutorial and enforcement branches of the state also lack the funding to successfully carry out their missions, as Guatemala has the second-lowest tax base in Latin America (after only Haiti) (GHRC, 2007). Human rights advocates, investigative journalists, and those who aid them in attempting to mitigate organized and official crime are met with threats and intimidation (GHRC, 2007). Many people in Guatemala readily believe that their government is involved in intimidation and murder to silence those with information about crimes committed by officials, as in February, 2007, when national police officers who confessed to the murder of diplomats from El Salvador were themselves murdered by masked gunmen inside a highly secure prison (GHRC, 2007), or when people took to the streets in 2009 to demand the resignation of President Alvaro Colom after lawyer Rodrigo Rosenberg predicted his own demise and accused the president of orchestrating his murder in a posthumously-released video made in the days before his death (New York Times, 2009). However, government officials themselves, up to and including then-president Colom, have reported receiving personal death threats from drug cartels (Llorca, 2009).

The clandestine forces that exert such control throughout Guatemala are difficult to differentiate; drug cartels, street gangs, corrupt state police, human and weapons traffickers, and corrupt public officials form a complicated web of control and competition among them that undermines the legitimate actions of the state (GHRC, 2007; New York Times, 2009). Guatemala is not unique in this regard, as drug trafficking organizations are known to link with other anti-government organizations such as insurgents in Colombia and Afghanistan (Keefer and Loayza, 2010). Guatemala's rate of violent deaths is among the highest in the region (GHRC, 2007; New York Times, 2009) and perhaps in the world (Rosenberg, 2007), but fewer than 2% of homicides are prosecuted, and fewer still lead to convictions (GHRC, 2007; Rosenberg, 2007; Scholfield, 2008). This inability of the state to adequately prosecute crimes has led extrajudicial killings – in particular the lynching of suspected criminals in rural (and increasingly, in urban) areas – to be widely accepted or even viewed as necessary by many Guatemalans (GHRC, 2007; AP, 2009 (3)). The newspaper reports on the day following a nationally televised lynching that took place during the course of this study contained a great many photos. One image showed a smiling woman running away from the flames as an accused murderer who had just been doused in gasoline burned to death on the ground behind her. Significantly, news helicopters, reporters and photographers on the ground had time to and were able to gain access to the event in progress while local and state police either could not or would not stop the hours-long beating and eventual murder of the suspect.

Beyond clandestine powers, *narco*-traffickers, corrupt officials, and the remnants of violent military and paramilitary groups, street crime remains a serious threat to Guatemalans (Rosenberg, 2007). The willingness of the population to elect former general Otto Perez Molina – who was personally in command in some of the areas where the worst atrocities against civilians were committed during the civil war and who advocated the current use of the army to crack down on street crime –illustrates how serious the crime situation has become (Rosenberg, 2007).

In 2008, Guatemala had a 26,000-strong national police force, compared to 120,000 private security personnel in a country of 13 million people (Deibert, 2008), or two national police officers per thousand citizens, compared to nine per thousand among private security. Guatemalans of means simply hire their own private security because they lack faith in the state to provide adequate protection (GHRC, 2007). Businesses in the capital of Guatemala and other major Guatemalan cities frequently have guards armed with shotguns immediately in front of or inside their buildings. Institutions like banks may be expected to hire additional security, but hotels, pharmacies, grocery stores, shopping malls, and small shops also frequently and prominently display armed security. However, private security forces have strong ties to organized crime, including drug traffickers (Deibert, 2008). Organized crime has an interest in undermining the state in Guatemala (Deibert, 2008) so that it may continue to operate with impunity, which consequently undermines the state's ability to work in any area, including electricity-based rural development or to provide adequate security for organizations who would otherwise develop the rural electrification projects that are the subject of this research. Government officials who have tried to rein in the power of organized crime, as by deploying troops to areas controlled by *narco* traffickers, have been murdered or died under mysterious circumstances, while the government has neither adequately investigated circumstances nor prosecuted those involved (Deibert, 2008). As long as the government is not in fact in control of parts of the country, it cannot participate in development activities or support or protect outside agencies that could otherwise expand electrification and other development programs in those areas.

The historically powerful actors within Guatemala are alternately in competition or collusion with the increasingly powerful Mexican drug cartels. Since the election of President Felipe Calderon Hinojosa in Mexico in 2006 (U.S. Department of State, 2008), the Mexican government has waged a high-profile and violent war against drug traffickers (Llana, 2009) who have traditionally operated with impunity. Drug cartel-related crime continues unabated since the election of Enrique Pena Nieto, President of Mexico since 2012 (CIA, 2013). The Mexican drug cartels are increasingly in control of the trafficking of cocaine from South America into U.S. markets, displacing Colombian organizations that have been weakened in part by U.S. aid to Colombia to combat them (Llorca, 2009) and, increasingly, the import of methamphetamines into the U.S (Llana, 2009). The battles between the rival gangs have typically been bloody but casualties were largely limited to gang members (Stratfor Global Intelligence, 2008). Since the Mexican government crack-down began, increasing numbers of bystanders and soldiers or law enforcement personnel have been victims of violence (Stratfor Global Intelligence, 2008). The increased pressure on the drug gangs has caused some of them to relocate parts of their operations both north and south of the Mexican borders, to southwestern U.S. states (Associated Press, 2009 (1)) and to Central America, especially Guatemala (Llorca, 2009; Associated Press 2009 (4)) and Honduras (Associated Press 2009 (4)). Guatemala's weak justice system and police force are plagued with corruption and ill-equipped to contain the heavily-armed and well-organized Mexican criminal organizations (Llorca, 2009).

Los Zetas are a quazi-independent mercenary gang that started as the militant branch of the Gulf Cartel (Deibert, 2008; Llorca, 2009) but have since established themselves as a power in competition with their former bosses. They, and other Mexican drug cartels, operate within or have taken control of territory inside Guatemala in the departments of Alta Verapaz, Huehuetenango, Izabal, Zacapa (Deibert, 2008), and others. *Los Zetas* successfully recruit hit men and other “workers” from young men among the rural populations in Guatemala (Llorca, 2009) who have few opportunities in their home communities. Peten is a particular hotbed of drug and human smuggling activity (Deibert, 2008), and as such was largely excluded from this study due to concerns about physical safety and security.

The clandestine organizations that run the organized crime syndicates are separate from, and in many ways more of a threat to the stability and power of the state, than are the violent but loosely organized street gangs or the Mexican drug cartels, although the clandestine powers sometimes “use the gangs as muscle” and are increasingly allied and entwined with the cartels (Deibert, 2008). Government and international resources are increasingly spent on fighting crime while people literally starve (Bonello, 2011).

Physical insecurity and lack of state control have far-reaching effects on Guatemalan society in general and on rural development specifically. These, together with current poverty and the legacies of racism and state-sponsored violence, form much of the context in which this study must be understood. However, *Chapines* are proud and resourceful, with a cultural heritage that can be traced back millennia and which has withstood conquest, colonization, dictatorships and war. The current-day threats continue to inhibit “progress” and economic and human development, but *el pueblo* of Guatemala – the folk, the people as a nation – does not show evidence of succumbing to these new pressures; they will continue to survive.

3.5. Hypotheses

This section describes the *a priori* hypotheses tested and research questions addressed in this study. These questions and hypotheses are founded in my findings from academic literature, conversations with development professionals, and personal observation, as described throughout this section. Many refer to "success," which is defined in Chapter 2. Hypotheses are stated for topics about which an outcome has been observed or assumed in prior observation or research. Research questions are posed about topics about which previous observations have been inconsistent or are absent. The hypotheses and research questions are grouped into three categories, defined further below: economics and utility; institutions and relationships; and characteristics and consequences.

3.5.1. Economic value and utility

Reasons suggested for success and failure of rural electrification programs are often related to money, as described in this section and in Chapter 2. In this section, I present hypotheses and research questions related to economics, together with a review of previous research that has lead to these hypotheses and research questions. Similarly, I present background on system uses and success, with accompanying hypotheses and research questions examined in this study.

Following are the research questions posed with regards to economic value and system utility:[33]

– *Are there people who are earning more or saving money by using the system instead of traditional power sources?*
– *Are there people who have lost income opportunities or are incurring greater expenses because of the system?*
– *What do people use their systems for, and how do different uses lead to different success rates, independently of economic impact?*

My initially hypothesized answers to these questions at the outset were straightforward:

[33] Please see Chapter 5 for discussion of the outcomes of these research questions and hypotheses.

- *Most users would save money relative to previous energy sources, and those who did would have higher success rates than those who did not save money.*
- *Some few would earn money with their systems, and those would have the highest success rates.*
- *Vendors in the communities would lose income due to decreased sales of candles and gas for lamps. Greater negative economic impacts would lead to lower success rates.*
- *Systems used for direct income generation and for cell phone charging would have higher success rates than those not used for one of these purposes.*

The underlying hypothesis addressed in this section is that systems will be more successful if they provide measurable value – monetary or otherwise – to their users. In this section, I review previous findings on changes in energy costs and new economic opportunities enabled by rural renewable energy systems in general and rural PV systems specifically. I also consider the potential for the loss of income to some members of a community as a result of a PV donation, and review the common non-economic applications of PV systems in the developing world.

3.5.1.1. Energy costs: PV may be cost-effective relative to other energy sources in rural areas

In general, the use of solar PV in rural locations displaces the use, and therefore the cost, of traditional light sources such as candles and kerosene lamps. These savings can more than offset the cost of system maintenance (Lysen, 2013; Kolk et al., 2012; Nygaard, 2009; Grimshaw and Lewis, 2010; Acker and Kammen, 1996; van der Plas and Hankins, 1998; Duke et al., 2002). Numerous studies have shown this to be true in regions around the world (Deichmann et al., 2011; van der Plas and Hankins, 1998; Breyer et al., 2009; Acker and Kammen, 1996; Ley, 2006).

Decentralized renewable generation can be more reliable and cost-effective than extending the existing electric power grid over long distances or difficult terrain (Kolk et al., 2012; Narula et al., 2012; Deichmann et al., 2011; Urban et al., 2009; Chakrabarti and Chakrabarti, 2002; Huacuz, 2005). Some households in the developing world have grid access (having either an actual grid connection to the home or having power lines passing almost over their homes) but still choose to have solar home systems installed because it is less expensive than buying some or all power from the grid (Acker and Kammen, 1996). Renewables further offer the advantage of not being subject to fuel price volatility (Deichmann et al., 2011; Fuss and Szolgayová, 2010; Koo et al., 2011). However, it must be noted that increased access to electricity does not necessarily serve to alleviate poverty (Casillas and Kammen, 2010)

Initial capital costs of PV are high. However, the cost of photovoltaic panels has been decreasing (NREL, undated) – especially as driven by competition from inexpensive Chinese panels (Nygaard, 2009). In individual markets, increasing penetration of solar home systems drives competition and generally reduces prices (Nygaard, 2009). Renewable energy technology costs in remote applications have decreased over the past decade (Alazraque-Cherni, 2008).

In some circumstances, the potential for energy savings has been large enough to allow solar home system implementation to expand on a purely market-based model, as described in this section. In Kenya, Zimbabwe, Sri Lanka, Honduras, the Dominican Republic, Cameroon, Bangladesh and other less developed countries, renewable energy systems are successfully marketed and sold to rural households without subsidy (Lysen, 2013; Kolk et al., 2012; Acker and Kammen, 1996; Duke et al., 2002). Cash sales of solar home systems to rural households offer the advantages of having low transaction costs and offering users a variety of options (Nieuwenhout et al., 2001). Independent of travel costs, Kenyan solar home system owners were grateful for the decreased need to travel provided by their PV systems; they no longer needed to take trips to recharge batteries or buy kerosene (Acker and Kammen, 1996). However, purchasers of novel solar home technologies face substantial risk: a large upfront investment must be made by those with little or no experience upon which to base expectations of maintenance costs or savings in costs of kerosene or candles (Acker and Kammen, 1996).

Offering a variety of sizes of expandable solar home systems for cash can make them more affordable and accessible to the rural poor than can microcredit programs (Nieuwenhout et al., 2001). However, access to microfinance can improve access to solar home systems by those who cannot pay cash upfront (Lysen, 2013; Lahimer et al., 2013; Nygaard, 2009; Nieuwenhout et al., 2001; Khan and Khan, 2009), though cash purchase options may be preferred even by users with access to microcredit (Breyer et al., 2009).[34]

Microfinance can be problematic: it increases transaction costs significantly when dealing with dispersed and small borrowers and vendors (Lysen, 2013; Duke et al., 2002). Microfinance conditions, such as proof of a reliable income source, are too stringent (or inflexible) for many agrarian households which see the bulk of their annual income at the harvest (Mulugetta et al., 2000). Credit programs for the rural poor are not favored by lending institutions (Chaurey and Kandpal, 2010) because of high transaction costs, lack of collateral and costly credit appraisal procedures (Nieuwenhout et al., 2001). Guarantors such as governments are generally needed before lending institutions will provide credit to the rural poor for solar home systems (Nygaard, 2009; Nieuwenhout et al., 2001; Acker and Kammen, 1996). Other factors that have led to the success of some credit programs are decentralized service availability and bonuses offered to personnel when loans were fully repaid (Nieuwenhout et al., 2001).

Thus, the published literature suggests that renewable energy in general and, in some cases, stand-alone solar electric systems in general have the potential to decrease energy costs. I hypothesize that where users are saving money, their systems will be more successful than where they are not.

3.5.1.2. Economic opportunities: PV may generate income for users, but there are few opportunities

Income-generating opportunities can be realized with renewable energy systems that would not be available otherwise (Casillas and Kammen, 2010; Deichmann et al., 2011; Mondal et al., 2010; Kirubi et al., 2009; Chakrabarti and Chakrabarti, 2002), sometimes at lower cost than alternative energy sources (UN, 2012).

[34] Although not a subject included in this thesis, financing opportunities are hypothesized to increase users' abilities to pay for maintenance and therefore increase system success. See Chapter 8 for details.

Microenterprises such as solar battery charging stations can be profitable uses of renewable energy in rural locations (Acker and Kammen, 1996). However, direct income generating activities (electric sewing machines or grain grinders, for example) are relatively rare (Chaurey and Kandpal, 2010; Nieuwenhout et al., 2001). The indirect effects of having better quality of light for more hours appears to be more substantial (Kirubi et al., 2009): stores can be open longer, manual sewing can be done for more hours, and household activities can be delayed until later hours to allow more time for income-generating activities during the day, as examples (Nieuwenhout et al., 2001). On the island of Sagar Dweep in West Bengal, India, where 56% of the population engages in non-agricultural income generation (in "trade and business"), solar energy systems allow these income generation activities to continue for more hours per day than previously (Chakrabarti and Chakrabarti, 2002). Rural renewable energy systems that present income-generating opportunities tend to be more successful than those that do not (Karekezi and Kithtyoma, 2002; Chakrabarti and Chakrabarti, 2002; Troy, 2002; Acker and Kammen, 1996).

A donated renewable energy system may itself be viewed as an economic opportunity to a user via resale. The academic literature does not explicitly consider this opportunity. However, it has been observed by development professionals. For example, in Mexico, very large numbers of solar home systems were donated to households without training or explanation (Ley, 2006). The components of these are now available for purchase throughout Central America and Mexico, but few of the original recipients make direct use of the donated systems. Because of the definition of success used in this thesis (see Chapter 2), systems that have been sold are considered to be failed systems. Although I do not pose research questions or hypotheses specifically related to asset liquidation as an economic opportunity, I view it as a gap in the published literature and consider it qualitatively in this research (see Chapter 5).

Where income generation from rural PV systems is possible, it is hypothesized to lead to greater system success. However, these cases are expected to be few.

3.5.1.3. Loss of income

If solar home systems are successful in reducing energy costs to users, the vendors of their previous energy sources (e.g., candles and kerosene) will necessarily lose revenue from those users. Aside from the normative statement that former vendors of kerosene "should" be included in the solar supply chain (Lysen, 2013), the literature does not address the issue of these lost revenues. I pose the question of whether this reduction in income is observable, potentially filling this gap in published literature.

3.5.1.4. PV uses

Beyond the economically productive uses noted above, solar electricity is widely used for lighting in developing countries (Lysen, 2013; Harish et al., 2013; Wong, 2012; Durlinger et al., 2010; Solanki and Mudaliar, 2010; Acker and Kammen, 1996; etcetera). Mobile phone charging and radio are important applications of rural PV (Lysen, 2013; Komatsu et al., 2011; Grimshaw and Lewis, 2010; Breyer et al., 2009). Television and electric irons are also desired by users, but solar home systems are generally not sized to power them (Lysen, 2013). In general, "technology push" approaches to rural electrification are less successful than installing solar PV to meet a specific need (Mondal et al., 2010).

Studies suggest that users are generally more satisfied with their systems if their expectations of the limits and abilities of their systems – the systems utilities – are reasonable and realistic (Brent and Rogers, 2010; Nieuwenhout et al., 2001; Ley, 2006). Users complain that solar home systems do not provide sufficient power to meet their needs, particularly during rainy seasons, or are disappointed that they cannot afford sufficient PV for cooking or ironing; this dissatisfaction is evidence of a failure to set realistic expectations before installation.[35] This theme of "managing expectations" of system utility was reiterated often by project developers in formal and informal conversations that took place during the course of this research.

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[35] Source for this paragraph is (Acker and Kammen, 1996) except where otherwise noted.

I hypothesize that the uses for solar energy in rural communities found in the literature will be similar to those found for solar energy systems included in this thesis. I further hypothesize that systems used to meet needs that can be met without electricity will be less successful than those used for applications that demand electricity.[36]

3.5.1.5 Conclusion: economic value and utility

Clearly, the issues surrounding the economic benefits and other tangible uses are many. Hypotheses beyond those listed at the beginning of this section are addressed in Chapter 8, Conclusions, Section 8.8, Areas of Further Research. However, the utilitarian aspects of these projects are not the only influences on system success. The following section considers the institutions and relationships surrounding projects.

3.5.2. Institutions and relationships

Rural renewable energy systems exist within social and institutional contexts, from international agreements to local family ties. The success of these systems influences and is influenced by the relationships among the people and the institutions surrounding them, including system governance and relationships with donors. Following is a review of what has been written about some of these topics, as well as related hypotheses and research questions explored in this thesis. These are broken into four categories, as follows.

Project governance:

– *What are the governance structures related to the systems?*
– *Does it matter whether committees are formed to manage projects or savings? Does their legal establishment lead to greater success, or do those established by intra-community trust work as well?*

[36] For example, systems used to charge cellular telephones, which cannot be charged otherwise, are hypothesized to be more successful than those used for lighting exclusively, which can also be accomplished using candles.

Project origin and training:

- *If people are the originators of their projects (they ask, rather than the donor offers), will they tend to care for them more because they are more in line with beneficiary needs?*
- *Are projects more likely to fail if people are not trained in their maintenance and administration when systems are installed?*

Ownership, accountability and donor relationships:

- *If people are required to contribute financially or in kind to their systems, will they have a stronger sense of ownership and take better care of them?*
- *Do donors and beneficiaries maintain a relationship? Does it matter?*

Unintended consequences:

- *Do unintended negative social consequences due to donated systems decrease the likelihood of project success?*

Overall, the many overlapping and interdependent institutions and relationships that surround rural renewable energy systems form a complex web of motivations, decisions and ultimately actions that can lead to the success or the failure of these systems. Neglect for non-technical aspects of the system (i.e., social and institutional issues) during design can lead to system failure (Brent and Rogers, 2010). The underlying hypothesis addressed in this section is that the institutions and relationships surrounding donated solar electric systems influence project success. In this section, I review the previous findings that have contributed to these research questions and hypotheses on the topics of general and project governance and management, how projects originate and the training given to beneficiaries, issues of ownership and donor relationship. I also consider the potential for conflict to arise as a result of these donated systems.

3.5.2.1. Governance and management

This subsection reviews current knowledge on the governance of communities in the context of rural electrification, and the management of rural renewable energy systems. I include topics of regional and national governance, as well as community and project leadership.

Regional and national governments are part of the context of governance for rural stand-alone solar electric projects and can influence project success. Low electrification rates are often due to poor organization in the government agencies responsible (Nygaard, 2009). National energy policy often focuses on *access* to electricity (Acker and Kammen, 1996); all members of a community are normally considered to have access once electrification activities have been undertaken, regardless of whether all members of the community are able to avail themselves of the energy. However, national governments can achieve synergies in their development goals by coordinating them (e.g., electrification together with health or education goals) (Chaurey and Kandpal, 2010).

Remote government agencies can have both positive and negative impacts on rural renewable energy systems. Some governments, including Mexico's, have included solar photovoltaic systems in their rural electrification plans (Ley, 2006; Acker and Kammen, 1996). The impact of this inclusion will depend upon how and if the plan translates to action. In other cases, government involvement can have negative impacts by increasing uncertainty or system costs directly: transparency in grid extension planning and execution is important to the success of remote or stand-alone electric systems (Chaurey and Kandpal, 2010; Acker and Kammen, 1996). Lack of transparency adds to the risk and uncertainty of investing in stand-alone or small community autonomous electric systems (including investment in maintenance of donated systems), and discourages long-term investment "in case" the grid arrives unexpectedly.

Community-level governance structures – both traditional governance and governance related specifically to rural electrification projects – have the potential to significantly affect system outcomes. Project developers may emphasizes community-level governance of projects, including charging tariffs or collecting savings for future maintenance needs, the involvement of both men and women in all aspects of projects and technical and institutional training to ensure the sustainability of the projects (*Fundación Solar*, 2003 a, b, c, d; Nieuwenhout et al., 2001). Many factors must be considered when creating institutions for the governance of rural renewable energy systems. For example, women and men have distinct uses for the electricity that is brought to their communities, so successful governance requires the participation of both (Pless and Appel, 2012; *Fundación Solar*, 2003 a, b, c, d). Those who have historically been leaders in a community are not always those chosen to lead an energy project, especially if the donor is perhaps overly-involved in forming a new leadership committee. Lack of trust between traditional community leadership and formal project governance can lead to system failure (Brent and Rogers, 2010).

Anecdotally, very few locations exhibit a "culture of savings" in which saving for the future costs of the system is intuitive. This may make the creation of institutions to govern project finances advantageous or necessary. As an example, in a survey of solar home systems in Guatemala, the observed 45% failure rate was blamed in part on the fact that few recipients of the donated systems saved any money for battery replacement, despite being instructed that they should start saving immediately (Nieuwenhout et al., 2001). In contrast, some communities in Guatemala have created solar funds: members pay small monthly amounts into accounts with good transparency, and those funds are used to replace batteries – a frequent need in solar home systems (Nieuwenhout et al., 2001), and such organizations with established maintenance funds aid in system success (Frame et al., 2011)

Centralized systems that connect to many households, such as small hydroelectric plants, require better administrative structure, transparency and trust than do stand-alone solar systems (*Fundación Solar*, 2003c), such as those included in this study.

Thus, previous research suggests that a governance structure for a donated renewable energy system, whether newly established or integrated into existing leadership responsibilities, is important to projects' success. Anecdotes from Guatemala suggest that some donors or project developers see the legal establishment of these structures as important (Ley, 2006). However, the weak legal framework in Guatemala (described in Section 3.2., above) leads me to question the relevance of the legal standing of these governance entities.

3.5.2.2. Project origin, user training

This subsection reviews the roles of community members and donors or developers in initiating projects, and the effects of user training and socialization on system success.

Project origin is important to overall system success. Development projects initiated by beneficiaries may be more successful than projects originated by donors, and projects initiated by donors with whom beneficiaries have a long-term relationship are more successful than projects originated by donors who are new to beneficiaries (Alther, 2008). In particular, success is suggested to be greater for project implementation programs having an in-country partner (if the sponsoring agency is foreign) to facilitate communication across languages and cultures, sending appropriate price signals to end users, using valid planning and analysis tools and techniques, and connecting power projects to other development efforts (Taylor, 1998).

Regardless of the originator, involvement of all stakeholders from the outset may ensure a more successful development program (Agbemabiese, 2009). Project developers should work closely with potential beneficiaries to ensure the technology meets actual beneficiary needs (Breyer et al., 2009).

After a project is proposed, beneficiaries should be involved in the planning and implementation stages (Alther, 2008). Raising beneficiary awareness – a process described as “socialization” or “sensitization” – and user participation in decision making can contribute to project success (Chaurey and Kandpal, 2010; Alther, 2008; Frame et al., 2011; Agbemabiese, 2009; Kirtikara, 1997).

Donations of solar home systems to communities often include only initial hardware costs, leaving little or nothing for ongoing operations and maintenance costs (Nieuwenhout et al., 2001). Donated solar home systems often fail because it was not initially realized that they would need ongoing maintenance (Nieuwenhout et al., 2001). Indeed, some donor projects allocate up to ninety percent of funds to the technology, leaving almost nothing for the training of local people (Acker and Kammen, 1996). In a specific example of a solar homes project in Zimbabwe, sponsor and government resource constraints prevented adequate training in the operation and maintenance of solar home systems (Mulugetta et al., 2000). While the user is key to sustained operation in a donated system, the sponsor is the enabler; without adequate resources and training, users may be unable to maintain their systems regardless of their intentions (Ley, 2006).

However, as a part of planning and implementation, many projects include technical or administrative training for beneficiaries. Such training can contribute to the overall sustainability of projects (Chaurey and Kandpal, 2010; Breyer et al., 2009; Kirtikara, 1997; Alther, 2008; Frame et al., 2011; Agbemabiese, 2009), especially as repair services can be slow, expensive or entirely unavailable in remote areas (Nieuwenhout et al., 2001; Mulugetta et al., 2000). In some cases, adequate training has led individuals to engage in maintenance or installation of PV systems on a commercial basis (Taylor, 2005; Acker and Kammen, 1996). Frame et al (2011) state that ongoing or "refresher" training is important to system success (Frame et al., 2011). In practice, training sessions after project initiation appear to be so infrequent that a sample could not reasonably be generated to test this hypothesis.

Projects initiated by those who know the potential beneficiaries well – preferably the beneficiaries themselves – may see better success than those initiated by outsiders to the community. Whether initiated by community members or outsiders, planning and implementation processes that meaningfully involve all stakeholders are expected to have better outcomes. Training of beneficiaries in the care of their systems, and sometimes in management or administration, may also help projects succeed.

3.5.2.3. Project ownership and relationships with donors and developers

This subsection reviews relationships between donors or developers and community members, and explores the issue of project ownership and its influence on system success.

The provision of labor or money by the recipient community engenders a sense of commitment, responsibility and ownership (Ley, 2006; Nieuwenhout et al., 2001), and a sense of ownership in turn leads users to care more for their systems and see greater system success (Frame et al., 2011; Alther, 2008, Karekezi and Kithyoma, 2002). These two assumptions – that beneficiary contribution increases a sense of ownership, and ownership leads to project success – seem to be accepted as self-evident in much of the literature and discourse on the subject and, as such, are rarely stated explicitly: studies may explore ways of increasing beneficiaries' ownership of projects but may not examine why ownership is important. In this thesis, I hypothesize these assumptions to be true but, unlike many studies, I test their validity rather than accepting them as self-evident.

Questions of ownership of rural renewable energy systems are closely tied to the relationship between beneficiaries and donors: who owns the project and who, therefore, is responsible for its maintenance? The availability of the donor to aid or advise in maintenance is also important. Lysen (2013) explains succinctly that "the institutional setting of the project and the long-term commitment of the stakeholders are vital for the success of the PV project" (Lysen, 2013).

Lack of long-term commitment to systems by donors can lead to project failure (Karekezi and Kithyoma, 2002; Taylor, 1998; Kirtikara, 1997). A key to system success is the ability to contact the donor or other outside party for technical support (Frame et al., 2011). However, developer contact and support after implementation is challenging in rural developing-world communities (Breyer et al., 2009). The need for this ongoing relationship may in part be due to the lack of influence the user may have on the vendor responsible for installation and possibly maintenance (Mulugetta et al., 2000): vendors may be motivated to maintain relationships with donors who may give them repeat business, but not find responding to needs of poor and remote customers worthwhile.

Despite the advantages of an ongoing relationship between donor and beneficiaries, some communities will be slow to participate in projects due to a lack of trust between the community and the donor (Brent and Rogers, 2010; Ley, 2006). For example, in Chel, Guatemala, years were spent by development organizations just building a relationship with the community to enable the construction of a small hydroelectric system that the development organization and the community agreed was needed at the outset (Ley, 2006).

An ongoing donor and beneficiary relationship may lead to greater project success, if there is adequate trust and responsiveness by both parties. The expectations of one another of the parties in this relationship will largely determine beneficiaries' understanding of system ownership. A strong sense of ownership, in turn, may lead to greater system success.

3.5.2.4. Unintended social consequences

Outcomes associated with development interventions are not always positive. Donated projects or systems may become a source of conflict or exacerbate conflict or inequity within a community. Solar home systems programs are generally targeted to the poor, but often the users have higher than average incomes relative to their peers (Nygaard, 2009; Acker and Kammen, 1996; Nieuwenhout et al., 2001), and a solar home system may be a highly visible status symbol (Acker and Kammen, 1996). This is a potential source of conflict as electric light creates a very visible distinction between those who have it and those who do not.

The absence of clearly defined rules may create tensions within a community where they did not exist before the project was implemented. Uncontrolled access to (and therefore competition for) the same electricity can lead to disputes between beneficiaries (Brent and Rogers, 2010).

Religious conflict is also possible. Part of one community in Guatemala rejected solar energy on the grounds that it was hurtful to the sun, and their Mayan religious beliefs hold the sun as sacred; the Christian segment of the community, however, embraced the project (Azuria, 2006). Through inclusion of religious leaders in further discussions, practitioners of the traditional Mayan religion there eventually came to view the project as beneficial as well.

Although not widely discussed in the literature, donated solar energy systems may result in negative social consequences. I hypothesize that projects that do not create or exacerbate these conflicts, or projects implemented with steps to mitigate social conflict, will ultimately be more successful than those that do not acknowledge the potential for conflict as a result of the donation.

3.5.2.5. Conclusion: institutions and relationships

The institutional contexts of donation programs and projects may profoundly influence system outcomes. Some of the issues examined in this research include management and governance of projects, beneficiary and donor involvement in project initiation, and user training at the time of implementation. The relationship between donor and beneficiary is considered important, and is closely tied to near-ubiquitous assumptions about the importance of beneficiary ownership on system success. Finally, the potential for conflict as a result of the implementation of donated systems is considered. Results related to these hypotheses are detailed in Chapter 6.

3.5.3. Characteristics and consequences

As detailed above, the people and communities of Guatemala are varied. In this section, I proposes research questions related to the characteristics of the people and communities included in this research, and about the characteristics of the physical systems that are installed, and review related literature. Further, I pose questions related to the success of systems when the systems effect some physical change upon their environments. Also included in this section is a review of literature related to these questions and hypotheses.

- *How is project success influenced by the characteristics of the communities in which projects are situated?*
- *How is project success influenced by user poverty, ethnicity, religion and age?*
- *What other characteristics of users influence success?*
- *Are systems with high quality parts and robust, standard design more successful than those using inexpensively replaceable parts and locally adapted design?*
- *Are systems maintained under a highly structured regime more successful than those in which maintenance is improvised as needed?*
- *Have local ecosystems, environment or landscapes been adversely affected by the systems' presence?*

The underlying hypothesis of this section is that the characteristics of communities, systems and users influence project success. In the field of rural electrification, few authors have specifically addressed the characteristics of user and their communities that can lead to successful system outcomes, with many studies limited to looking specifically at users' economic situations as their predominant characteristics. For this reason, I have few hypothesized answers for the many research questions I pose on the topic. Conversely, the issue of the physical characteristics of the PV system itself – the system specifications, installation and components – is addressed decisively, suggesting clearly the hypothesis that better-quality systems will lead to more successful outcomes, as described below. In subsection 3.5.3.1, I review literature related to the characteristics of communities in which donated rural electrification systems are found and the characteristics of system users. In the subsequent subsection, I address issues related to the components and design of the physical systems. Finally, in subsection 3.5.3.3, I consider the consequences of these systems on the ecosystems where they are installed and the health of community members, and the relationship between these consequences and system success.

3.5.3.1. Characteristics of users and communities

The characteristics of users and communities are hypothesized to influence the success of renewable energy systems. The most obvious characteristics are much broader than those included in this study: located in rich nations versus poor nations; urban versus rural; included under various forms of national governance. The scope of this study narrowly examines communities that are rural, incontrovertibly poor, do not have access to the national electric grid, and are located in the Republic of Guatemala.

Literature related to the specific characteristics of the Guatemalan context is discussed in section 3.3, above. From this literature, I have derived few hypotheses but many questions about the influence of user and community characteristics on system success. The questions associated with this topic are, by design, extremely broad and are intended to allow inferences from data gathered rather than the testing of specific hypotheses.

3.5.3.2. Characteristics of system equipment and installation

The quality of the design, installation and equipment used in a rural renewable energy system can affect the system's success in a number of ways (Duke et al., 2002), as described further below. In general, there is consensus that higher quality components[37] lead to better system success (Chaurey and Kandpal, 2010; Breyer et al., 2009; Nieuwenhout et al., 2001). Low quality equipment has led to the direct failure of solar home systems (Duke et al., 2002). When projects fail, confidence in the technology may be lost – even when the failure was due to the implementation process rather than the technology itself (Ley, 2006). This loss of confidence may be seen in users, sponsoring organizations, governments or the media. However, I have found little systematic research on the quality of systems in the field.

[37] "Components" are defined in this research as the physical equipment necessary for an energy system to function. These may include (but are not limited to) equipment such as solar panels, wind turbines (the blade and generator assemblies that convert moving air into electric power), diesel generators, wires and batteries. The definition of components also includes items such as water pumps, lighting fixtures and electrical outlets: equipment that enables someone to make practical use of the energy.

Persistent maintenance problems – even those that the users have the expertise and resources to correct – can "sour" people to their renewable energy systems. The presence of low quality components can lead to decreased consumer confidence in solar home systems in general (Duke et al., 2002). In a Guatemalan solar home system project, ballasts for fluorescent light bulbs often burnt out and were replaced once, but solar home systems were often abandoned if the replacement also burnt out quickly (Nieuwenhout et al., 2001). In another example, in Kiribati, an extensive solar home systems program was largely unsuccessful (with a 90% failure rate) in part because householders bought cheap components to save money in the short term (Nieuwenhout et al., 2001).

However, where choice is available to householders, users of solar home systems will select components of varying size, cost and quality (Acker and Kammen, 1996; Nieuwenhout et al., 2001). Product quality can vary widely among vendors, with some providing very low quality (and sometimes "pirate") equipment (Duke et al., 2002; Mulugetta et al., 2000), which may be more relevant to solar home system markets than to donated programs implemented by more knowledgeable development agencies. Solar home system owners are often unaware of the brand of even their own module, and so cannot make quality comparisons between brands (Duke et al., 2002).

Solar PV panels themselves are the least problematic of components in solar home systems; their output degrades slightly but predictably after initial installation if the modules are "good brands" (Acker and Kammen, 1996; Nieuwenhout et al., 2001). Instead, batteries, charge controllers, lights and other balance of system components are likely to fail more quickly (Ley, 2006; Kirtikara, 1997; Acker and Kammen, 1996)
In a study of solar water pumping systems in Thailand in which one third of projects failed, only 1% of those failures were due to the solar PV panels themselves; other failures were related to control equipment, pumps, water leaks, or problems with the water supply (Green, 2004). Similarly, the use of appropriate "deep cycle" batteries (rather than cheaper automotive batteries) leads to greater battery longevity, lower overall cost, and greater system success (Nema and Sayan, 2012; Ley, 2006; Acker and Kammen, 1996).

The value of a charge controller in a system is somewhat contested: field data does not show the presence of a charge controller to extend battery life at all because they are so often bypassed or disconnected by users with inadequate training (Green, 2004; Nieuwenhout et al., 2001). Rather than using the charge controller, users tend to rely on visible signs of battery drain (dimming lights, for example) before disconnecting the load from the battery (Acker and Kammen, 1996). This leads batteries to be too deeply discharged and therefore damaged. Despite manufacturers' claims, higher-cost, higher quality charge controllers have not been shown in the field to increase battery life over simple and inexpensive charge controllers (Nieuwenhout et al., 2001). However, it remains "widely believed" that charge controllers are an important part of a robust system (Messenger and Ventre, 2010; Ley, 2006; Acker and Kammen, 1996). The inclusion of a charge controller is only one aspect of system design. High quality, robust design is important to stand-alone PV systems (Díaz et al., 2011; Ley, 2006; Flowers, 1997), though both standardized and dynamic approaches to design of rural PV systems can be effective (Chaurey and Kandpal, 2010). Appropriate analysis tools, including computer models, are necessary to make workable projects (Flowers, 1997). However, I have not found studies that assess the design process *ex post*, nor that compare the success of projects that used different design processes.

Along with design quality, installation quality is important and can depend on the installer. Installations of solar home systems can range from individual household purchasers to internationally certified vendors and installers, and the resultant quality and success of the systems can vary as a consequence (Duke et al., 2002; Mulugetta et al., 2000; Acker and Kammen, 1996).

Some installation techniques can give varied results, even if the quality of the installation is consistent. Mounting PV panels directly on rooftops offers the advantage of a stable and inexpensive installation (Acker and Kammen, 1996). The disadvantages of having panels mounted directly on rooftops include increased temperature by not having an air space between the panel and the roof to keep the panel cooler (PV is more efficient at lower temperatures) (Messenger and Ventre, 2010; Acker and Kammen, 1996).

Thus, while installation in accordance with industry norms is normally preferable (Shepperd and Richards, 1993), there may be advantages to tailoring installations to its environment.

There seems to be little research on the effects of national equipment or installation standards in developing countries, but it has been observed that the presence or absence of national equipment standards had little impact on the overall success rate of installed solar home systems (Nieuwenhout et al., 2001).

Thus the quality of components chosen and the quality of the design and installation of rural electrification systems can influence system outcomes. Good quality components in general should lead to better system outcomes, although the presence of some components (such as charge controllers) may have questionable influence. Similarly with design and installation: more robust design and better quality installation may lead to greater system success, although adaptations to meet local conditions may be appropriate. However, poor quality must never lead to threats to human health and safety. Issues regarding health and the natural environment are the subject of the following section.

3.5.3.3. Health and environmental consequences

The characteristics of the physical systems and the ways in which they are implemented can have consequences on the health of users and the environment that surrounds the systems. These consequences may be positive or negative, as described in this section.

Renewable energy technologies have the potential to improve human health in general (Winkler et al., 2011; Balkema et al., 2010) and specifically by reducing the air pollution resulting from combustion of traditional fuels (Bruce et al., 2011; Martinot et al., 2002). Indoor air pollution from the use of traditional fuels at the household level is significant, affecting especially women and children (Bruce et al., 2011). Kerosene and diesel generators also pose significant fire risks (Acker and Kammen, 1996). Electricity may eliminate some of the possible ill health effects of traditional fuels, including poor air quality, as mentioned above, as well as paraffin poisoning in children and severe burns (Kornbluth et al., 2012; Bruce et al., 2011; Acker and Kammen, 1996; Foster and Tre, 2000; Nieuwenhout et al., 2001).

However, the indoor air quality issues resulting from combustion for lighting are logically smaller than the effects of stoves using traditional biomass for heating and cooking; PV electricity is not a realistic option for cooking in rural developing world applications.

Security and the perception of security are improved or perceived to be improved for families with access to electricity (as through solar home systems or grid extension) because they can install security lights that let them see outside without leaving the safety of the home, and bright indoor lights are perceived to discourage would-be intruders (Ahmad and Byrd, 2013; Acker and Kammen, 1996).

As noted above, rural solar energy systems do not generally displace fuel wood use, and as such do not meaningfully contribute to a reduction in deforestation and related local environmental damage. More general environmental effects may be mitigated by the use of PV when the electricity generated is used in place of kerosene, paraffin and other petroleum products.[38] One concrete environmental benefit may be the reduction in the use and disposal of dry cell batteries, but this benefit is reduced by the burden of disposing of solar batteries (Acker and Kammen, 1996).

Rural stand-alone solar electric systems may benefit human health by reducing instances of burns and poisoning, but may do little to improve indoor air quality or local deforestation. Potential adverse health and environmental effects caused by improper solar battery disposal are seemingly not addressed by the literature.[39] User perceptions of environmental impacts – good or bad – may do more to influence system success than the actual (and apparently small) changes to the local environment.

[38] See Chapter 5 for a detailed discussion of the uses of stand-alone solar electric systems.

[39] See Chapter 7 for results related to user experience with battery disposal.

3.6. Conclusions

An underlying hypothesis of this research is that the factors that lead to the success and failure of rural development projects in general, and rural stand-alone PV projects in particular, are interrelated. The technical question that asks whether a system meets industry codes and standards makes sense only in the context of the industry as an institution. Environmental damage caused by systems may have either physical or temporal downstream effects on another group that will suffer from that damage. Although categorized for clarity, the hypotheses and research questions posed by this work are better viewed as a network than as a list.

The fundamental questions asked are simple. What does it mean when a project is called successful? What are the contributions towards this success or lack of success of economics, institutions, communities and individuals? The answers to these questions are not so simple. Chapter 4, following, discusses the methodology used to address these questions.

Chapter 4. Methodology

4.1. Introduction

In this chapter, I explain the methodology used in this research, provide supporting background information, and note the limitations of the selected methodology.

I use a mixed methods approach to gathering both qualitative and quantitative data, and to analyze that data to test my hypotheses, seek answers to my research questions, and to explore for answers to questions suggested by the information itself. Literature reviewed in Chapter 3 does not highlight a consistent methodological approach used by researchers in this field of study. It does, however, highlight categorical shortcomings: most assessment of rural renewable energy systems is done shortly after implementation by the entity responsible for the implementation; independent research on the topic tends to be very narrow in focus (not simultaneously considering technical, economic, social and environmental issues); "the experts" are the primary sources of information rather than system users; and perhaps most importantly, success is rarely well defined.

The methods I used to gather information for this study including a review of available literature, institutional document analyses, surveys and semi-structured interviews and direct inspection of energy systems. Interviews and surveys were conducted predominantly with members of communities in which stand-alone PV systems had been installed, and with project donors and developers who represented both NGO's and various levels of local and national government. These are described below.

In this chapter, I first describe my methodologies for data gathering and data analyses, followed by considerations and limitations of sampling. Section 4.4 includes details of the design, validation and limitations of the survey instrument. In section 4.5, I review the differences between types of projects that are included and not included in this research, enumerating specifically the categories of projects referenced throughout this research. Finally, I describe biases that are inherent to this type of research and how I have taken them into consideration in my work.

4.2. Mixed methods approach

I designed this research with the intention of collecting and analyzing both qualitative and quantitative data in real-world situations. This research is certainly not a double-blind control study; such an approach would be prohibitively expensive, requiring many years of study and the installation of stand-alone solar electric systems in many communities. This approach is not merely impracticable, but in fact impossible if I wish to capture the nuances of the responses of systems and users to unpredictable events such as weather disasters, which cannot be designed as a part of an experiment. Instead, this study is designed instead to obtain both qualitative and quantitative information from observations of actual systems and donation programs implemented in existing communities.

As such, I used what Creswell (2008) describes as a mixed methods approach using concurrent procedures. A mixed-methods approach "is one in which the researcher tends to base knowledge claims on pragmatic grounds" (Creswell 2008), where the problem is more important than specific methodology, and the researcher uses a variety of available approaches to understand the problem. I chose this method as I sought to gather both qualitative and quantitative data simultaneously. Qualitative and quantitative data can then be analyzed both independently and jointly, creating a more complete picture of the results. I chose this approach to data gathering and analyses because I felt that quantitative data, absent a context that can only be assessed qualitatively, would provide results that are less useful for informing future research or future rural electrification efforts. As an example, quantitative data may show that *Ladino* populations in Guatemala have higher levels of success with their rural stand-alone solar electric systems than do indigenous populations. Without an analysis of the qualitative factors that lead to this differential, the resultant policy recommendation may well be that electrification efforts should be focused on *Ladinos* to the exclusion of the indigenous. Even a more nuanced quantitative analysis which showed that the communities with the highest success rates were *Ladino* communities and that these communities had higher incomes would fail to address why either income or project success was higher in one population than another, and as such fail to inform policy beyond "expect projects in indigenous communities to fail."

The inclusion of qualitative analysis allows for meaningful interpretation of quantitative results as well as providing tremendous insight on its own. Some quantitative questions, such as whether there is a correlation between success and the distance between a user and a shop where he or she can buy a replacement battery, become more meaningful when qualitative questions such as amount of time taken by an individual to cover that distance and the mode of transportation used. A person with access to a truck, for example, can cover much larger distances than a person who must go on foot. Some questions simply cannot be answered quantitatively but clearly have implications for policy recommendation and development strategy, such as whether and how an energy system caused conflict in a community.

4.3. Sampling universe

One of the initial goals of this research was to compile a relatively complete database of donated stand-alone PV systems in rural Guatemala from which to select a statistically meaningful random sample. I did not accomplish this, which has ramifications for quantitative analyses of the data gathered.

No database of all donated PV systems installed in Guatemala existed prior to the start of this research. The Village Power Database, a database that was comprehensive of large donor programs (although by no means exhaustive), was previously held by the National Renewable Energy Laboratory (NREL). Responsibility for it was later transferred to the Global Village Energy Partnership (GVEP). However, neither organization can now account for the whereabouts of even historical versions, though current project developers still claim to report information relevant to the database.

A GVEP representative suggested I seek it from *Fundación Solar*, a major energy-related NGO in Guatemala. *Fundación Solar*, like other NGO's I contacted which are participating in energy development in Guatemala, neither had a copy of the Village Power Database nor a database or listing of solar energy projects in which *Fundación Solar* had itself participated. Information about the locations and scopes of programs in which *Fundación Solar* and other NGO's had participated was limited to select case studies published as white papers and the memories and occasional files of current employees. I found no evidence of project-specific institutional memory in the NGO's; project histories remained with the individuals involved in the projects and were not usefully archived when individuals left the organizations. Some individuals in NGO's expressed a desire that I examine particular projects in which they had been involved, and were more accommodating in providing information for research on those projects than on others. Any statement about their motivations in project selection would be purely speculative.

Many other systems were donated by smaller organizations such as churches and foreign charities and development organizations (ranging from the Catholic Church to Engineers Without Borders USA). Because the Guatemalan government requires no reporting for installations of fewer than 5 kW,[40] no database of these independent projects exists and an inclusive survey of them would require physical inspection of every community in Guatemala, which may still omit projects if they have been sold or removed. Other remote PV systems have been installed by NGO's with non-energy-related objectives, such as *Fundación Defensores de la Naturalesa* which has installed PV as part of ranger stations and similar projects inside ecologically protected areas where bringing the electric grid is impracticable or undesirable. Again, such organizations with which I spoke had no records of projects that specifically contained PV systems. Finally, PV is installed under a donor model by multiple organizations within the Guatemalan government, including under two different departments within the Ministry of Energy and Mines, the national disaster coordinator CONRED, sporadically by the Ministries of Health and of Education, and possibly others. Systems installed by CONRED and under the Directorate General's office of the Ministry of Energy and Mines provided the most complete records I encountered in attempting to build a database of systems, but even these were fraught with errors and omissions. CONRED's records of its systems were consistent with what I found in the field. However, as this study was meant to include donated systems in general rather than solely government-sponsored systems, the MEM and CONRED data were useful but not sufficient.

[40] Information here is from an interview with Byron del Cid, Ministry of Energy and Mines.

Ultimately, I did not compile the data from these sporadic sources into a single database because I do not believe that the information was, in aggregate, either useful or reliable. The database of systems compiled for this research contains only those that I elected to include in the study, using the methodology for community selection described in subsection 4.4.1. Subsection 4.4.2 describes my methodology for selecting individuals within communities, for protecting their identities, followed by my rationale for excluding "expert opinions" in favor of community-level responses.

4.3.1. Sampling methodology: selection of communities

The sample of communities included in this research can be described in part as a convenience sample and in part a purposeful sample, the rationale for and description of which are included in this section. The communities visited included those suggested by governmental and non-governmental organizations with ties to stand-alone rural solar electric projects in Guatemala, those included in government databases, and those observed during otherwise-planned travel. This sampling methodology limits the applicability of these results, but was necessary given concerns for safety, resource constraints and the lack of information generally available on such projects in Guatemala.

No global (if incomplete) database or collection of databases existed to which I could add and from which I could draw a sample. Had a reasonable sampling universe been created, the sample of systems still could not have been random. Parts of Guatemala were excluded from the study out of safety concerns for both researcher and informants. Large (and increasing) parts of Guatemala are *de facto* controlled by drug cartels and other criminal syndicates. For example, based on the "common knowledge" in Guatemala that large parts of the department of Peten are effectively lawless, I excluded all systems in Peten from this research excepting one, which was geographically adjacent to and part of a project based primarily in an adjoining department. While Peten was the only departm1ent categorically excluded from the study, I avoided smaller areas based on local knowledge or personal observation. Although some systems in this study are located in territory only marginally governed by rule of law, these results should only be considered valid for locations where NGO or government workers can travel freely.

Physical and economic constraints limited the communities visited in two ways. First, communities included tended to be in clusters under the same programs. This provided the advantage of being able to compare programmatic approaches, and allowed more communities and systems to be included than would have been possible if a substantial travel distance was always required between them.

Second, accessibility was a substantial consideration for inclusion. Some communities with donated systems are more than a day's hike from the nearest passable road, forcing anyone traveling there to camp in unknown terrain or beg lodging from strangers. Some are simply inaccessible except by helicopter during the rainy season, and while traveling by helicopter would allow much more access to some of these locations, it is very expensive and creates additional social barriers with communities being visited.[41] Thus, any community to which I could not walk from a road, conduct observations, and return to the same road during the daylight hours of one day was excluded (walking and even driving after dark are generally not safe). Because of this, no community that was more than 2 ½ hours walk (for me – local people typically travel faster) from a road was included. The majority of communities included were visible from graded or paved roads, or accessible by dirt road in four wheel drive vehicles.

The sample was further biased towards accessible communities because I included systems that I noticed during otherwise-planned travel. Many of these systems were privately purchased by homeowners (and thus not included), but some were part of donation programs.

Rather than claiming that the people included in this research are representative of all Guatemalans, or even all rural Guatemalans with donated PV systems, I postulate that the information gathered from the people generous enough to donate their time about their specific circumstances can give insight into general causes of success and failure of stand-alone PV systems in rural Guatemala. Others studying rural electrification

[41] I accompanied a news reporter to several communities via helicopter and we were well-received in communities that expected us. However, an unplanned landing in a community brought out seemingly all of the men and boys of the town, armed with machetes. The reporter explained that rural, indigenous communities associated helicopters with the military and massacres during the civil war. See Section 3.4 for details on Guatemala's civil war and its lasting effects.

using PV have used such convenience samples and gained insightful, albeit not statistically analyzable results (Acker and Kammen, 1996).

Thus, the validity of the results is limited to areas governed by rule of law, those reasonably accessible by bus, four wheel drive truck, or other vehicle, and predominantly those well known to current development professionals.

4.3.2. Sampling methodology: selection of respondents and their systems

The vast diversity of people in Guatemala cannot be overstated. People of interest for this research are those who are poor, rural and who have or have had donated PV systems in their communities. This is still a large group of people, however.

Both indigenous and *Ladino* people were included, but Guatemala's third notable ethnic group, the Afro-Caribbean *Garifono* population, was not.[42] Individual respondents were chosen based on their willingness to participate, and were young and old, male and female. Though all were poor, some were clearly poorer than others.

The PV systems in this study include solar home systems, systems for school or community use, those for tourism and other income-generating activities, systems for disaster preparedness and relief, and those used primarily for communications, and mirror the "typical" solar home systems described in Section 1.1.

This research does not present a random and therefore theoretically representative sample of rural stand-alone PV system users within the selected communities. I used both convenience and purposeful sampling methodologies in selecting respondents to be interviewed. Because I did not announce my visits in advance, the first requirement for inclusion was, perhaps obviously, that a community member had to be present and

[42] The *Garifono* ethnic group is considerably smaller than either the *Ladino* or indigenous populations, and have apparently been involved in few PV donation projects.

unoccupied enough to be willing to talk to me. Refusal to participate was very low, although respondents were not offered any compensation or promise of future compensation to participate.

Because the research might seem intrusive and people were sometimes distrustful, the first interview in many communities was with a community leader of some sort. This need not have been an elected official, but often someone would be assertive enough to approach me when I arrived in a manner that suggested authority. In some communities, people were unwilling to talk to me until they had received explicit permission from a community leader. In a few cases, women were unwilling to talk to me because they were unable to secure their absent husbands' approval. In some cases, the community leader elected to accompany me throughout the community. This had the potential to create bias in three ways. First, the leader may suggest approaching households based on his own agenda or lead me to households with which he is more familiar. Second, respondents may feel pressured to answer questions one way or another based on the other person's presence. Finally, respondents may have felt safer or more comfortable answering when an individual they trusted was present.

Another public figure who I often approached to request an interview was a local shopkeeper. He or she was already in a position where visitors to the shop window were expected, and the shop window provided a safe barrier between me and the respondent. Conducting this initial interview with a public figure such as a leader or shopkeeper also gave other community members the opportunity to learn that I was asking about their PV systems, and to make themselves available (or not) before I arrived at their own doors.

When completing these initial interviews, I normally asked the respondent for the suggestion of a neighbor with whom I might speak, or I approached a household, school or other building where I observed a solar panel. I very deliberately sought to speak with owners of functional systems and of systems that no longer functioned, or with households who neighbors informed me had formerly had systems. The intent in seeking both respondents who had working systems and those whose systems no longer work was to ensure that my sample contained both successful and unsuccessful systems. Functionality is not identical to system success, as I argued in Chapter 2, but was a convenient proxy that could be assessed very quickly. In some communities, I also spoke with respondents who were in the community at the time of implementation but who did not participate in the project. I was able to speak with few of these, for two apparent reasons. First because users and former users reported that all or nearly all community members accepted the donations, and second because I conjecture that those who were not participants were also likely marginalized within their communities and neighbors were therefore less likely to direct me to them when asked.

Intentionally, I did not document the presence or absence of other individuals – community leaders or others – during the interviews because third parties very often came and went during the course of the discussion. While isolating the respondent out of earshot of other community members would have ensured confidentiality within the community, it would have been inconvenient (if the interview had to be moved every time someone approached, or if I had to interrupt the interview to ask who a newcomer was or note that someone had left) and may have made respondents uncomfortable and unwilling to talk to me. The legacy of the Guatemalan civil war, as described above, includes a very low level of trust of outsiders and I believe people were more comfortable with their neighbors and family members readily available, if not immediately present.

This study included 201 interviews with community members or groups of community members from 65 communities in 26 municipalities in 12 departments in Guatemala, not uniformly distributed. Among these, two communities involved a single interview about a PV system formerly used to support the construction of a now-functioning hydroelectric project and one was a single interview with the manager of a revenue-producing project owned by a church (and thus considered donated by the church and communal to the church members). Single interviews in seven communities were with regards to an interconnected early warning system for floods and severe weather events, and multiple interviews in four communities were in reference to a single tourism project. Others involved multiple interviews in communities that had or had had stand-alone PV systems installed in their communities for solar home lighting, communal productive uses, or school or clinic communal use. Please see Appendix C for a summary of respondents and their locations.[43]

Interviews continued in the community or series of closely-connected communities within the same municipality and involved in the same program until answers converged: if the first two or more respondents all had the same answer for a question or type of question, that question was generally excluded from subsequent interviews in the same community. Though this approach further decreased the utility of quantifiable results, it allowed interviews to focus on topics specifically of interest to respondents, or about which there was disagreement within the community or little information had yet been gathered. As such, data may be presented as both raw data (actual responses) and extrapolated data (answers consistent within a community extrapolated to other members of the same community who were not asked or did not respond).

Care must be used in interpreting the results of this study within the context of this sampling methodology. Creating non-random samples within communities for the sake of breadth and depth of information (how does a non-user's perspective differ from the perspective of someone with an operable or an inoperable system?) precludes drawing conclusions about the specific success rate within the community. For example, saying that 50% of systems that were included in this research in a particular community were successful does not imply that 50% of systems in the community in general were successful. These analyses contain qualitative assessments of program success, and qualitative and quantitative evidence of factors that differentiate successful systems from those that did not succeed.

4.3.3. Confidentiality and anonymity

Respondents who lived in communities which had benefited from donated stand-alone solar electric systems were the primary source of data for this research. As they were poor, many were illiterate and many had been victims of or were close to victims of violence during the civil war, I considered them to be

[43]All personal and place names given are aliases to protect the confidentiality of sources.

a sensitive population. As such, this research was subject to the scrutiny of The Johns Hopkins University Institutional Review Board.[44] Respondents were assured that the information they provided would be kept confidential, available only to those involved in the research. Communities were excluded if I did not feel I could maintain this confidentiality.[45] Their anonymity could not necessarily be guaranteed because of the nature of some of the questions asked. For example, I asked if respondents had leadership roles in the project. If a respondent said that he or she had held a specific post in managing the project, his or her identity would be easily surmised by anyone familiar with the project in that community. However, I attested (and the IRB agreed) that no threat was posed to these respondents if their identities were learned.

Community members were interviewed individually or in small groups. In the case of a group interview or when other community members were present during an individual interview – which was very often the case – other community members within earshot were not asked to maintain confidentiality.[46]

4.3.4. "Expert opinions"

In addition to community members, I interviewed project donors, developers and administrators representing various levels of the Guatemalan government, foreign governments and private NGO's.[47]

As discussed in Chapter 2, the meanings of success and failure can be vastly different for project developers than for the users of systems. This research focuses on success and failure from the points of view found in the communities. Experts in the field of rural electrification using PV in rural Guatemala have in general gained their expertise by being directly involved in the process. They may bring expertise on the process from the point of view of project developers, but bring less on community members and

[44] See Appendix D for IRB documentation.

[45] See Section 6.9.1 for a description of a series of communities that were excluded because of a pending legal action, and I feared that any data I collected would be subject to subpoena.

[46] Enforcement or monitoring of confidentiality within the community was impossible; I chose not to create the pretense of confidentiality among community members within earshot rather than assure anyone that such confidentiality – well outside my control – would be maintained.

[47] These respondents were not guaranteed confidentiality except in cases where the information they provided could potentially cause harm if attributed to a specific individual. This includes primarily information related to *narco* activity in the vicinity of energy-related projects, but also includes criticism of other individuals or organizations that could harm the speaker's reputation or future employability.

their relationships to their renewable energy systems. Though development professionals provided substantial information through in-person interviews, the true experts on what community members perceive and experience are the community members themselves.

4.4. Questionnaire design

The questionnaire was designed originally to relate all outcomes directly to system success, asking the simple question of whether a particular factor contributed to system success or not. However, even in pre-testing this approach proved too simplistic to analyze the data meaningfully. The primary shortfall was that the definition of success is more nuanced than was originally anticipated when the questionnaire was written. Additionally, I found other outcomes and information to be meaningful beyond the yes-or-no question of whether a factor correlated to success. Almost all "basic" questions were followed with questions requesting further comment or clarification. Thus, the mappings included in this chapter reflect how questionnaire data was viewed for analysis rather than how the questions necessarily originated.

Figure 1 shows the relationships among the principle lines of inquiry of this research. The remainder of this section follows the outline of the figure, reviewing questions related first to the definition of success, then to economics and utility, followed by institutions and relationships, and finally community, user and system characteristics and the unintended physical consequences of system implementation. The "outcome" of any individual system or the systems in general included in this study cannot necessarily be summarized succinctly in a few words. Rather, the outcome referenced is the amalgamation of the results included in each of the categories below. Success is distinct from the other results in that other outcomes are compared to outcome "success" where possible, though not necessarily to each other. For example, energy cost savings and community ethnic makeup are each evaluated against success, though not necessarily against one another. Subsequent figures relate individual question topics to the results included in Chapters 5, 6 and 7. Importantly, as explained in the results chapters, specific outcomes and the answers to individual questions do not necessarily fit into a single category illustrated in the hierarchical figures. Although these simplified structures aid in categorizing results, they neglect the many and complex interrelationships between and among results that are explored in detail in Chapters 5, 6 and 7.

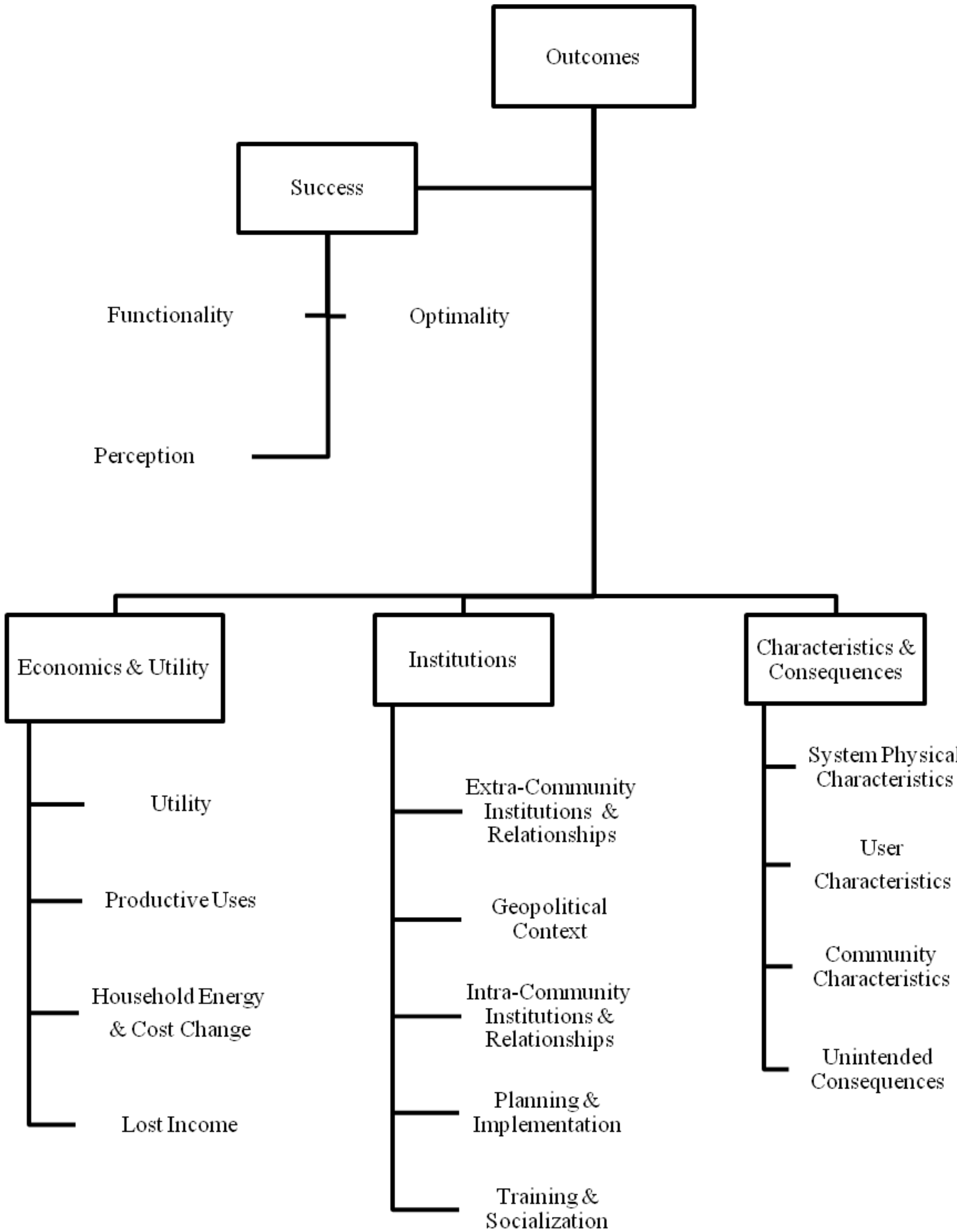

Figure 1. Major outcomes hierarchy

4.4.1. Success

The details of how success was defined and analyzed are enumerated in Chapter 2. Figure 2 shows the breakdown of the broader questions into more specific ideas, and subsequently into individual components that were phrased as questions or series of questions that were either posed to respondents or were analyzed as described here.

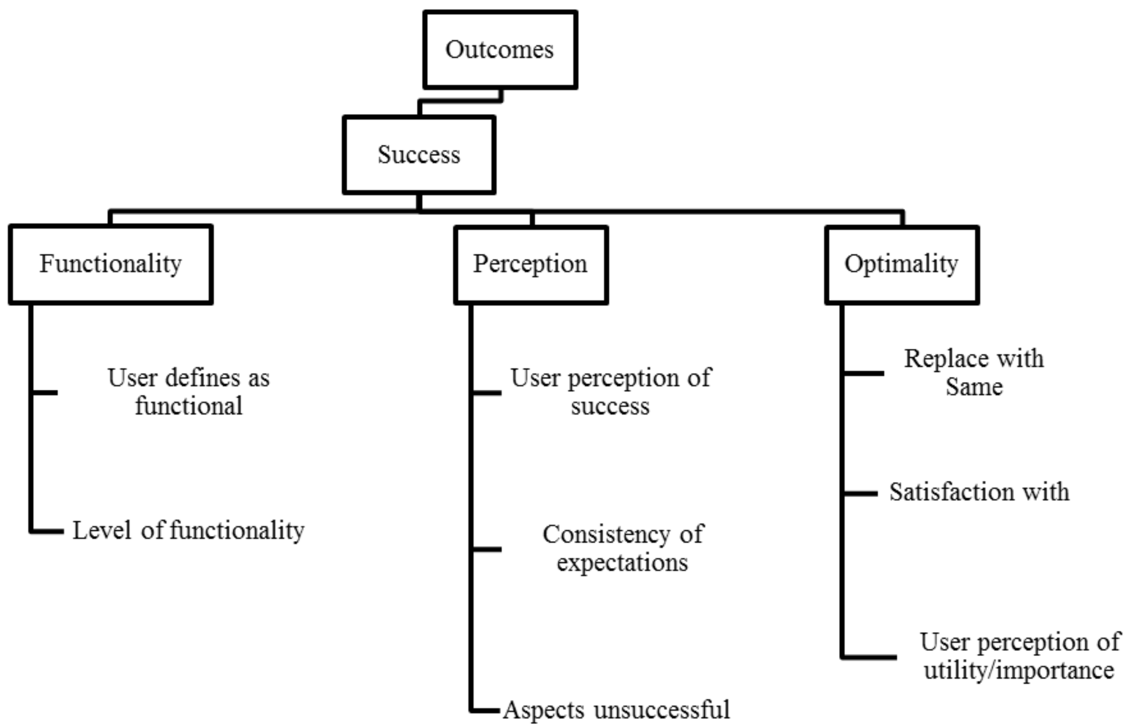

Figure 2. Success outcome hierarchy

4.4.1.1. Functionality

Functionality was assessed using two criteria. The first was a direct question to system users, asking whether system users considered their systems functional and the degree to which they functioned. The base question asked only whether the system was functioning, and follow-up discussion included how well the system worked, how long it functioned at a time, or, if it was not functioning, what steps (if any) were being taken to repair it. The other determinant of system functionality was a physical inspection of the system consistent with standard stand-alone PV system evaluation procedures.[48]

4.4.1.2. Perception

The only *a priori* definition of success that was included in this research was the user's perception of whether his or her system was successful. This question proved inadequate during survey validation as few respondents were willing to state that they found their systems unsuccessful. As such, respondents were asked as follow-up questions how they defined project success, and which aspects of their projects they found unsuccessful.

4.4.1.3. Optimality

Optimality is a component of success that was difficult to assess. Although the question, "is this energy system optimal to meet your needs" could be translated into Spanish and perhaps into the Mayan languages of some of the respondents, I did not feel that it would be a meaningful question to the population being interviewed. As such, I asked indirect questions to attempt to assess the concept of optimality. I asked these at different points during the interview, in different contexts. The primary question was whether users were satisfied with their energy from the system and, if not, why not. A second question was whether users would replace their energy system with an analogous stand-alone PV system, if the original system were damaged or destroyed and if they had the means to do so. Again, respondents were invited to expand upon their answers and explain the advantages or disadvantages they saw to PV as compared to other forms of energy. A third question asked whether the system was relevant and important to them in their daily lives, based on the logic that something that was not fundamentally useful as an energy source could not be considered an optimal energy source.[49] Finally, users were asked what else they would like to be able to do with the energy that their PV systems were unable to accommodate. Ultimately this question was not

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[48] See Appendix B for complete assessment protocol, developed by Sandia National Laboratories.

[49] I reiterate here that energy is a means, not an end.

included in defining whether a system was optimal for a respondent, but offered insight into the needs that the development community was meeting and was leaving unmet.[50]

4.4.2. Economics and Utility

The details of how economics and utility were analyzed are enumerated in Chapter 5. Figure 3 shows the breakdown of information sought for major research questions and hypotheses on topics of economics and utility into components that can be examined individually, as described in this section.

[50] An example examined in more detail in Chapter 5, is that of blenders. Many women interviewed said that they would like to be able to power electric blenders with their energy systems, presumably reducing their kitchen labors in preparing food. However, I have not heard of any donor program that has the specific goal of providing blenders or the electricity to power them. The desire for a blender was not included in the analyses of whether a system was optimal and subsequently successful, but it highlights a gap between donor expectation and beneficiary need, which is a meaningful conclusion of this research.

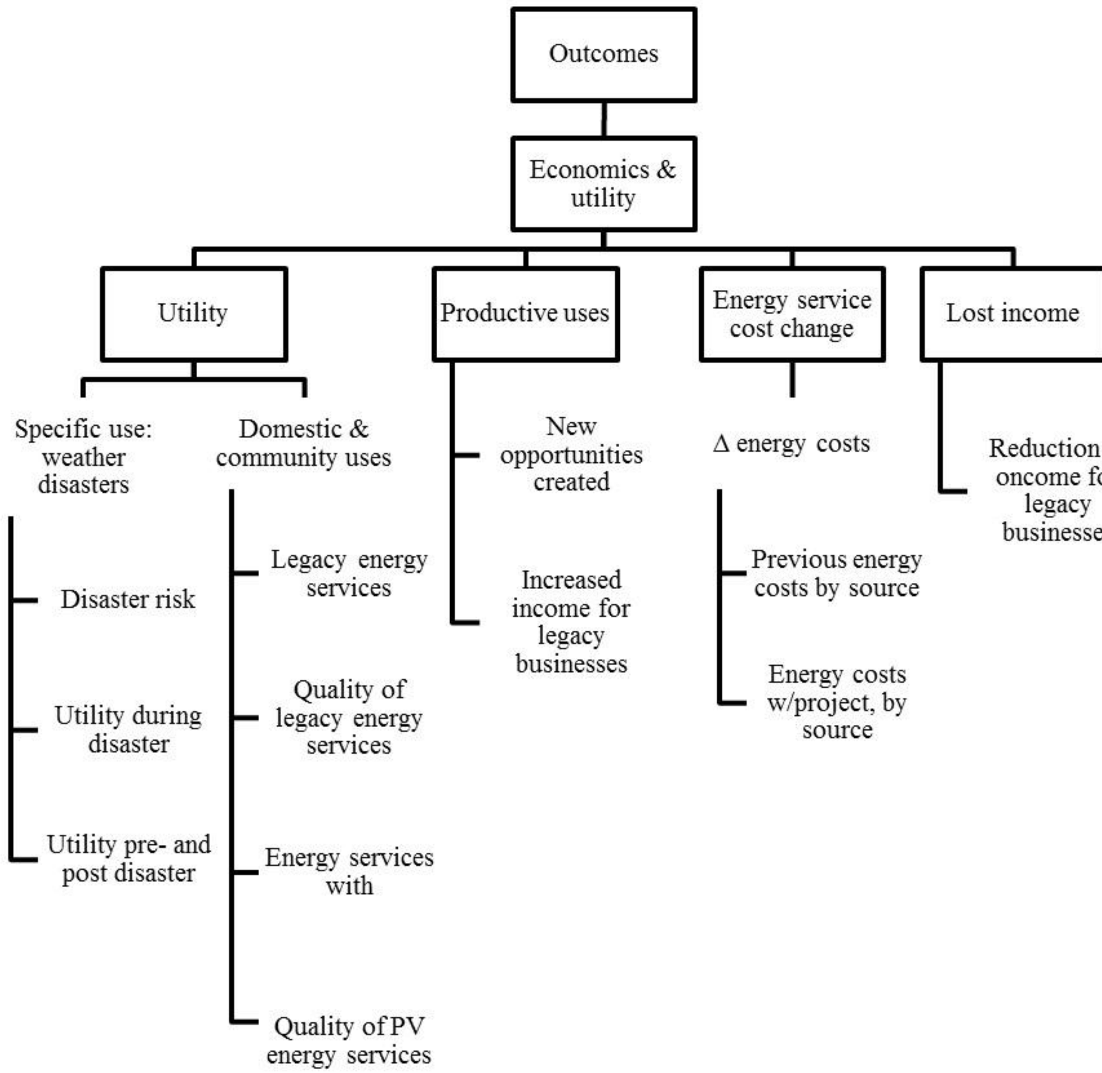

Figure 3. Economics and utility hierarchy

4.4.2.1. Utility

Utility in this research refers to uses of rural stand-alone PV systems for other than income-producing activities, which are considered separately with economics. Specifically, domestic uses (such as household lighting) and community uses (such as television for distance learning in a school) were considered at the outset of this research. I asked questions to learn how energy use changed: if legacy energy source use decreased and if new energy demands were added. I also addressed the question of whether the quality of energy, especially lighting, was different using PV versus traditional energy sources. I added the question of utility in weather-related emergencies as these emergency situations emerged as a common and important theme among respondents. Weak infrastructure and government support services often leave communities without outside assistance during the severe weather events that are common in hurricane-prone Central America. Further, a subset of systems included in this research was designed specifically to assist in disaster preparedness and relief, opening the question of whether stand-alone PV systems are helpful in weather-related emergencies in general.

4.4.2.2. Productive uses

"Productive uses" in the context of this research includes specifically and only those activities performed with the PV systems that generate income. To assess these, I asked whether existing income-earning opportunities were enhanced (could more money be made from an activity that previously provided an income?) and whether new income-earning opportunities were created. I further assessed whether these income opportunities relied directly on the energy system (for example, if someone purchased electric-powered carpentry equipment) or if the energy system was an indirect contributor (for example, if a store owner sold more pre-paid phone cards because people in town were now able to charge cell phones).

4.4.2.3. Energy service cost changes

I assessed changes in energy costs both directly and indirectly. Users were asked whether they paid more or less for energy services when the PV system was in place than when it was not. They were also asked about prior and current consumption (in quantity as well as cost) of specific energy sources such as candles, batteries, kerosene, firewood and other energy sources common to rural Guatemala or suggested by respondents. Questions about energy cost changes included the added expenses associated with the PV systems, such as any tariff or any maintenance expenses. Importantly, respondents were also asked about increases in energy cost due to increases in energy use: users with newly available electrical energy may increase their overall energy consumption by adding televisions or cell phones, which cannot be powered by traditional candles or kerosene.

4.4.2.4. Loss of income

A hypothesized contributor to the failure of rural renewable energy systems was the loss of income associated with them, if sellers of traditional sources like candles lost business when the systems were installed. Respondents were asked whether there were economic losers at the community level, and those respondents who themselves sold traditional energy sources were asked if they saw any decrease in income and whether they saw a net decrease or increase in income resulting from the systems.

4.4.3. Institutions and relationships

The details of how institutions and relationships were analyzed are enumerated in Chapter 6. Figure 4 shows the breakdown of information sought for major research questions and hypotheses on topics of the institutions surrounding these systems and the relationships that are formed and changed as a result into components that can be examined individually, as described in this section.

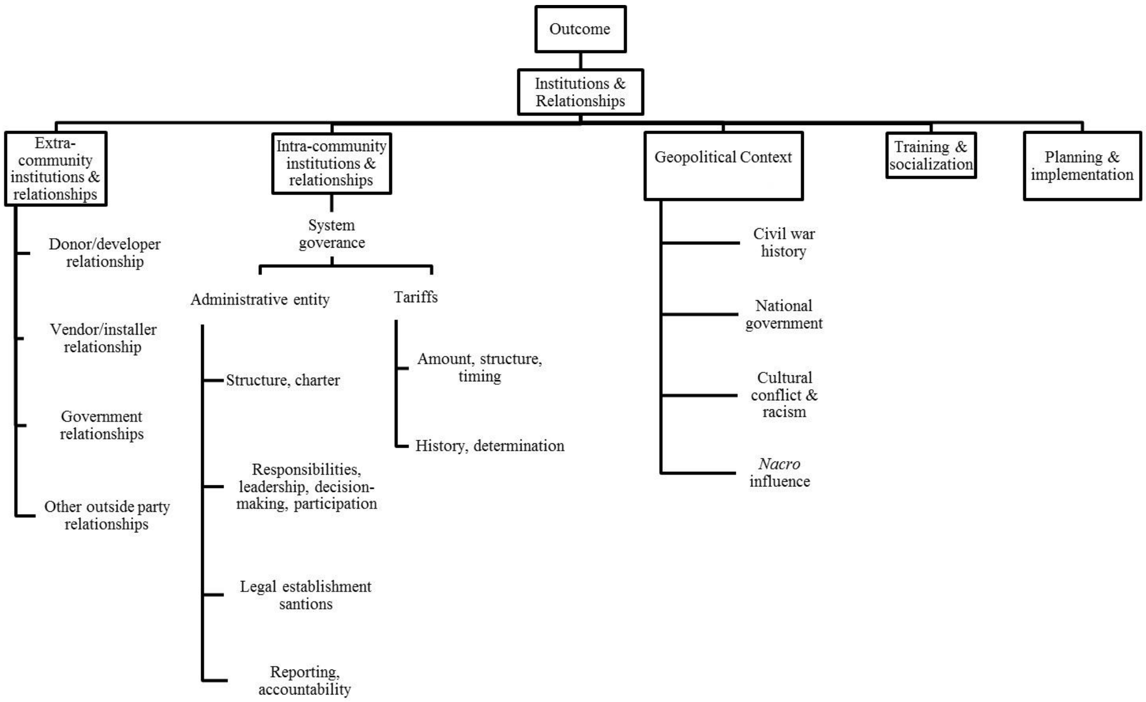

Figure 4a. Institutions and relationship hierarchy

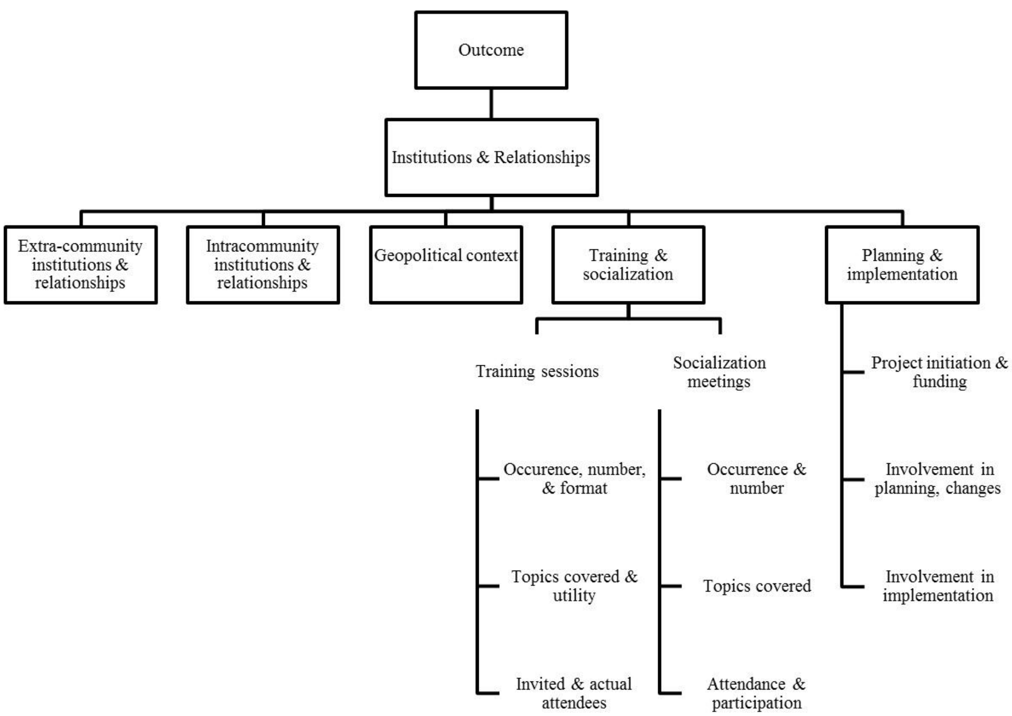

Figure 4b. Institutions and relationship hierarchy

4.4.3.1. Extra-community relationships

The relationships of interest here are the relationships between members of the community and outside individuals and institutions: donors, developers, vendors, installers and government entities at the municipal, department and national levels. The relationships between two communities that both have PV systems and the relationships between communities in which one community benefited while the other did not are important, but they are outside the scope of this research.

The distinction between the donor, perhaps a large multinational institution that provides funding, and the developer, perhaps a smaller in-country NGO that planned and implemented the project with the developer's funding, was not clear to many respondents. As such, while I had originally formulated questions about the nature, quality and longevity of the relationship with each individually, I merged these questions so that they related to both developer and donor.

Similarly, the vendor and installer were frequently the same entity and the distinction was not apparent to respondents when different individuals or agencies assumed those roles. Users were asked about the quality and longevity of the relationship – and the vendor's responsiveness to concerns and warrantee claims, and also what role the developer or donor had played in acting as a liaison between the community and the installer or vendor where the vendor had been unresponsive or unscrupulous in its dealings with the community.

Relationships with "government" were assessed using a few specific questions as to whether local, regional and national government officials were supportive of the donated projects, but conversations with regards to government were largely open-ended as experiences differed enough to preclude many consistent questions.

4.4.3.2. Intra-community relationships: conflicts and networks

I made no attempt to quantitatively define social conflicts or networks based on their severity, quality, or other characteristic that required a judgment of human attitudes or behaviors. Instead, I asked straightforward questions to which respondents could answer “yes” or “no” as to whether the donated systems had caused any sort of social conflict. If the respondent answered in the affirmative, I sought more details in an open-ended format. I further asked whether respondents had observed two specific types of social conflict: whether the system was in conflict with anyone’s religion or had caused religious conflict; and whether the donations had caused or exacerbated inequality in the community. The former was asked just as the more general social conflict question was asked. To explore the question of equity, I first asked whether all members of the community had had equal access to the project. If the answer was no, I invited more open-ended responses to the nature of that inequity, and then asked whether the unequal access caused any conflict within the community. This approach unfortunately excludes cases of inequity being exacerbated between project beneficiaries (i.e., a “rich” beneficiary somehow gains more from an equivalent system than does a relatively poor beneficiary of the same system), but I chose to exclude explicit questions of previously existent community equity as questions that may make respondents uncomfortable. If respondents themselves brought up the topic, I encouraged them to share as much as they were willing.

If any form of conflict was reported and explained by respondents, I asked whether and how the conflict had been resolved.

In exploring the theme of solar energy in disaster preparedness (see Section 4.4.6, above), I asked whether the donation of the systems had helped them to build social networks that aided them in the event of a weather-related or other disaster. I asked whether any such social networks were created as a result of the institutions build around the donation projects (e.g., by being a part of an energy committee, neighbors had gotten to know each other better or become more willing to help one another), or as a result of the solar systems themselves (e.g., neighbors grew closer or more supportive just by spending time together by electric lamplight, where previously they stayed home in the evenings).

Beyond the general hypothesis that systems which created conflict would be more likely to fail, this line of questioning was in largest part exploratory, seeking potential outcomes and relationships between outcomes that I did not anticipate.

4.4.3.3. Intra-community institutions: system governance[51]

Many aspects of the institutions and relationships within a community may change unintentionally with the donation of solar energy projects. In this section, I address questions of deliberate changes to community institutions and relationships: the administrative and governance structures created to manage the systems. Specifically, I ask about respondents' perceptions and understandings of the following:

– *Structure, charter*

I hypothesized that the presence of an administrative entity to manage donated systems at a community level would be associated with more successful systems, and asked, as a research question, whether the type or structure of the administrative entity would be related to success. I asked respondents whether any administrative structure existed to govern or manage their systems. I asked for a description of the type of structure, the participants, and how participation was manifested (i.e., rotating leadership positions, votes in general assemblies, etcetera).

Of particular note, I asked whether a charter had been written, and whether ongoing administration was consistent with that charter. In more open-ended questions, I asked respondents to describe the participation of the project developer in the creation of the administrative entity and its charter: was it required by the

[51] Language associated with governance and administration was not foreign to many respondents because of the programs under which many of these systems were implemented. *Reglamento interno*, roughly translated as "charter," *estados de cuenta*, or "financial statements" and similar language was introduced by the development entities that encouraged or mandated the establishment of governance structures as a condition of system installation. Thus it was not only possible, but in fact common that an illiterate farmer who had never had a bank account knew the definition of "financial statement."

developer; was the developer helpful in its creation; did the developer set out rules that the charter must contain, or merely aid in the creation of rules appropriate to the community?

Although not included in the original questionnaire as designed, I modified questions slightly to glean information about governance structures that had been established initially but were no longer in place, a circumstance that was much more common than had been anticipated during questionnaire design. As such, in communities where governance structures had existed but had been dissolved, I asked questions of how long the structure had been in place, why it was dissolved, and why it was not re-started if the circumstances that led to its dissolution had changed. These questions did not contribute to knowledge related to any particular hypothesis, but lent insight into the functioning of communities and their attitudes towards their PV systems.

– *Responsibilities, decision-making, participation*

To test the hypotheses that active participation in ongoing decision making leads to greater system success, I asked questions about the levels and types of involvement. Most importantly, I asked whether the respondent participated in governance and decision-making at the community level, involving systems beyond the one in his or her own home, currently or previously. In follow-up questions, I asked who was eligible or welcome to participate, including whether a respondent's lack of participation was voluntary or whether he or she had been excluded.

I sought information about the way respondents participated: as leaders, as members-at-large, or in other capacities. In more open-ended questions, I invited respondents to comment on the leadership of the system of governance and leaders' responsiveness to user concerns.

– *Legal establishment, sanctions*

I asked questions about respondents' understanding of the legal status of the institutions created to manage, govern or administer the systems in their communities. I specifically did not confirm with government institutions outside the community (regional or national government offices, for example) whether respondents' understanding of the legal status of the administrative entity was correct.

Specifically, I asked whether respondents believed the entity to be legally established and, if so, if they knew what type of legal structure it was (*COCODE, comité*, etcetera).

I also asked whether the structure had the authority to impose sanctions against participants who failed to live up to their obligations (for example, failure to pay a tariff), and whether these sanctions were enforced. This line of questioning was intended to explore whether the perception of legality of a governance structure led to higher probabilities of success of systems, whether the imposition of sanctions also led to greater success, and whether the perception of legality increased the likelihood that sanctions would be effectively enforced.

– *Reporting, accountability*

I had no specific hypotheses about whether confidence in an administrative entity would make that entity more effective or lead to greater system success. In part, this was because measurements of "confidence" are methodologically beyond the scope of this research. Some degree of accountability of the governing body to its constituents can, however, be assessed through straightforward questioning. I asked whether respondents knew how monies collected were spent, whether they were sufficient to cover the expenses associated with the systems, and whether they knew how any deficit was covered or where any additional monies went. Further, I asked whether the governing entity produced financial statements that detailed how much money was collected and how it was spent and, if so, the frequency with which these statements were produced.

– *Tariffs*

Tariffs and tariff structures are included with institutions and relationships in this section because they reveal more about these institutions and the relationships in the community than they do about the economic burdens they impose. The tariff cost is included in questions of economics when users were asked how much they pay for energy; in this section, I describe questions posed about the institutions that determine and enforce the tariff and the relationships between people involved where money changes (or fails to change) hands.

Specifically, respondents were asked whether they were asked to pay a tariff for the use of their systems. They were also asked about the tariff: how the amount was determined, who collects it, what the timing of payments were, whether there is transparency in how the monies are handled, and whether the tariff accomplished its intended purpose of providing the financial resources to maintain the systems.

They were also asked whether they or anyone else in fact complied with the tariff as structured. Open-ended follow-up was sought in this regard, to assess the degree to which there was confidence in the institution that established and maintained the tariff, as differentiated from an inability to pay because the cost was too high or other motivations to comply or not comply.

4.4.3.4. Geopolitical context

The geopolitical context in which these systems, programs and institutions are set are complex. Information about these did not come directly from the communities and respondents in the form of answers to specific questions. Instead, much of what was included in the description of this context comes from reviews of the academic literature, as well as of the popular press (which provides more current, if less rigorously verified, information). Employees of the government of Guatemala, local NGO's, and others in the development community shared insights, as did respondents in their answers to other questions and in the topics they chose to discuss in the more open-ended parts of the interviews and members of the public at large with whom I came in contact.[52] These contexts, and the associated sources of information, are detailed in Section 3.4.

[52] For example, I did not conduct an interview with a waitress at a restaurant in one municipality, but her warning to stay away from a particular area because of drug activity was considered valid enough to shape my travel plans. I did not verify her account (beyond the nods of a few people within earshot) nor do I attest to know which areas near her restaurant are specifically under the control of

4.4.3.5. Training and socialization

In support of the hypothesis that greater levels of training and socialization would lead to greater success, questions of socialization meetings and training sessions were addressed simply. I asked whether and how many such meetings and trainings occurred, who was eligible to attend, whether the respondent had participated, and then asked in a more open-ended format what topics were covered.

4.4.3.6. Planning and implementation

The original questions I had structured about community involvement in planning and implementation were straightforward and structured like the training and socialization questions described above. However, these questions yielded less information, so I instead invited unstructured commentary on the respondents' knowledge of the initiation of the project and its funding, their involvement in any changes to the project between the time it was proposed and what was finally implemented, and their involvement in the implementation process

4.4.4. Characteristics and consequences

The details of how system and user characteristics and unintended consequences were analyzed are enumerated in Chapter 7. Figures 5a, b, c and d show the breakdown of information sought for major research questions and hypotheses on topics of characteristics and consequences into components that can be examined individually.

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the *narcos*, but I consider the information generally valid enough to inform my understanding of the geopolitical context of the northern departments in Guatemala. In another example, someone who I had hired as a driver boasted that there were no indigenous communities in his department.

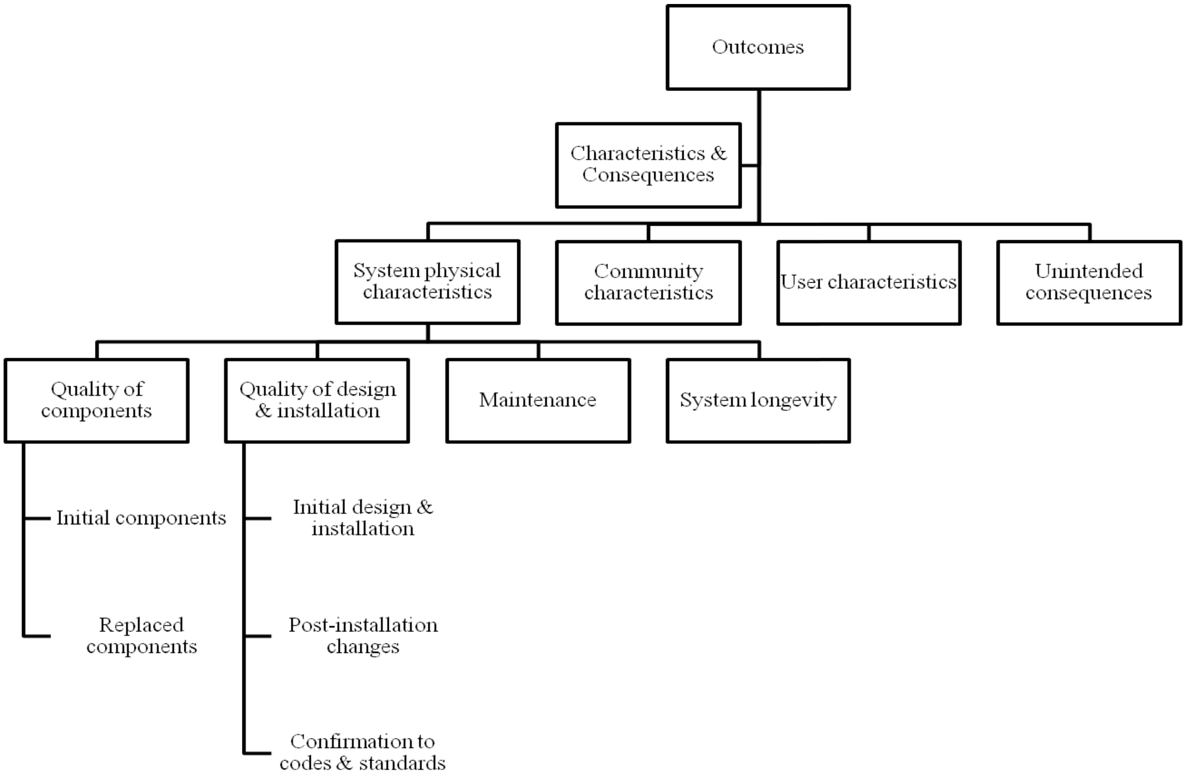

Figure 5a. Characteristics and consequences hierarchy

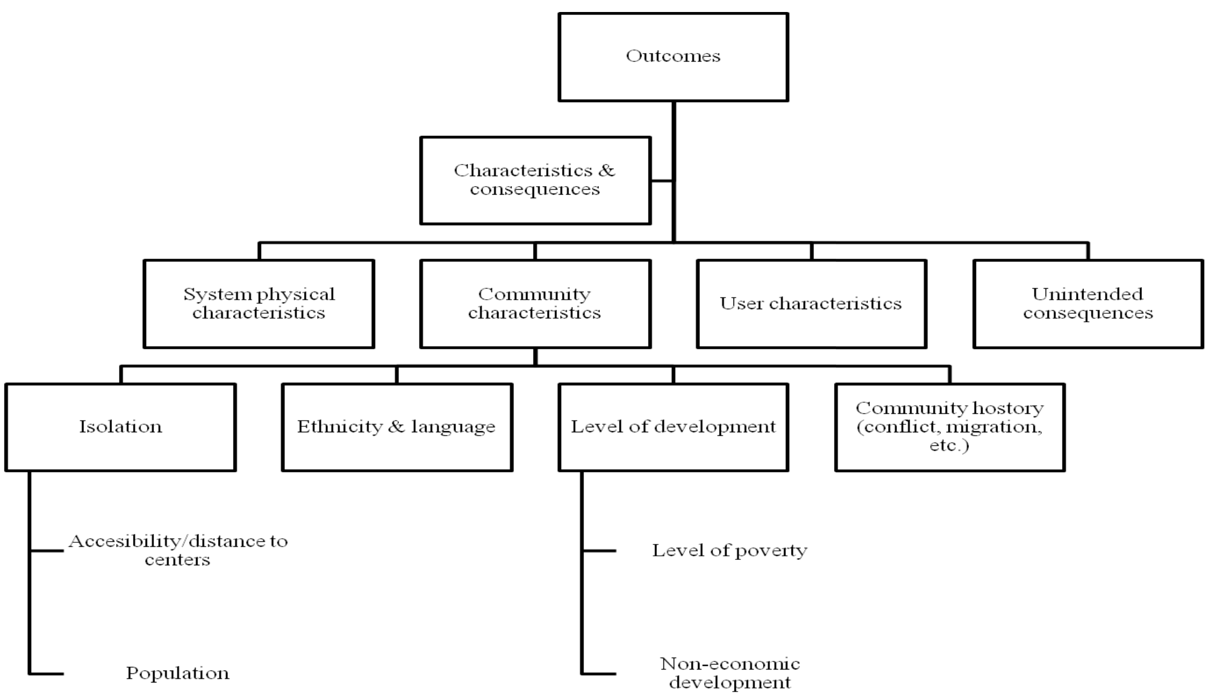

Figure 5b. Characteristics and consequences hierarchy

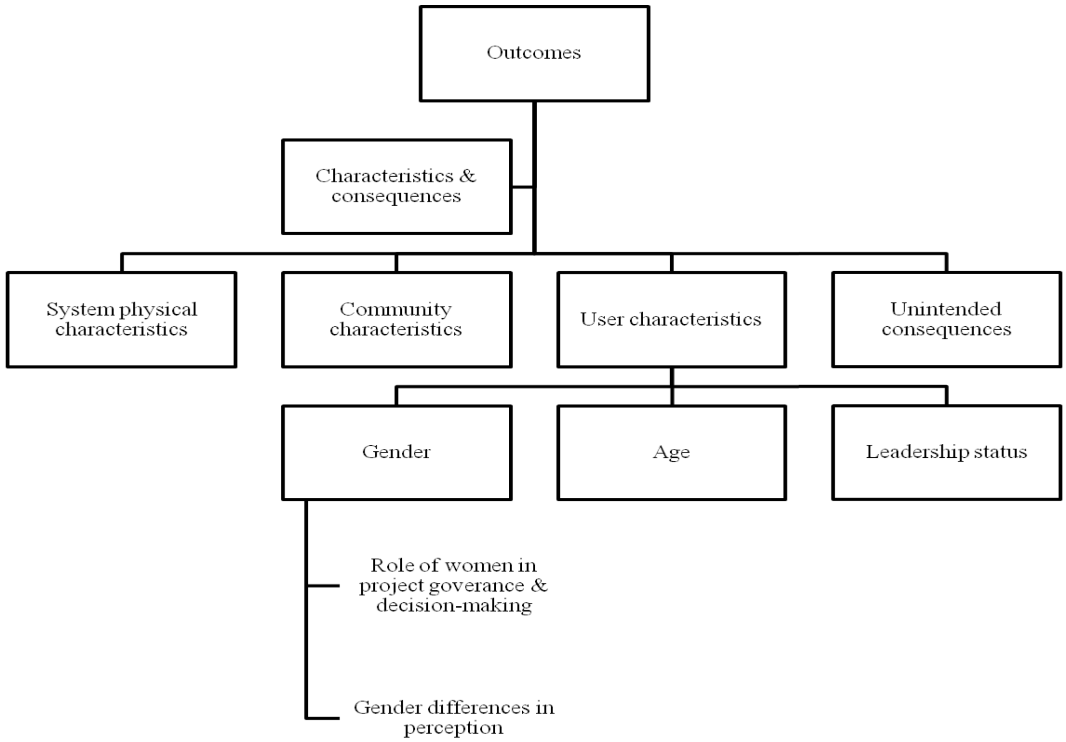

Figure 5c. Characteristics and consequences hierarchy

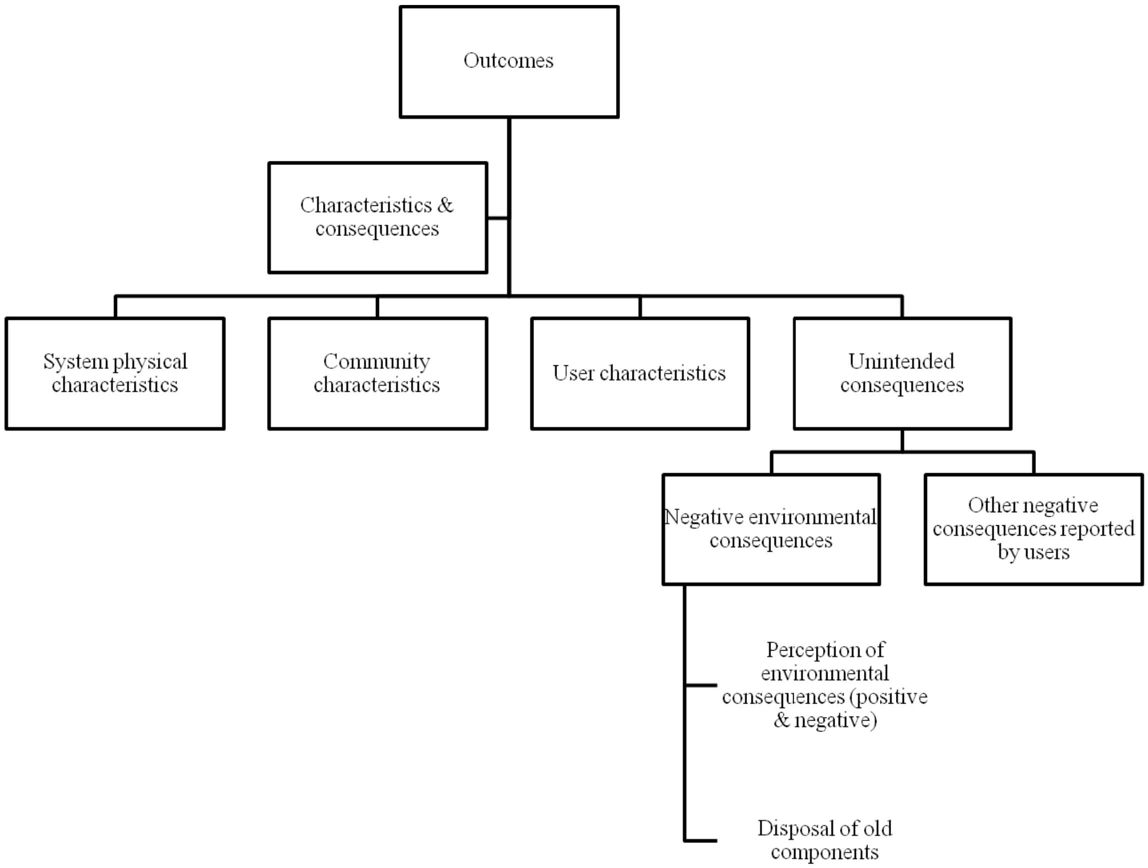

Figure 5d. Characteristics and consequences hierarchy

4.4.4.1. System physical characteristics

Project developers with whom I spoke provided few, if any, detailed records of implementations, and users themselves lacked the technical expertise to assess the physical quality and appropriateness of their systems or their conformance to safety codes and industry standards. As such, I physically inspected systems to assess the quality of the components and installation. Conformance of system design to norms and standards could only be assessed indirectly, as a system may be installed or implemented contrary to its original design. These questions of system physical characteristics were assessed using an inspection protocol developed at Sandia National Laboratory, and includes, among other things, an inspection of the condition of the panel and wiring, an assessment of the level of liquid in the battery, and voltage measurements at key components. An example of the form can be found in Appendix B.

Users were asked whether they had replaced any of the original components or altered their systems in any way. If original components had been replaced, the quality of the replacement components could be assessed, though not that of the original components (unless the user kept the old component, as they sometimes did). The initial system installation quality could often be assessed even if the user had altered the system. Users rarely removed bypassed components or old wires so the original design (as installed) was generally evident.

Also included in the category of system physical characteristics is the physical maintenance performed on the system. Large failures in maintenance could be evident in system technical inspections.[53] However, whether more routine maintenance was performed as scheduled was assessed by asking users whether and what types of maintenance they performed. Straightforward questions of whether users performed maintenance on an ongoing basis were inadequate. I also asked users to enumerate the types of maintenance activities they performed and the frequency with which they performed them.

Finally, in this category falls system longevity. The ages of the systems were assessed based on questions to users and, where available, project documentation from developers or personal communication with developers about specific projects.

4.4.4.2. Community and user characteristics

The distinction between community and user characteristics is, in many ways, arbitrary. As an example, I have chosen for expedience to categorize a community as belonging to a particular ethnic group, rather than an individual respondent. There is no theoretical basis for this distinction, nor is it meant to imply that ethnicity is not an individual as well as a community characteristic – the decision was solely for reporting purposes. As such, in this section I enumerate both the community and user characteristics that are analyzed in this research.

[53] For example, if users failed to add water to the battery as needed, this was evident by the low water level visible in the battery.

In addition to ethnicity, I assessed community isolation, focusing on the technology in question. The proxies for the concept of isolation were distance to urban centers or larger communities where replacement parts and service for the system might be obtained, and the size of the community itself. The former was assessed based primarily on respondents' answers to questions about their own knowledge of where replacement parts might be obtained and how long it took them to get to that location and how they traveled. Distance in kilometers and time needed for me to reach a community were both inadequate measures to assess isolation from a technological perspective for several reasons. First, depending upon terrain and means of transportation, it might take a vastly different amount of time for one respondent to cover the same distance as another. Second, the relevant distance to be measured is not the distance to the nearest location where replacement batteries, for example, are available; the user may not know of or be welcome in the nearest location so the relevant distance is the distance to the nearest location that the user would him- or herself visit.

Community history was assessed in largest part indirectly. I considered asking respondents directly whether their community was burned or whether massacres took place to be too presumptuous, and likely to obstruct further communication with the respondent. As such, I relied in largest part upon the literature on the history of Guatemala and the communities' locations relative to the events in that history to serve as a proxy for the "community history." Respondents who were willing to volunteer information about their experiences were of course not discouraged, but I did not initiate that discussion with direct questions or prompting.

The level of poverty in a community was similarly assessed based on communities' locations relative to known areas of poverty in Guatemala. However, I relied on direct observation as the most reliable source of information about a community's general or approximate level of poverty. Specifically, I observed buildings: extreme poverty was assumed where the exterior walls of houses were made from bundled cornstalks, contrasted with the relative affluence of a house with drywall on its interior walls. I made similar observations about large possessions: ownership of a cow,[54] a truck or a horse was assumed to indicate relative wealth. I did not ask respondents explicit questions about their earnings or possessions for a variety of reasons, including that people frequently lie about income, that those engaged in subsistence farming often use barter rather than cash (making cash income less meaningful), and that those engaged in occasional or day labor may not have a clear recollection of the sources and amounts of their incomes.

I attempted to assess the level of non-economic development in communities. For this, I used recent development projects as a proxy. However, for reasons described in the subsequent section, this approach did not yield reliable information about communities' levels of development.

Considerations of respondents' and users' genders were not addressed in specific survey questions or observations, and I had no *a priori* hypotheses about where gender differences would emerge. Instead, I made note of differences in responses to other questions when these differences emerged along gender lines. Husbands' tendencies to answer for their wives or to take over interviews that I began with women were complicating factors in drawing conclusions based on the genders of the respondents. Family demographics were delicate to assess, so I only asked about the composition of the household – in particular about children in the household – during conversations in which I felt the respondent was particularly comfortable.[55]

Finally, I had hypothesized that active involvement in the project would lead an individual user to have a higher probability of success. To assess "involvement," I asked specific questions about attendance at training sessions, participation in project planning, ongoing involvement in decision making, and current or

[54] Culturally as well as economically, a cow is considered a status symbol in Guatemala, to the degree that a cow is colloquially called a *ganado*, which translates approximately to "prize" or "earnings."

[55] Rumors persist among rural and especially indigenous communities about foreigners who attempt to kidnap babies for sale into adoption markets, and rumors persist among foreign development and expatriate communities about community members lynching well-intentioned tourists and healthcare workers who took too much interest in their children. Although all are poorly documented and almost certainly exaggerated if not outright false, I believe the potential harm done to the confidence between myself and the respondent outweighed any benefit of categorically documenting the numbers and ages of people living in households.

former leadership status with the project. These were taken in aggregate to judge the degree to which a respondent was involved in the project.

4.4.4.3. Unintended consequences

Any development project can have negative or positive consequences that were unforeseen or unintended at the outset of the project. Perhaps the most common is the creation or exacerbation of conflict within a community. This is addressed in Section 4.4.3, above. Another potential negative consequence is the possibility of decreasing economic opportunity, which is addressed in Section 4.4.2, above.

I assessed the potential for negative environmental consequences based both on respondents' judgments and my own, relying here on "expert opinion," unlike in much of the rest of this study. I asked respondents directly whether they felt there were negative consequences to their environments as a result of the solar projects. I also asked how users disposed of components – especially batteries – that were no longer functioning. I used this as a proxy for environmental damage because the lead from batteries improperly disposed of presents a local danger to human and ecological health. Note that this research does not attempt to weigh any environmental damage caused by PV systems at the site of installation against any mitigation of damage when compared to alternative energy sources.

Additionally, I asked respondents to suggest other negative consequences that did not fall in to the categories of social conflict, economic losses or environmental degradation.

4.5. Questionnaire validation

In the creation of this questionnaire, I developed questions based upon my hypotheses and research questions, as described above, and added questions that I felt would add depth or context. The questionnaire was translated by Debora Ley of the Environmental Change Institute at the University of Oxford, who is a native Spanish speaker with eleven years of experience working in rural energy in Mexico and Central America. With her assistance, I arranged the questions to flow conversationally rather than structuring the questionnaire to follow my hypotheses and research questions rigidly.

I initially validated this questionnaire in the community of Nueva Alianza, in the department of Quetzaltenango, Guatemala. Nueva Alianza is a rural community that has been very actively involved with the development community and has succeeded in getting assistance to start projects in water purification and bottling, pig and chicken farming, macadamia nut and coffee growing, biodiesel, ecotourism, and other development projects. I chose to validate my survey in this community for several reasons. First, I knew them to have both successful (hydroelectric) and unsuccessful (biogas) energy projects, which allowed me to test questions from both perspectives. They were also native Spanish speakers, which removed the confounding factor of translation from Mayan dialects. Because of their work with the development community and their ecotourism project, they are not mistrustful of foreigners and as such, many people were willing to speak with me. Finally, they give tours of their community and projects as a part of their ecotourism activities; they permitted me to pay for a tour and participate in that tour for the most part in the form of interviews with community members. This allowed me to take the extra time necessary to rephrase questions and refine the questionnaire while speaking with them without detracting from their livelihoods.

Several downsides emerged from using Nueva Alianza as the location where I validated the survey and practiced interview technique. The first is that the energy systems in their community, including the lone PV system, were communally owned and operated by the community's governance. As such, I was not able to prepare as well as I would have liked for responses related to systems wholly owned and operated by individuals. Second is that their governance structure was fully developed and operational. This reinforced an inaccurate assumption I had about the prevalence and strength of institutions to govern rural energy projects. Another substantial disadvantage to validating the questionnaire in Nueva Alianza was that everyone with whom I interacted spoke the language used by the development community. Because of the ubiquitous involvement of community members in the development projects in the community, they shared common definitions of terms like "project" and "donor," definitions that were not as consistently understood in communities that had less consistent contact with the development community. Finally, the advantage to me of a Spanish-speaking community was also a disadvantage: I did not have the opportunity to validate the survey's translation into the Mayan languages spoken by some of the communities included in this research.

Even after validation, as the research progressed, some questions had to be refined, expanded or abandoned because they did not measure what they were intended to measure, or because they were understood inconsistently by respondents. Many of the refinements were subtle, changing just a word, where other changes were more profound. For example, a question that was expanded was whether anyone in the community saw a decrease in income because of the project. Originally, there was no follow-up question if the response was "no." However, I added a follow-up question to the negative response listing specific examples of how income might decrease: do local shops sell fewer candles or flashlight batteries, or less kerosene? This question allowed me a more nuanced understanding of the economic effects (or lack thereof) perceived by respondents.

As an example of a question that was abandoned, respondents were asked what other recent donor or development projects, besides their PV systems, had been implemented in their communities. This question was intended to serve as a proxy for the level of development of the community: without my pre-defining what "development" was (stating specifically schools, potable water, improved roads, etcetera), I wished to know what development had taken place. This question was effective at assessing level of development in the community where the questionnaire was vetted, but I now believe this was an artifact of that community. *Nueva Alianza* was very involved with "projects" developed with outside donors and identified these strongly with community development and progress. However, in other communities, especially those with less ongoing involvement with donors, the concept of a "project" was more nebulous. Community members didn't necessarily identify projects the way I do. Some might include road improvement undertaken by the government, while others would limit their definitions of projects to those implemented by NGO's. The question of projects being "recent" added to the ambiguity in answers and decreased the effectiveness of the question at assessing the information I sought. If a school was built in a community ten years prior, it is not clear whether that is a recent project. It also illustrates a fundamental shortcoming of the question: a community that is at a higher level of economic or other development may have less need of donor projects.

Although survey methodology normally strives for the greatest possible consistency, I gained more information by deviating from my script and focusing on questions that were particularly relevant to a specific community or seemed to be on topics of greatest interest to a particular respondent. The sampling methodology itself makes broad statistical inferences problematic; questions that were not asked consistently further confound statistical analyses. This approach resulted in varying numbers of responses to each question. However, respondents provided more information and seemed more candid when my questions were conversational rather than scripted.

In conclusion, the survey instrument used to gather data for these analyses was developed from my original hypotheses and research questions. It was translated by a native Spanish speaker with experience working with this and closely related populations, who further assisted me in arranging the questions into a conversational format that would be more comfortable for the population being interviewed.[56] Although I tested and validated the questionnaire with members of a rural Guatemalan community, I continued to adjust questions throughout the early period of the study despite that such changes render changed questions statistically invalid. These changes were designed to provoke more insightful responses from people included in the study as I learned more about how they responded.

The primary sources of information for this research were the responses of community members to the questionnaire as described above, and their comments and responses to further questions included in the semi-structured interviews of which the questionnaires were a part. Further information was gathered from peer-reviewed literature, project documents obtained from project developers and donors, news media,

[56] Surveys were administered in indigenous communities where Spanish was not commonly spoken with the aid of a translator of the same ethnicity but not native to the specific community.

unstructured interviews and conversations with development professionals and government officials in Guatemala, and direct observation and conversations with residents of the regions in which I conducted this research. Overall, factual reliability was considered less important than the perceptions of community members,[57] who were the true "experts," rather than developers or social scientists, in clarifying how the communities understood, used, and integrated their solar PV systems into their lives and societies.

4.6. Project inclusion and exclusion

In this section, I detail the types of projects considered for inclusion in this research, and my rationale for the exclusion criteria used. In section 4.6.2, I differentiate market-based and donation-based dissemination of PV systems in rural areas, followed by discussions of donation types. Section 4.6.3 looks in detail at the conditions present in market-based dissemination. Finally, I define the five specific categories of donation and donor-ownership programs included in this research.

In rural electrification, policy makers often focus on *coverage* or availability of, rather than use of electricity sources (Foster and Tre, 2000). The number of communities with grid access or households with PV in a region determines the region's rate of electrification, regardless of reliability and whether those with access are willing or able to pay the price for electricity. This may mean that Guatemala's published rural electrification rate of over 50% (Ahmed et al., 2005) far exceeds the actual availability of electricity.

Included in this "coverage" area are communities with donated stand-alone PV systems, implemented under many institutional and economic arrangements. The systems included in this study are all donated under one of the schemes described in this chapter. The identified strengths and weaknesses of these arrangements, and the problems with systems encountered under each, must be considered specific to the programs studied. However, just as similar problems are hypothesized to be seen across varying regions, many of the problems in these programs are hypothesized to be found in other arrangements.

[57] For example, whether project governance structures were legally established was considered less important than whether respondents believed they were; community members often confounded the name of the project developer with the donor, a confusion which was not considered material to this research, etcetera.

4.6.1. Systems included and not included in this research

Institutions and arrangements for the implementation of rural renewable energy systems can be placed in five basic categories, with different implications for managing and maintaining the project for each category: donations, cash sales, fee-for-service, consumer credit (Nieuwenhout et al., 2001), and equipment loans. The systems included in these analyses include donations and equipment loans, described in detail below.

None of these models involve incurring debt to the donor, as some partially subsidized programs do. Excepting a small number of government owned and managed systems, these do not involve ongoing subsidy for system maintenance or expansion from the donor. Either of these financial links between donor and beneficiary may substantially impact project success, but that hypothesis is not tested by these analyses.

As this is a cross-sectional study of projects that are already in place, and focuses on actual projects rather than project documents or developer-reported history, it is difficult to differentiate theory failure – in which the project fails despite being implemented as planned because underlying assumptions are wrong – versus implementation failure – where the ultimate process or product is not what was planned (Bertrand, 2005). In this section I present the information that was available on both theory and implementation, based in largest part on the knowledge of the *users* themselves, although the limited information obtained from project donors and developers is also included. The emphasis on community-level knowledge (rather than "expert" knowledge) is deliberate. Chapter 6 explores further users' participation in and understanding of designing and implementing projects.

In this section, I discuss the most common arrangements for the implementation of PV for rural electrification and the strengths and weaknesses that have been identified with each, focusing on the broad categories of market-based dissemination of PV and PV donation programs. In the final section of this chapter, I present the programs and projects included in this research.

4.6.2. Market-based versus donation-based programs

The difference between systems acquired under a market-based model and those acquired as part of donation programs is not obvious. Heavy government or donor subsidy does not necessarily imply a donation program, as when government focus is on PV market building rather than on rural electrification *per se*. Similarly, heavily subsidized micro-credit programs for PV still may rely on market mechanisms to select, distribute and install hardware; an equal subsidy of a direct PV donation program where users are required to provide some monetary contribution can be undertaken entirely by the donor, without need of local markets or distribution mechanisms – and with no decision from potential beneficiaries except saying "yes" or "no" to participation.

For this research, the donation model is differentiated from the market model on the basis of *decision making*, rather than an arbitrary level of beneficiary contribution (most beneficiaries of donated systems are expected to contribute money, labor, or other in-kind contribution, but the level of contribution varies widely). If the decisions of end users are largely limited to opting in to or opting out of a program sponsored by an outside entity, that program is considered a donation program in this research. The donor decides the availability of the technology and the merit of would-be users as potential beneficiaries (whether or not beneficiaries initiate the interaction with the donor).

On the other hand, market-based programs are those in which end users and PV providers interact to negotiate price, timing, technology, and means of payment. Users decide whether and when to enter into the negotiation, the amount of their incomes they are willing to invest, and the types of technologies they will use, subject to the availability of credit or capital, hardware, and installation expertise. Though either credit or hardware may be subsidized or restricted to particular groups, users make purchasing decisions based on their own resources and values, they themselves dictating the timing and degree of their participation in programs that are considered market-based for purposes of this study.

4.6.3. Donations and donor ownership

This study focuses on the category of systems that I call “donations,” where donors or people outside the community make decisions about what hardware will be installed and who will be eligible to participate, and decide what the contributions (if any) of the end users will be. In addition to equipment donations, another type of system – not encountered in the literature – is a loan program. Money is not loaned to users to purchase systems and users are not charged for the use of their systems, but another entity (in the cases included in this research, the Guatemalan government) owns all or part of the hardware. Beneficiaries are allowed free use of the system, subject to conditions stipulated by the equipment owner, described in detail below.

4.6.4. Privately purchased stand-alone PV systems

Market-based dissemination of PV in rural Guatemala is significant. The institutions and circumstances that drive markets, however, are very different than those that drive donations. This section examines market models of PV dissemination as a point of comparison to the donor model included in this research.

4.6.5. Private ownership through markets

The scope of this research is limited to donated systems, not those installed under market-based arrangements or institutions, which is an important limitation of this work (see Section 8.7). Markets are widely used to disseminate PV technology in rural applications, but are more appropriate to some circumstances than others.[58] Because of their importance as an alternative to and their interaction with donor programs, I present here a brief description of market-based programs, which deals largely with household-level rather than community-level systems.

As discussed in detail in Chapter 3, successful markets for solar photovoltaic systems in rural developing world locations are found to rely upon the available supply of hardware and the human capacity to manage it; the creation of demand by recognition of solar energy as a viable and desirable alternative to more

[58] For example, solar home systems owned by individual households might be an appropriate market for stand-alone PV systems, but community-owned schools and clinics may not.

traditional energy sources; the availability of financing to enable people to meet the high capital costs of solar energy systems; a supportive role from donor agencies; and the active role of governments in enabling market conditions.

4.6.5.1. Supply: technical knowledge and physical availability

As found in this study and discussed in Chapter 7, the qualities of the design of the photovoltaic system and of its components have an impact on the durability of systems. Systems with low quality components can fail sooner and, when the components are not replaced, remaining components may be sold or simply abandoned. Users sometimes opt for low cost, low quality components when replacements are needed in either purchased or donated systems, and these replacement components can lead to system failure even when initial component quality is high.

Availability of replacement components of any quality depends largely on the presence of markets as institutions: suppliers of equipment, knowledgeable installers and technicians, and networks connecting these to customers and potential customers. In market-based systems, training and the building of human capacity on a local level are necessary. This stands in contrast to donors, who are typically "outsiders," who may meet adequate quality standards by bringing in experts or materials from other countries or regions.

4.6.5.2. Demand: for home and business

For a market-based expansion of rural PV systems to occur there must be "demand pull" more than "technology push" (Mulugetta et al., 2000): rural consumers must recognize the economic benefits of purchasing systems and have confidence in their abilities to recoup their investments. However, potential purchasers of these unfamiliar technologies face substantial risk: a large upfront investment must be made by those with little or no experience upon which to base expectations of maintenance costs or savings in costs of kerosene or candles (Acker and Kammen, 1996). Consumer risk aversion, itself a rational response, may lead to the economically "irrational" rejection of a technology that can save consumers money over traditional lighting. Familiarity with the technology through use by donors or neighbors can build or erode confidence, depending on the performance of early adopters' systems. Circumstances favorable and unfavorable to consumer demand for PV are discussed in this section.

Factors that can contribute to household demand include economics and social acceptability. Solar home systems can decrease household energy costs by saving users money on traditional fuel sources such as candles and kerosene for lamps, and more potential users may purchase systems if their neighbors also have them.

As with any society, rural populations in the developing world are not homogenous. High upfront costs of solar photovoltaics can mean that the "middle class" and relatively affluent segments of categorically poor and rural communities are those who are most able to purchase solar home systems. In marked contrast, the intentions of donation programs are generally to benefit the poorest segments of society. However, as discussed in Chapter 5 it may be that donation programs benefit the same relatively affluent users as do market-based programs.

The availability and use of solar PV may play a small role in *defining* the rural middle class as small business owners and shopkeepers use the systems to increase their income potential. Energy is widely seen as a critical component in increasing income in developing communities, but evidence of direct income generation as a result of household-scale PV systems is conspicuously lacking. The high capital cost of solar home systems leads them to be designed to meet specific loads with little or no excess capacity. Unless systems are designed to meet the demand for energy of specific productive uses, normal household applications will consume all of the energy produced and stored.

4.6.5.3. System financing

Despite the long-term economic benefits, high upfront capital costs are a barrier to market-based dissemination of solar home systems. Some purchasers can afford cash sales of systems through formal market channels or less formally through the purchase of previously owned systems.[59] Cash sales have the advantages of low transaction costs and eliminating the need for a seller or financier to establish the "creditworthiness" of a purchaser who may have little or no formal credit history.

Micro-financing is another option that can be used for market-based dissemination of solar home systems in rural communities. Individual and collective micro-credit arrangements, often organized by outside institutions, can allow system purchase by households that otherwise would not have access to sufficient capital. However, those with the most reliable income streams or largest assets may be considered to be most able to repay a loan: micro-financing, then, does not eliminate the bias towards the relatively affluent in the market-based dissemination of PV in rural communities (Corsair and Ley, 2008).

Informal financing mechanisms such as loans between neighbors or family members are the primary financial tools of the rural poor. However, hybrid ownership schemes and private financing by vendors and government- or NGO-subsidized loans are options for overcoming the significant burden of initial capital cost and the capital cost of battery replacement (see Chapters 3 and 5 for detailed descriptions of some of these financial tools). Subsidized credit again blurs the line between donation and the free market.

Another market-based option for solar electricity is the "fee-for-service" model. Fee-for-service models governing solar home system ownership and maintenance are often operated much like traditional utilities. One entity owns and maintains the equipment, while users pay for the use of the electricity, based on a per-fixture cost, a fixed monthly cost, or a per-kWh cost. Users benefit by not needing access to capital, while system owners can earn profits from their investments. However, this model is subject to high transaction costs, and the poorest potential users may again be excluded because they are unable or perceived as unable to pay for the service.

[59] See Chapter 8 for a discussion of "secondary beneficiaries," or those who benefit from the low-cost purchase of systems donated to another party.

High capital costs remain as perhaps the most significant barrier to market-based dissemination of solar home systems. Means to overcome this barrier exist, but they tend to favor the affluent and middle classes in rural communities[60] – not the poorest who are often the target beneficiaries of donation programs.

4.6.5.4. Donor and market interaction

Donor programs have both positive and negative impacts on the supply, demand and financing of rural solar energy systems in developing countries. Donors may help build markets by creating a local demand for products and expertise. They may contribute to building human capital by training local people in maintenance and installation, and by connecting local vendors with supply networks. Donors are more likely to conform to industry standards and norms for quality and safety, because of their knowledge, mandates and available budgets.

However, donation necessarily distorts market prices, devaluing the product donated with what is effectively competition at a price of zero. If donors import all materials and expertise, they damage rather than build the institutions and markets that can help sustain the systems that they are donating.

Donors play a substantial role in the creation and support of viable photovoltaics markets in rural areas by creating demand, providing training and sometimes financing systems, but the donor community must recognize its impacts on these emerging markets to avoid undermining them. Ruining the livelihood prospects of a small PV vendor is not likely to be consistent with any donor's mandate.

4.6.5.5. Governments' roles in markets

Energy policies, import tariffs, taxes and subsidies of various energy sources can change the economic viability of PV: whereas PV may be the least-cost alternative in one country, just across the border in another country with analogous resources, it may be significantly more expensive than the alternatives due

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[60] See Chapter 5 for further discussion of this topic.

to government policy. Further, unintentional ambiguity and outright corruption can affect prices if equipment must be imported.

Government decisions about national utility grid expansion can also affect PV markets, as solar home systems are generally installed in locations where other electricity sources are not expected in the foreseeable future because of the long payback period necessary to make them economical. Because of this, uncertainty in the location and timing of grid extension can make solar home systems a higher risk investment.

Governments can opt to make market-building a priority in the area of PV for rural electrification (see Chapter 3 for two examples in Latin America). Their efforts to build and reinforce supply, installation and micro-credit institutions can increase the prevalence of purchased solar home systems in rural areas even after periods of subsidy or institutional support have passed. Like any donor, governments must ensure their goals are well defined; for reasons discussed throughout this section, expanding electricity coverage by means of market-based dissemination of PV may not contribute to other government goals like poverty reduction.

4.6.5.6. Conclusions about market-based PV dissemination

This research does not deal with the success of privately purchased PV systems in rural Guatemala, and more research is needed on the topic. However, market-based mechanisms – under suitable conditions of supply, demand, and financial resources – seem to be a viable option for expanding the availability of solar energy for rural development, though caution must be used when assessing whether the market contributes to development goals as the poorest segments of rural developing world population are least likely to benefit. The donor community plays a significant role in helping to establish demand and providing needed training. Governments play an important role in creating and enforcing standards that ensure quality, and in creating market conditions favorable to the technology.

Since end users themselves – not an outside donor – decide whether solar energy meets their social and economic goals, differences in success rates between the market and donor models may be driven in part by whether users or donors make the decision to install PV as a means to reach those goals, a hypothesis which merits further study but is outside the scope of this research.

4.6.6. Forms of donations and donor-ownership included in this research

Systems included in this research are from one of the following basic categories, defined below as they apply specifically to this study: government owned and managed; government loaned or donated for rural development; disaster relief; post-conflict development; and miscellaneous others.

In aggregate, all systems included in this study were donated or loaned to their users, by the definitions used in this research. The actual ownership structure, accountability of donor to beneficiary and beneficiary to donor, responsibility for maintenance, administration and governance, and many other factors vary widely. The influences of these variations on system success are examined in the Results chapters that follow.

Category	No. and % of systems
Government owned & managed	9, 7%
Government loan or donation	53, 42%
Disaster relief	21, 17%
Post-conflict development	20, 16%
Other	24, 19%

Table 1. Breakdown of systems by category

4.6.6.1. Government loaned or donated systems for rural development

The Ministries of Health and of Education have been involved sporadically in projects to electrify rural health clinics and schools using stand-alone PV systems, as reported by members of communities whose schools or clinics have such systems or that are near communities that do. These systems provided lights in community buildings that are normally used only during the day. Neither the institutions that installed them nor the Ministry of Energy and Mines (MEM), which might be expected to take responsibility for such rural electrification projects, provided training, maintenance or follow-up for any of these systems. They were given to “the community” or “the school” without the requirement (or the assistance needed) to establish any administrative or ownership structure.

An unrelated PV rural electrification program run by the office of the Directorate of the Ministry of Energy and Mines is intended to bring power to communities that are anticipated to get access to the national electric grid within the five years following installation. In selected communities, MEM donates a battery, lamps, and balance-of-system components to households, but does not donate the panel. The panel is loaned to the user, remaining property of MEM, and must be surrendered by the beneficiary at MEM’s discretion. When functioning as designed, the program allows communities to have access to limited power from solar home systems for a few years, and then requires them to give the panels back to MEM once they are connected to the national grid. The panels are then placed in another community that is expected to be reached by the grid within five years. The longevity of quality PV panels (most have warrantees of 20 to 25 years) makes this a practicable solution. The high cost of the panels compared to the other components of the system makes this an economically logical solution: it is worth the labor costs to re-collect the panels, but not used batteries or installed wiring. Employees of MEM report having used this model to install systems in new communities.

There is a condition under which MEM will reclaim a panel before the grid has reached a household. If the entirety of the system is not maintained, MEM may reclaim a panel and use it for another household or in another community. The logic behind this is that the panel is no longer providing value to someone who does not have a working battery or lights, so it should go to another family that will value it enough to maintain its electric system. This seems to be perceived as a concrete threat by users, but is rarely carried out.

When the program is operating as designed, MEM has a fairly current idea of the status of all of its systems, as they are expected to visit each beneficiary community every six months. In fact, MEM lacks the resources to make these semiannual visits even to relatively accessible communities, and some particularly remote communities have not been visited in years (also indicating that beneficiary communities do not necessarily get access to the national grid within the timeframe anticipated at the time of installation). Other communities in which MEM systems are located are not safe places for MEM employees to travel: parts of Guatemala are under the control of drug cartels and other criminal elements that do not wish to have government interference of any sort. Any government activity, not just the activity of law enforcement, is seen as a threat. Thus even the lists of communities and the counts of systems held by MEM are not entirely accurate because they have not been updated.

4.6.6.2. Government owned and managed systems

This is a small category in this study, consisting of a group of only nine projects owned by the National Coordinator for Disaster Reduction (*Coordinadora Nacional para la Reducción de Desastres,* or CONRED). These projects are unique in this study in that they were installed for disaster reduction efforts, but local community members benefit much like beneficiaries of donated or loaned systems. The primary intended use of these systems is for radio communication with other communities and with centralized coordinators, with one exception of a system used to provide lighting to a community building in the event of a disaster.

The radio systems are all installed in people's homes. Seven are part of a larger flood early warning system for the Coyolate Watershed. In this early warning system, CONRED selected communities based on location within the watershed and accessibility to CONRED representatives. In each of these communities, someone in the community (usually the leader) volunteered to be a "collaborator" and have a PV-powered radio communications system installed in his or her home. Collaborators in the upper watershed measure rainfall and report it daily (or during unusual events) via radio to a centralized location staffed by

CONRED employees. Mid-watershed collaborators monitor a simple stream gauge and report stream levels daily, or immediately if they exceed a predetermined level. Lower watershed collaborators receive reports of river levels and alerts when a flooding event is likely. In the event that a flood is coming (as determined by mid- and upper watershed conditions), the lower watershed collaborator is responsible for notifying his or her community and communities in the immediate vicinity. These alerts give residents several hours advanced notice to elevate possessions above the expected water level during small events, or evacuate during extreme events.

CONRED dispatches its employees to provide maintenance to the systems, including replacement of batteries or other components as needed. Users have minimal maintenance responsibilities, generally limited to the addition of water to the batteries as needed and cleaning dust from the PV panel.

Radio systems use very little energy. While PV systems are extremely modular and scale well, there are practical limits to how small a system can be. PV markets in Guatemala typically sell crystalline panels that range from 35 W to 100 W, though low-quality thin-film panels are available in smaller sizes. A single 35 W or 45 W panel with a single deep cycle battery, the smallest system that can be practically installed and the system type installed in this program, provides more than enough energy to run the radio systems. It is a "known secret" that the households avail themselves of the excess energy even though such use is not officially sanctioned.

Because users have an obligation to communicate with CONRED daily, and because such communication depends upon systems being operable, the agency knows where the systems are located and whether they are currently functioning. While budget constraints do not allow for perfect system maintenance, the systems are categorically well maintained.

4.6.6.3. Home systems donated for disaster relief

Hurricane Mitch in 1998 was devastating to many poor indigenous communities in the highlands of Alta Verapaz, according to local residents and NGO's. A substantial effort was made towards helping them recover from the disaster, coordinated by one of the world's largest humanitarian relief organizations.[61] The program was multifaceted. Among other things, rural farmers were provided with seeds to re-plant traditional crops that were wiped out by mudslides and heavy rains during the storm, as well as seeds for new cash crops to diversify their income sources. *Estufas mejoradas*, small and simple concrete wood-burning stoves that demand a fraction of the firewood needed for cooking on traditional fires, were provided to affected households. And the multinational relief organization contracted with a local NGO specializing in renewable energy to provide solar home systems to people in the beneficiary communities.

Notably, this was a *relief* operation – focusing on the immediate aftermath of the disaster, with a short timeframe and quick results demanded – not a *development* operation with sufficient time and funds allocated to meet a mandate of permanently changing a population's circumstances.

In relief operations, humanitarian organizations may be able to guess the needs of a population fairly accurately. Food, water, basic shelter, cooking fuel, acute medical care and assistance locating family members are arguably self-evident needs of people who are abruptly displaced due to a catastrophe. Things like electric lighting and seeds for cash crops may be intended to have longer-term impact, and may not qualify automatically as needs for all people affected by disasters.

Conceiving, planning, developing, implementing, and following up upon a project that involved installing solar home systems in "dozens"[62] of communities and hundreds of households within a one-year timeframe was difficult. The local NGO claims now to have objected initially and throughout, asking for more time, which they were neither promised nor given (although it must be noted, they accepted the project under the

[61] Information is from interviews and conversations with Iván Azuria of *Fundación Solar*, the local NGO involved, and residents of the region

[62] Project documents were unavailable and neither community members nor the member of the NGO interviewed recalled the exact number of communities or households included.

conditions given). “Socialization” or integration of the energy systems into the communities was notably lacking. One socialization component that was missing was an assessment of the long-term needs of the communities in question. Another component that was truncated due to time and funding limits was training: both technical and administrative training sessions were few and brief.

Consistent with the program’s original plan, users were 100% owners of their systems with full responsibility for their operation and maintenance as soon as they were installed.

Successes and failures related to the solar home systems included in this project are detailed in the Results chapters that follow. The overall program had varying degrees of success with its different components. The improved stoves that were installed seemed to remain in use at the time of these interviews. On the other hand, there were reports of crop failures when some of the donated seeds were planted. The specific causes of these cases of mixed successes were not assessed in this research.

4.6.6.4. Home systems donated for post-conflict development

The civil war, described in detail in Section 3.4, left an indelible mark on Guatemala, but its impacts were felt more strongly by some populations and in some areas than others. In the northern highlands where largely indigenous populations were controlled, re-settled, and sometimes massacred by government troops, the current level of poverty is unsurprisingly high. As part of the Peace Accords signed in 1996, the government agreed to provide development assistance to these populations. As part of this development, a solar home system program was initially created for widows and orphans and then expanded to include all members of selected communities.

Although the program was part of the Peace Accords and so technically the responsibility of the Guatemalan national government, significant funding came from outside sources, and the program was administered by *Fundación Solar*, a Guatemalan NGO that had a presence in the immediate vicinity. Under the guidance of this NGO, community members who wished to participate formed representative organizations. A project head in each community became that community's representative in an area-wide organization. The purpose of this organization is both to act as the users' collective voice when dealing with outside parties, and to provide system management and maintenance. All beneficiaries signed agreements stating that they would pay into the maintenance fund, and in return they would be eligible for service and replacement of components as needed.

As such, the program provided technical and administrative training to designated individuals rather than to entire communities. Although users themselves were sole owners of their systems, institutions were put in place to assist both technically and economically with maintenance.

4.6.6.5. Other systems

Other donated stand-alone PV systems in Guatemala have been included in this study. Two such systems were donated as part of the development of hydroelectric projects. Because of the low infrastructure demands, PV can be installed quickly and used to enable development of the larger energy project. It can be used to power or charge telephones as a means of communication, for example. Both panels were put to other uses after the hydroelectric projects were completed.

Several communities near Lake Izabal have or had women's weaving cooperatives that use PV lighting installed by an NGO to allow women to work later in the evenings. One of these is included in this research.

A coordinator who works with several NGO's assisted me in seeing two tourism development projects involving lighting as part of a community-owned rustic eco-hotel. Another project was related to an archaeological dig. A North American archaeological team has been excavating Mayan ruins on the border between the Departments of Petén and Alta Verapaz for "many" years. At one point, three communities surrounding the site demanded that they be included in the benefits of excavations on land that was historically theirs and of artifacts that belonged to their ancestors. Apparently without objection, the principle archaeologist assisted them in creating a tourist stop on *La Ruta Maya*, the tourist corridor in Guatemala that highlights the natural landscape and the ancient cultures of the Mayan population, which made the archaeological site accessible to the public while bringing income to the communities. The interest of this research in the project are the PV systems that are used to power lights in buildings intended for visitors and the two-way radios that the guard/guides use to communicate in their work.

Separately, a PV system had been donated by an NGO to help rangers manage LaChua Park, but had been removed after the national electric grid arrived, so little information about it was available.

Finally, a system powering a rural health clinic and school was included. A series of three PV arrays, totaling a remarkable 700 W, powered a DC refrigerator intended for use with solar power, a TV and VCR used as a *telesecundaria*, or secondary school taught via video cassette because no teacher is available, and lighting for both the clinic and the school. The original sources of funding were from multilateral agencies, and part of the system was installed under the same program as the above-mentioned solar home systems for post-conflict development. The source of ongoing funding for maintenance of the energy systems and clinic and school equipment was not made clear. However, that the community played an active role in that maintenance was very evident. On several occasions, the men of the community had carried the refrigerator seven miles from the health clinic to the nearest road that could be accessed by a vehicle so that it could be sent to a major city for maintenance. Fortunately, the foot track has been widened to a road passable by a 4 wheel drive vehicle and the community members have been shown how to remove the compressor (the part most likely to need maintenance) from the refrigerator, each by itself eliminating the need for six strong men to spend hours hauling a refrigerator over a rutted dirt track. At the time of my visit, the compressor was in the U.S. being repaired by the manufacturer, with the local NGO involved in the original installation acting as intermediary as courier services do not reach such rural locations.

These "other" projects and communities vary widely in their contexts and designs. Common factors among them are that all were developed by non-governmental entities, and all were owned or managed by a group, not by individuals.

This collection of "other" systems includes all those that do not fit into the previous categories of government loaned and donated, government owned and managed, home systems for disaster relief and home systems for post-conflict development. These groups of systems represent a broad cross-section of the programs found in Guatemala.

4.7. Research bias

Biases are inherent in any study. Even randomized controlled trials – the "gold standard" of evaluation of interventions, of which this study is not – can show biases, can be of limited validity in field situations where causal chains are long (Victora et al., 2004) and can be impracticable or even unethical (Smith and Pell, 2003). Self-selection of participants and low rates of participation in novel programs or using novel technologies diminish the validity of even these "ideal" evaluations (Naudet and Delarue, 2008).

Three main biases are found in this study, all of which must be considered in interpreting data and drawing conclusions. These are researcher bias and informant bias, discussed below, and sampling bias which is discussed in detail in section 4.3.

4.7.1. Researcher bias

I have attempted throughout to maintain objectivity to the best of my ability. However, researchers themselves are products of their cultures and begin with their own understandings and interpretations (Miles and Huberman, 1994). Further, researchers will be "undeniably affected by what they hear and observe in the field, often in unnoticed ways" (Miles and Huberman, 1994). Thus, I seek to be aware of my own biases. The researcher's values may influence the way data is gathered and interpreted (Miles and Huberman, 1994). For example, I know myself to be an advocate of the use of photovoltaics in general, so I am careful to closely review any conclusions I draw that view them categorically favorably. During the course of the study, my skill with the Spanish language (and specifically with the dialects favored by rural Guatemalan *campesinos*) improved considerably. Thus, in later interviews, I was better able to understand responses and to ask more probing questions. As such, interviews towards the end of the study are more in depth in some ways. However, follow-up questions and requests for clarification were important tools to reduce translation bias throughout the study.

For field observations and recording, "what may be generated as 'data' is affected by what the (researcher) can treat as 'writable' and 'readable'" (Miles and Huberman, 1994). The problem of interpreting data in the form of words is compounded by the issue of translation by a non-native speaker. Literal translations of words can fail to carry the context in which they are spoken, and may lead to wrong or nonsensical interpretations. Spanish as a language compounds this problem because there are so many dialects: words and their meanings can vary dramatically in geographically close areas. As an example, to go somewhere *en pelota* in Mexico City means to go "as a group," in Guatemala it means to go "naked," and can translate literally to "in a ball." I have addressed this linguistic bias by asking respondents for clarification when I was unsure of their meanings, reassessing responses in some earlier interviews to reflect my expanded understanding of *Chapin* Spanish, and by conferring with native Spanish speakers to clarify potential misunderstandings.

4.7.2. Informant bias

Despite telling informants otherwise, many informants seemed to view anyone conducting interviews about their solar energy systems as donors or potential donors. Sometimes this was stated fairly explicitly, such as one respondent who referred collectively to me, the NGO that installed the system, and the donor community in general as "you." Some who had sold their systems made an explicit point of saying they would not sell their systems again if someone were to donate new ones, suggesting that I may be able to aid them in that bid. Others asked for contact information for organizations that might be able to donate systems for their neighbors or as expansions of their own.

As such, some responses may have been targeted towards a potential donor, rather than being completely candid. For example nearly all respondents who had received some sort of training associated with their systems stated that the training was useful, but that it was not sufficient. I speculate that these answers were truthful – that they had found the training useful, but could have benefited from more – but that they may have been colored by the hope that I could be instrumental in providing additional training to the community. They would have responded in the affirmative that the training was useful so that it would not seem a waste to provide further training, but that it was not sufficient, to motivate the desire to provide more. This was reinforced by the fact that topics about which informants wanted more training were not necessarily related to the energy projects, and informants were sometimes very vague about what type of training they would want. This seems to suggest that people recognize education as valuable to them in general rather than as specifically related to energy, and the belief that I may be able to provide it.

Above all, I was a foreigner and an outsider to whom they were speaking. Some responses involved "impression management" – the desire to be seen in a particular way by myself or others present (Miles and Huberman, 1994). People were understandably reluctant to admit ignorance, sometimes giving a "yes" or "no" answer to a question and only admitting that they did not understand what was being asked when asked to expound upon their answer. Because of the culture of low trust (found especially among the indigenous), people may have been guarded with their answers regardless of who conducted the interviews. Women in particular were shy of speaking, some allowing their husbands to conclude an interview that they had started, and some declining to be interviewed because their husbands were not home (I did not record the number or location of these instances). Some felt the need to establish superiority over (or perhaps equality with) the stranger who was asking questions, such as the man who asked me if I even knew how to make tortillas (I admitted with humility that I did not), or the man who asked confrontationally but fairly if my work was intended to benefit myself or him and the members of his community (I replied that it was my hope that it would most benefit future projects in Guatemala). Overall, I found few contradictions in responses that suggested that respondents wished to deliberately misrepresent themselves, and strove to create an atmosphere in which they would have little or no reason to do so by telling them that they would not gain from any particular responses, refraining from presenting my opinions and by asserting my ignorance as appropriate: I wished respondents to feel comfortable that they had superior knowledge of the answers I was seeking.

Ultimately, the cultural and economic gap between my respondents and myself remained. This was not an ethnographic study in which I had the luxury of spending long periods of time with the same people until both I and they became comfortable enough to at least in part forget our differences. However, I feel that there was little deliberate biasing of answers on the parts of informants and that people provided sufficient clarification when asked to eliminate most unintentional biases. I have noted in the results sections the potential impacts of biases, as appropriate.

4.8. Conclusions

This chapter describes the context in which the research has taken place and results must be understood, and the methodology used to conduct the research. What describes success and the effectiveness of methodologies may be very different among other subjects, with different energy technologies, or with different means of disseminating the same technology. The results that follow – the factors that drive success and failure – must also be understood in the contexts described here. This chapter suggests many areas for future research to understand how these contexts affect the success of rural electrification programs, including addressing questions omitted from this research due to methodological issues, and considering the research questions included here in other countries or regions, with other remote renewable energy technologies, and among systems disseminated by market mechanisms, rather than donors.

Guatemala was selected for this research as an example, not an archetype, of a location in which rural stand-alone PV systems have been known to fail. The country's history of violence and repression has created circumstances that may differ from other poor but more politically stable countries and countries that have experienced their own unique but turbulent histories. Specific impacts of this history on rural electrification may include, but are not limited to, increased poverty, itself a hindrance to "modernization" of all sorts; impermanence in the locations of physical communities, which discourages infrastructure investment and maintenance; and racial discrimination, which marginalizes the groups that may be most in need of assistance in electrification. Cold War rivalries influenced Guatemala's development, with powerful outside actors alternately supporting and undermining Guatemalan national governments to further their own ideologies and economic interests; some electrification plans may never have come to fruition when a government was toppled, but other electricity development schemes may have been funded by foreign entities to serve their own interests.

Violence, poverty and racism continue to inhibit development in Guatemala, with drug trafficking and other organized crime playing an increasing role in destabilizing official and volunteer efforts to provide access to improvements in quality of life and economic opportunity. In this context, long-term development goals such as electrification take low priority.

The sources of information for this research were primarily interviews with the beneficiaries of donated stand-alone solar systems and their immediate neighbors. They provide information and perspectives that may vary greatly from the ideas, ideals, and expectations of donors, developers and other "experts." Interviews with respondents were structured based on a script of questions, but were conversational in tone and frequently deviated from that script. This means of interviewing rendered the statistical analyses often used in survey research inapplicable.

No sampling universe from which to draw a random sample of communities could be created for this research. As such, communities were chosen using both purposeful and convenience sampling based on their accessibility, the political stability of the region in which they were located, and information available from governmental and non-governmental organizations. Respondents within a community were selected similarly by a combination of convenience and purposeful sampling.

Interview questions were developed based on hypothesized linkages and research questions. Interviews included structured survey questions as well as open-ended questions and conversation to learn more than was normally expressed in brief answers to specific questions.

Only donated systems were considered in this research. The market-based dissemination of PV technology in rural Guatemala was seen to be significant,[63] but is not included in this study. As described in this chapter, market-based distribution influences and is influenced by distribution under donation models, especially as robust for-profit markets increase the availability of the technical expertise and physical components needed to sustain donated PV systems, but system donations can undercut demand for or prices of systems for sale.

"Donation" is differentiated from "sale" here not by a specific level of monetary or in-kind contribution from users, but instead based on the decision-making process: for donated systems (which may require some beneficiary contribution), donors make the decisions about who is eligible to participate and what the system will consist of, while for purchased systems (including those purchased in the informal economy or made available under programs where hardware, financing or installation is subsidized), end users decide their own levels of participation based on their needs and available resources.

Forms of donation and donor ownership included in this study include systems donated or loaned by the Guatemalan government for general development purposes, those owned and managed by a government entity, solar home systems donated for disaster relief, solar home systems donated for development in communities most affected by the Guatemalan civil war, and sundry other systems that do not fit into these categories. These different donation models sometimes lead to very different outcomes, as explored in the Results chapters which follow.

[63] Compilation of data on market-based systems is difficult because systems tend to be installed individually rather than in groups, increasing their geographic diversity, because vendors may be sensitive to the confidentiality of their relationships with clients and thus unwilling to provide information on installations, and because the small-scale PV business in Guatemala is dynamic, with vendors going out of business and new vendors appearing frequently.

Chapter 5. Results concerning system uses and system economics

5.1. Introduction to the results chapters

The following three chapters report results concerning the factors that influence or are otherwise associated with system success, as defined in Chapter 2. The contexts of and underlying reasons for many of these factors are also explored.

Recapping the definition of success adopted in Chapter 2, a successful system is one that meets requirements concerning operability, perceptions and optimality requirements:

– *Operability*. The system either was functioning on the day of the interview, or concrete steps were being taken to have it repaired in the foreseeable future, or it was removed because its use was intended to be temporary until another energy source (typically an electric grid) replaced it. Operability was an a priori part of the definition, but that technically inoperable systems could also be successful emerged as a part of this research;

– *Perceptions*. The user considers it successful, feels that it has met his or her expectations, and finds it important in daily life or for specific events. The hypothesis that users could simply be asked whether a system was successful proved inadequate, and other measures of satisfaction and utility give more depth and meaning to user responses.

– *Optimality*. Assuming the resources were available, the user would not choose a different energy source if the PV system were lost or damaged. A system may be tolerable to users in that it functions and is consistent with what they were promised upon installation, but willingness to trade it for a "better" alternative suggests that it is sub-optimal and does not meet the user's needs.

The results that make use of the above definition of success are divided into three chapters: Chapter 5, concerning system economics and uses; Chapter 6, concerning the institutions and relationships that surround, change and are changed by the donation of PV systems; and Chapter 7, concerning the characteristics of users, communities and physical systems. Note that these factors are not necessarily exogenous influences upon a system's success, but can be affected and changed by the donation and success of the system. Therefore, each chapter documents results concerning this two-way relationship – both how those factors might influence the success or failure of a donated system, and also how the system has in turn altered its context.

The current chapter examines the economic circumstances surrounding donated stand-alone PV systems in Guatemala, including positive and negative local income changes and the appropriateness of rural electrification as a development intervention among the very poor. In it, I also consider the non-economic utility of these systems and whether different uses lead to different success outcomes. The questions addressed have been defined in Section 3.5.1 of the literature survey. The results documented here are based on the results of applying the portion of the questionnaire relevant to economics and use, and the statements and observations made by respondents during unstructured portions of interviews.

Chapter 6 explores the institutional contexts of these systems, and the relationships that surround them. This includes the effects of national political stability and rule of law and local governing institutions. Beneficiary involvement with project initiation, planning and completion, any training and socialization that were a part of implementation are illustrated, and negative social or cultural outcomes resulting from the projects, along with their association with and effects upon project success.

In Chapter 7 I define the characteristics of users, systems and the communities in which they are located, along with exploring the unintended consequences and conflicts that arose as a result of the physical systems. The influence (and lack of influence) on success (as defined in Chapter 2) of these characteristics is explored, based on responses of system users to relevant questions and physical inspections of the systems.[64]

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[64] See Appendix A for the survey instrument and Appendix B for the inspection protocol followed in technical inspections.

5.2. Introduction to results: economics and utility results

This subsection provides an overview of the contents of this chapter, including poverty alleviation as a goal of renewable energy systems, changes in income or expenditure on energy services for individuals and communities, and system uses independent of economic factors.

"*El pisto*," a slang term that means "the money" in Guatemala,[65] was the most common response to questions of why systems were not functioning. Economic considerations were a recurring theme with users of successful and unsuccessful systems, and with non-users as well. The interrelationship of stand-alone PV systems and economics in rural Guatemala are explored in this section, followed by an examination of the way these systems are used by beneficiaries and the influence of those uses on system success.

Both a priori hypothesized and unexpected results emerge from considering the utility of stand-alone PV systems to their users. This chapter considers the tangible gains and losses – and users' perceptions of gains and losses – that have resulted from the donation of these systems in rural Guatemala.

Higher economic value to system users was hypothesized to increase the likelihood that the project will succeed. Projects that present income-earning opportunities or that directly save money should succeed at a higher rate than those that have little or no economic potential. Conversely, projects that remove income earning opportunities should be less likely to succeed. However, the following results show that the answers are not as clearly definable as these hypotheses suggest.

Responses to questions throughout the survey often came back to money (see Appendix A for a complete list of survey questions). An inability to maintain the system, travel to meetings to participate in training and decision making, replace failed components with quality parts, and to participate at all while their neighbors were excluded all came back to money. I asked direct questions about the economic costs of

[65] "*Pisto"* was translated for me by a native Spanish speaker from northern Mexico as an alcoholic drink, and is found in on-line translation engines as ratatouille or a Spanish vegetable casserole. Care must be used in understanding colloquial terms in appropriate context.

using the system, in addition to money savings, money earning opportunities, and project funding. Specifically, I did not ask quantitative questions about users' incomes except how they were affected by the systems themselves. Survey research suggests that respondents frequently refuse to answer or give "socially desirable" (i.e., false) answers to questions that they consider sensitive (Fowler, 1995, p.28) or mistakenly omit informal or irregular cash transactions (Fowler, 1995, p.10), which is consistent with previous experiences I have had in asking income-related questions while conducting surveys in rural Guatemala. Therefore, I deemed such direct questions to be of little or no value.

The utility of the system in less monetary terms was hypothesized to be relevant to system success, and is discussed in this chapter. A specific use, the response of PV systems to weather-related and other disasters, emerged as an interesting theme, although I had no a priori hypotheses about this, as discussed further below.

These results are explored in detail in this chapter. Section 5.3 briefly summarizes previous findings on economics and utility in rural energy and related contexts and summarizes the working hypotheses that arose from this review of existing literature.

Section 5.4 explores the concept of poverty alleviation, very often an explicit or implicit goal of donor programs, and the effects on poverty of systems examined in this study on system users. Here I also present results showing how community members saved, lost or earned money as a result of donated systems, and, as importantly, their perceptions of these economic effects.

Non-monetary uses of donated systems are explored in section 5.5. These include household and institutional uses, and examine the changes or benefits users experienced when they obtained PV systems. The specific use of systems in emergency situations is described in section 5.6.

Finally, section 5.7 reviews the relationships I found between economics, utility and system success, and the relevance of this work as it relates to previous research on the topic.

5.3. Hypotheses and research questions

As described in detail Chapter 3, rural renewable energy projects are believed to save users substantial money on things like candles, dry-cell batteries, kerosene, and recharging car batteries – all frequent energy expenditures in rural developing world communities. These savings can more than offset the cost of system maintenance (Acker and Kammen, 1996; van der Plas and Hankins, 1998; Duke et al., 2002; Corsair, 2005).

Rural renewable energy systems that present income-generating opportunities tend to be more successful than those that do not (Chakrabarti and Chakrabarti, 2002; Troy, 2002; Acker and Kammen, 1996). However, direct income generating activities (electric sewing machines or video houses, for example) are relatively rare in rural developing world applications (Nieuwenhout et al., 2001), as was also observed in this study.

Thus previously published studies suggest that users will benefit economically from having access to rural stand-alone PV systems, but that the economic benefits will not be large or quickly realized. This research shows that many users do benefit economically, though sometimes in unexpected ways, while other users feel little or no economic effect, and some are in fact worse off economically because of donated systems, as discussed throughout this chapter. There is little published about the potential negative economic outcomes resulting from donated PV systems, or about relationships between how a system is used (other than for economic gain) and its potential for success. This literature, together with anecdotes from professionals and volunteers working in development and my own previous observation, suggest several research questions and hypotheses, as detailed below.

This research began with three basic research questions about economics and utility as they relate to system success (repeated from Section 3.5.1 of literature survey):

1. *Are there people who are earning more or saving money by using the system instead of traditional power sources?*

2. *Are there people who have lost income opportunities or are incurring greater expenses because of the system?*
3. *What do people use their systems for, and how do different uses lead to different success rates, independently of economic impact?*

As discussed in the literature review (Chapter 3), my initially hypothesized answers to these questions at the outset were straightforward:

- *Most users would save money relative to previous energy sources, and those who did would have higher success rates than those who did not save money.*
- *Some few would earn money with their systems, and those would have the highest success rates.*
- *Vendors in the communities would lose income due to decreased sales of candles and gas for lamps. Greater negative economic impacts would lead to lower success rates.*
- *Systems used for direct income generation and for cell phone charging would have higher success rates than those not used for one of these purposes.*

The underlying assumption driving these questions and their hypothesized answers was that the provision of donated stand-alone PV systems would decrease the level of poverty of the beneficiaries. However, the results of this research turned out to not support this assumption and the resulting hypothesized answers: donated PV systems may leave unaffected or even exacerbate poverty, as discussed throughout this chapter.

Specifically excluded from this research are questions of financing. The only financial tools considered to enable users to meet the costs of system maintenance are savings cooperatives or maintenance organizations put in place by donors or project developers. Questions were not asked about access to credit, savings outside these cooperatives and other means of access to capital. However, such access could be important in maintaining systems (Collins et al., 2009), and should be the subject of future research.

The results of my examination of these questions and hypotheses are discussed throughout this chapter. The first two questions, which concern the positive and negative (respectively) cost and income impacts of energy, are addressed in the next Section (5.4). The third question, which is about how people use the systems and derive utility from it, is the focus of Section 5.5.

5.4. Economic value and poverty alleviation

> *"We had savings, we weren't spending much on gas, candles, bulbs. We didn't have so much smoke and health improved..."*
>
> - community member, describing her household's circumstances while she had a functioning solar home system

The economic outcomes of stand-alone PV systems installed in the communities studied varied based on the type of ownership, the programs under which they were installed, and the characteristics of the communities and beneficiaries themselves. These outcomes are described in detail throughout this chapter.

This section is organized as follows. Section 5.4.1 examines the definitions of poverty and poverty alleviation. In section 5.4.2, the economic concept of "willingness to pay" is explored in the context of extreme poverty, along with the effects on poverty of changes in energy expenditures (5.4.3 and 5.4.4) and improvements in livelihoods (5.4.5 and 5.4.6) resulting from energy-related development opportunities. Sections 5.4.7 and 5.4.8 examine lost income and perceptions of lost income that results from donated systems, followed by explanations of income effects in the specific cases of systems that are sold by beneficiaries and community-based systems.

5.4.1. Poverty alleviation

I reference "poverty" and "the poor" frequently throughout this work. However, "the poor" is not a homogeneous group. Social and economic strata exist in even the poorest of communities: someone living on \$2 per day may seem from the researcher's perspective to be nearly as poor as someone living on \$1 per day, but the former is in fact twice as wealthy. Additionally, even at approximately equal income levels, different groups can have very different outcomes in analogous circumstances. This topic, in particular the difference in outcomes between *Ladino* and indigenous respondents, is examined in more detail in Chapter 7.

Many development projects either explicitly or implicitly include poverty alleviation among their goals. Few if any would view creating ongoing dependence as an intended outcome, but would instead include decreasing need – and thereby decreasing dependence – as part of the very definition of development. In this section, I examine the concept of poverty alleviation as it relates to development through rural electrification, and examine the outcomes observed in this research.

Poverty alleviation can occur either because the cost of providing energy services is reduced (substituting cheaper electricity for more expensive candles for example), because productivity and income is increased (e.g., longer store hours are made possible, increasing store revenues, or in the long term, electricity results in better educated workforce), or a mix of both. In general, expenditure reduction was more commonly observed than an increase in income among the projects surveyed here.

Despite the stated or implied economic goals of the projects, for many respondents involved in this study there were virtually no long-term economic changes that resulted from the implementation of the system. Systems installed in schools and health clinics were rarely used since these buildings were often designed with adequate natural light for their normal daytime use. Those users who failed to maintain their solar home systems saved money on lighting for as long as the systems functioned. After the first failure (such as a dead battery), they resumed using the traditional lighting sources available to them in the absence of PV: long-term poverty conditions remained unchanged.

5.4.2. "Willingness to pay" and "ability to pay"

"We would go to bed early" when the family couldn't afford candles before the solar home system was installed, said a participant in the post-conflict development program. Rather than the statement being in praise of the system that now allowed him to have light every night, it was a complaint about the lack of flexibility he now has in paying for his lighting sources as a participant in the maintenance organization. He told me if “you” (me, the project developer specifically, the development community and Gringos in general) intend to donate something, it should be donated outright without monthly payments attached. Before the solar home system, he and his family bought candles as needed. Sometimes they cut *ocote*[66] if they could not afford candles. But more often, as he told me, they went to bed early. With PV, he does not have the choice to not spend on lighting when money is tight. He accepted a commitment to pay into a collective maintenance organization when he accepted his solar home system, and upholding that commitment was sometimes burdensome.

His was one of the cases in which the respondent claimed to spend more on the solar home system than they had on previous lighting sources. Not only was the quantity of money demanded greater, but the schedule of payments lacked flexibility as well. The payment was due every month, whether he had found work that month or not, whether he had brought in his crops or not, whether he had any source of income or not. When he bought candles, he bought them on his own terms.

The day I spoke with him, he teetered slightly as he stood, and leaned far too close when he spoke (even by Guatemalan standards), and smelled of alcohol. His dog bit me on my way out of his house. As such, it was clear that he had resources enough to buy alcohol and feed a dog; however, his family’s food supply was in piles on the dirt floor: black beans still in the pod and corn still on the cob, all awaiting the hand labor of his wife and daughters to separate food from chaff. It was clear that his resources were limited enough that he still relied largely on subsistence agriculture for food.

Did the fact that his family made their monthly payments regularly in fact mean that they could afford to? This section examines that question.

Among failed systems surveyed in this research, demonstrated willingness to pay for lighting was less than the amount needed to save for the maintenance of the system. More than 10% (5/46) of respondents with failed systems who provided sufficient information indicated that their households sometimes relied on

[66] *Ocote* is a resinous pine used for torchwood.

ocote (which people typically cut themselves rather than purchasing); *ocote* is seen as a less desirable alternative to candles because of the thick smoke and poor quality of light it produces. Some simply went to bed early. Thus, for some, their demonstrated willingness to pay for lighting was also less than the cost of the candles required to meet all of their lighting needs.

Since electric lighting was seen as a superior light source by all respondents who commented on lighting quality and may have more value than light from the less expensive candles and *ocote* combination, one could say that people were unwilling to make the trade-offs required to purchase the preferable light sources; however, respondents seemed to view light as a basic necessity. Why would people be unwilling to make trade-offs to purchase a basic necessity? Perhaps the answer is that they are unable.

In all communities included in the post-conflict development, disaster relief and government loan programs, beneficiaries of solar home systems initially formed collective savings funds on the advice of the donating organization. Many of these maintenance organizations were abandoned after a short time.[67] When asked why these funds had not been used to maintain the systems, some responded that the funds were redistributed to the people who contributed them in the face of some pressing need, like a crop failure. Thus, people who were willing to pay for a system under what they consider to be normal circumstances may in fact be unable to pay in the long term because of occasional, more urgent needs. This was especially true in communities involved in the disaster relief program. None of those communities had functioning collective maintenance savings at the time of these interviews.

Energy poverty – being unable to afford energy needed – is often defined based on the percentage of income spent on energy (Foster and Tre, 2000). This common definition is inadequate both because the cutoff is necessarily arbitrary, and because reasons for spending more or less income on energy vary. A household that spends a large percentage of its income on energy may do so because its income is so small, or may do so because it has disposable income that it chooses to use on energy-intensive activities (Foster

[67] The reported length of time that savings or maintenance cooperatives were in place varied among respondents within communities to the degree that I cannot say with any certainty how long they functioned. Typical estimates were between a few months and a few years.

and Tre, 2000). Defining ability to pay (ATP) is inherently subjective. By one definition, if a household can pay for an essential service (in this case, energy for lighting) without the expense causing them to be unable to pay for other essential services (e.g., food, water, medicine) or liquidating productive assets (land, tools), then the household can be said to have the ability to pay for that service . However, judgment of what items can be included in the category "essential services" and the minimum amount that can be spent to meet these basic needs must be defined to measure against this test. The idea of "need" differs dramatically across different cultures, across different households within the same culture, and even among individual household members (Muela et al., 2000); the concept is inherently subjective (Muela et al., 2000).

By one definition, if an increase in the cost of a service results in a bigger proportional drop in usage for the poor than it does for the rich, this is an indication of the lack of ability to pay (Donaldson, 1999). This analysis requires that there are measurably different income strata within the population in question, and that the cost of a service changes – two conditions that are not met in this study.

Willingness to pay metrics have historically been used to define fees for essential services in developing world applications (Russell, 1996; Guyatt et al., 2002). The willingness to pay for a good or service is a function of income and personal preferences; it measures how much of one commodity a consumer will purchase, at the expense of all others and within the limits of his or her income. This approach treats all commodities equally. If people spend all of their income on medical care but do not buy food or diamond rings, it is because they prefer medicine to food and jewelry. Willingness both to go without rings and to risk death from starvation in order to avoid death from an illness would be reflected as consumer choice in WTP analysis.

This approach is inadequate when the consumers in question are very poor because it assumes WTP reflects ATP, and that consumers are able to allocate their income in a way that provides for their own concepts of basic need. However, the poor may leave some basic needs unmet (like food) in order to meet an immediate need (medicine for an acute illness, for example) or may liquidate their productive assets to meet the immediate need, leaving them unable to meet future needs (Russell, 1996).

A household may mobilize more of its resources – sacrifice more of its basic needs – under some circumstances rather than others. In an example from highland Kenya, the cost to a household of purchasing insecticide-treated bed nets, critical in the fight against malaria, was equivalent to the cost of sending three children to primary school for a year (Guyatt et al., 2002). A household that demonstrates a willingness to pay for bed nets cannot necessarily be said to have an ability to pay for them. If they must choose between sacrificing health and sacrificing a child's primary education, they are unable to meet all of their basic needs. In other cases, much may be sacrificed to treat an illness in the household's primary wage earner, where a child may be allowed to die if faced with the same illness (Muela et al., 2000). Home lighting is perhaps more easily sacrificed than other basic needs: food is more important than light. "What do we need electricity for? So we can watch our children starve to death at night?" lamented a Guatemalan mother (Manz, 1988, p 43). This does not necessarily suggest that lighting is not an essential service any more than the examples above suggest that primary education or the life of a child is not essential.

Respondents who did not participate in savings cooperatives generally claimed that they could not afford to put money into maintenance funds established at the projects' inceptions, and consequently had no savings to replace the battery when needed. They were unable to explain why they were able to pay as much as Q70 per month or more in other lighting expenses (candles, gas for lamps, and batteries for flashlights) both before and after the useful life of their system (as limited by the unreplaced battery), but unable to save Q20 per month while the system was operable. While this may seem internally inconsistent, the types and timing of payments may dictate affordability as much as the magnitude of the payment. When purchasing candles or other lighting alternatives, households can adjust their consumption to match their available resources. The "average" or "typical" consumption they reported may represent what households use under stable conditions. This would overstate their annual expenditures if many nights they use fewer than they "typically" do because resources are scarce but do not consume substantially more than usual when resources are abundant.

Poor households accrue and hold both debt and savings, much of it in the form of small loans exchanged between neighbors (Collins et al., 2009), showing that they are familiar with mechanisms that might allow them to pay for battery replacement. Whether they choose not to use these basic financial tools to pay for home lighting because it is not a high enough priority or they cannot use them because the quantities of money are beyond what is available to them is not clear.

Lack of access to capital made battery replacement, the largest expense in maintaining a solar home system,[68] difficult or impossible for many. Those who dealt more in cash economies (for example, shop keepers or those who raised cattle rather than engage in subsistence farming) were better able to secure the capital to replace batteries and other system components, but my sampling methodology precludes making statistical inferences for the population. Collective savings and maintenance organizations that would have made access to capital easier were created under most donations programs included in this study, but many were quickly abandoned by users, as discussed further below and in Chapter 6.

The types and timing of payment may dictate the affordability of a thing, even if real costs are the same. The costs of some essential services can be paid with goods or labor, or over time (Russell, 1996; Muela et al., 2000; Collins et al., 2009). Very low incomes are often earned sporadically, and this uncertainty in income is as much an economic obstacle as is its low level (Collins et al., 2009). Among subsistence farmers, the flexibility to pay in food or labor, or to pay when the crops come in rather than at a fixed point in time can put an otherwise unaffordable basic service within economic reach (Russell, 1996; Muela et al., 2000; Collins et al., 2009). This is especially true as poor households in both developed and developing countries tend to hold a large percentage of their net worth in physical assets rather than cash (Collins et al., 2009). A neighborhood store owner may be willing to extend credit to or accept alternative payment from a household, but a remote battery vendor is unlikely to accept a promissory note or a pig as payment, so the greater expense of purchasing candles and kerosene for lighting may be more affordable than maintaining a

[68] Replacement of the PV panel itself is more costly than replacement of the battery. However, PV panels are designed to last 20 to 25 years, and failure of the panel was not found to be a technical cause of system failure in this research. As such, panel replacement is excluded from all economic analyses.

solar home system. *Tiendita* owners were not asked about credit offered to community members, and only one volunteered that he had a structured program to do so.

In some cultures, community members' social networks provide gifts and loans that make up a large portion of people's ability to pay when large basic-needs expenses come up (Russell, 1996; Muela et al., 2000). Social networks may be more willing to help with some types of basic needs expenses than with others (Russell, 1996; Muela et al., 2000). This suggests, in this case, that neighbors might be more than willing to lend someone money for an emergency doctor's visit, but unwilling when the cost is a replacement battery for a PV system. Small loans may also be more common. Neighbors might regularly loan each other a few *Quetzales*[69] to buy candles, but would be unable to amass sufficient capital to help buy a battery that cost less than the sum of the candle loans.

One approach to overcoming the obstacle of capital expenditure is a fee-for-service model. Charging for basic services based on a service provider's judgment of an individual's ability to pay rather than on a formula standardized for a population, or having fees that are negotiable on some other basis, can also make basic needs affordable , although allowing individual providers to make these subjective judgments can also be problematic. Guatemala's long history of civil conflict has led to low levels of trust within communities and between communities and outsiders, as detailed in Chapter 6. This factor may be an insurmountable obstacle when allowing local service providers to determine rates subjectively.

Having procured something at a highly subsidized rate can make people less willing to pay a higher price for the same thing later (Guyatt et al., 2002). This reflects a change in willingness to pay but not necessarily in ability to pay. People may simply be less willing to sacrifice other basic needs more than they feel they have to, with that limit having been established in the earlier program.

And finally, misunderstanding of the processes or technologies involved can make an essential service unaffordable. Most households in the post-conflict development program paid 20 *Quetzales* per month into

[69] The conversion rate was approximately 8 *Quetzales* = 1 $US at the time of this research.

a maintenance fund managed by a committee in a nearby municipality. Yet, there were inoperable systems in one community that needed only basic and relatively inexpensive maintenance to make them usable, which should have been within the resources and capabilities of the maintenance committee. All members of this community interviewed believed they were paying a fee for the use of the system, either as a rent or repayment of a loan made by the NGO that donated the system. They were not aware that their consistent monthly payments entitled them to technical help and replacement hardware. Thus, the cost of ownership for members of this community was far more than it needed to be. People either spent their own resources to buy replacement components like batteries (or in one case, an entire new solar home system) or were deprived of the benefits of the system due to an inability to both pay the 20 *Quetzales* to the committee and save independently for future maintenance. In other instances, beneficiaries have been mistaken about which component was failing, and therefore spent resources needlessly replacing a functioning piece of the system. Various solar home system users reported that their lamps, wiring, or charge controllers had failed or were failing, when knowledge of general system operation and specific technical inspections revealed that the cause of inadequate system performance was that the battery needed replacement.[70]

Solar home systems often reduce the resources households must spend on lighting energy, but not always. Saving for future expenses seems to be an unrealistic expectation for the poorest communities in this study. This might be explained by an extremely high discount rate held by those in extreme poverty: money today is worth infinitely more than money at any point in the future if the money today is necessary for survival to see that future. High capital costs and inflexibility in payment terms puts battery replacement out of reach for many users with low and fluctuating incomes or who participate in non-cash economies. Misunderstanding of technical or administrative aspects of a project can reduce users' abilities to pay by driving up maintenance costs.

[70] Respondents often volunteered during my technical inspections which components they believed were faulty; I failed to record these elements of conversations that took place during the physical inspection and cannot quantify how often users were mistaken about causes of system inoperability.

5.4.3. Changes in energy expenditures

Respondents in communities with solar home systems reported that most individual users who managed to keep their systems operational, either by their own devices or through continued involvement of donors, realized the financial benefit of reduced lighting costs and, for a few, increased income opportunities. Specifically, only 9% (4/44) of respondents who provided information about their cost savings and income generation opportunities reported spending more money on energy while they had operable solar home systems than they did prior to the acquisition, as shown in Table 2. One of the four reported his energy expenditures increased because, having experienced some electricity in his home, he wanted more and bought a diesel generator to supplement his household's power.

With PV	
Spend Less or the Same	91% (40/44)
Spend More	9% (4/44)
Community System (N/A)	16 respondents

Table 2: Change in energy expense with PV system

Information included in compiling Table 2 included comments volunteered by users: at some point during the interview, the respondent explicitly stated that his or her household spent less on energy with the system in place. Interview subjects were also asked explicitly if it was more expensive to provide household energy with the system in place than without it.

Respondents were asked to estimate their typical expenditures on candles, kerosene, batteries and other purchased energy sources prior to the receipt of their solar home systems, and were asked to estimate their expenditures on these same energy sources at the time of the interview, if the solar home system was still operational, or during the time it was operational. Respondents were also asked what tariff, if any, they were expected to pay. Where respondents gave sufficient information, the difference between energy expenditures without the system was compared to energy expenditures (including tariff) with the system in place to determine whether the system represented an increase or a decrease in energy cost.

Finally, comments associated with questions of whether and how respondents or community members saw increases or decreases in income as a result of the system were used to categorize changes in expenses if respondents specifically commented that any additional costs or decreases in income were offset by increased income allowed by the system.

Thus, very few respondents who provided sufficient information saw increases in energy expenditures as a result of the donation of PV systems. At least one of these four began spending more because he chose to expand his energy services well beyond his previous uses by acquiring a diesel-powered generator. Some beneficiaries in the government loan program and the government-owned and -managed flood early warning system program chose to acquire energy-consuming devices like tape players and televisions, although they did not report these resulting in increased costs. These additional loads are in excess of the systems' design specifications and therefore are likely to shorten battery life. More frequent replacement of batteries adds to the overall cost of the system, and it was not clear that users understood that they were undertaking additional costs by breaking "the rules" against such appliances that were issued when the donation was made. The other three who reported increased energy expenditure, however, are users who incurred an economic burden as a result of a donated solar home system. This raises questions about the presumed ubiquitous effectiveness of donated PV in poverty alleviation.

5.4.4. Cost savings and poverty alleviation

Households often have an energy use portfolio, rather than relying on a single source (Foster and Tre, 2000). In the U.S., many households make use of both electricity and natural gas or fuel oil. In developing world applications, many households use combinations of traditional biomass, candles, petroleum-based fuels (gas, kerosene, diesel, etc.), and others, sometimes including electricity (Foster and Tre, 2000). To understand the impact of energy use on poverty, one must look beyond electricity since many of these sources can be substituted for one another (Foster and Tre, 2000). This research focuses only on electricity and the fuels it directly displaces, an acknowledged limitation of this work.

Stand-alone PV systems have been donated by non-governmental organizations, loaned to users by the government to provide electricity until the national grid can be expanded to reach a community, and sold at highly subsidized rates to users with the expectation that they will repay a fixed portion of the cost. However, it is not only the third category (excluded from this research) in which the users incur ongoing expenses for their systems. Lighting systems' batteries[71] and light bulbs must be replaced periodically, with charge controllers and lamps being replaced less often.

The programs included in this study target the rural poor. Where are these users expected to get the money to pay for maintenance? Does this new cost burden exacerbate poverty, even as it brings "development" to a community?

The disaster relief, post-conflict development, and government loan programs set up collective maintenance funds into which users were expected to contribute on a monthly basis and then draw upon as needed. This eliminates the need for seemingly impossibly large expenditures of capital when maintenance is needed: the money is already in the bank. Other programs encourage users to save money for future expenses without creating a structure under which to do so. These savings programs met with varied success, as described below.

Solar home systems provide some or all of a household's indoor lighting needs and therefore displace previous household lighting costs. Without solar lighting, households must spend money on candles, kerosene, batteries, or other energy sources if they are to meet their lighting needs. Thus, economically speaking, a household is better off with the solar home system if the amount it must save for future capital costs is less than its previous expenditures on lighting energy.

Respondents reported that savings programs in this study typically collected 20 *Quetzales*, or around 2.50 $US per month (respondents reported an average of 18.6 *Quetzales* per month, with mode and median of 20 *Quetzales*). Even when paying into these savings programs, most households with whom I spoke were

[71] Deep-cycle batteries recommended for solar home systems have an expected life of 3 to 5 years if well maintained.

economically better off with their solar home systems. Some households still used candles, gas lamps, and batteries for flashlights while they had working PV systems. Flashlights were used for travel outside the home at night, and combustion sources of lighting were used if the battery got low (as in the winter when there was less sun) or in rooms without electric lights. Among respondents who remembered and were willing to discuss their energy expenditures, the median expenditure on other energy sources prior to implementation was about 70 *Quetzales* (8.75 $US) per month, and 3 *Quetzales* (0.38 $US) while the solar home system was in use. Thus, paying 20 *Quetzales* to a maintenance fund or saving it personally, plus 3 *Quetzales* in other energy sources allows a savings of 47 *Quetzales* per month over previous energy expenditures. Since the prices of traditional energy sources continue to increase according to respondents, savings will increase over time.

However, this does not tell the whole story. Seven of the 42 respondents to questions about their energy costs saw these costs increase with the addition of a solar home system, if they were assumed to save or pay 20 *Quetzales* monthly for future battery replacement. Either their initial energy costs or their decrease in energy costs were less than 20 *Quetzales*. That is, 31% of unsuccessful systems were uneconomical while only 9% of successful systems theoretically cost their users more than traditional energy sources.

Users of successful systems spent an average of 105 *Quetzales* per month on energy sources before the installation of their panels, where respondents with unsuccessful systems spent an average of 65 *Quetzales*. The average savings seen by the successful system owners as a result of their systems was 99 *Quetzales*, compared to 48 *Quetzales* for their less successful counterparts. Thus successful users spent more on energy beforehand, suggesting they had greater access to resources independent of the project, and saved more money (percentage-wise and in total *Quetzales*): the “wealthy” among the poor were made better off by the addition of this resource, but the poorest may not have been. Donated solar home systems may aid in rural economic development, but that does not necessarily equate to the alleviation of extreme poverty.

5.4.5. Income opportunities

Income-generating opportunities provided by rural renewable energy systems are said to correlate to the success of the system (Troy, 2002). However, direct income generating activities (electric sewing machines or video houses, for example) are relatively rare in rural developing world applications. Modest economic gains were observed in a few cases in this study (too few to perform quantitative analyses), but not the remarkable changes that have been reported anecdotally in Guatemala and in other developing countries. Punta de Manabique is one of the economic success stories once celebrated in Guatemala, but was excluded from this study as described below.

Following the discussion of the Punta de Manabique project is a description of the ways respondents saved or earned money by using their systems and a discussion of the economic gains some respondents leveraged by liquidating their assets.

Punta de Manabique: exemplar of income opportunities with rural PV[72]

The peninsula of Punta de Manabique in Izabal, Guatemala acts as a barrier "island" protecting the mainland from the storms that come in from the Caribbean. The peninsula has been declared a special protected area because of its rich biodiversity and fragile ecosystem. The traditional inhabitants of the peninsula recognize the value of their environment and make conscientious and sustainable use of their resources in their industries. These are primarily fishing, charcoal-making and ecotourism.

Because of the physical geography, the fragile ecosystem and often tempestuous weather, providing electricity to these communities by extending the national electric power grid is impracticable if not impossible. However, the communities living on the peninsula recognized the economic potential of even small amounts of electric power. A consortium of international donors provided stand-alone PV systems to two communities and a wind-PV hybrid system to a third. Among the stand-alone PV systems, the first community, the economy of which had traditionally depended upon charcoal production, had recognized that it was over-using its ecosystem by cutting down trees for charcoal faster than they could re-grow. They

[72] Sources for this case study include (Ley, 2006) and interviews with U.S. and Guatemalan development workers involved in the project, except where otherwise noted.

sought to diversify their income sources and reduce their reliance on removing trees for their livelihoods by instead using their unique ecological surroundings to encourage ecotourism. The addition of the stand-alone PV system allowed the community to add light and refrigeration to its tourism center and substantially increase its profitability by increasing the comfort of its visitors.

The second community was a fishing village. They too had actively sought to make use of their environment without depleting it to diversify and enhance their income sources. In addition to selling raw fish to the mainland as they always had, the women of the community began to make value-added products like fish sausage, which was in demand at mainland hotels and restaurants. However, they were limited in their profitability by the short lifespan of unrefrigerated fish. Traditionally they purchased ice on the mainland and brought it by boat to their community on the sea-side of the peninsula, but ice itself is short-lived in the tropics. Like the ecotourism community, they requested and received a refrigerator where they were able to store their products. In this way, they suffered less loss of product and were less subject to daily price fluctuations: they could decline to sell fish for a day or two if the price was lower than they were willing to accept. Outside of the fishing season, the women of the community began using their refrigeration to make and sell ice cream locally. While they recognize that the money they earn from ice cream is small, they see it as an opportunity to use their resource, the refrigerator, to continue their income stream year-round. Since the women made use of the refrigeration system to bring money into the community, they were entitled to at least a share of the profits. Many of the women went to the mainland at the end of the first year and bought themselves shoes. They were the first shoes many of these women had ever owned.

The communities on the peninsula of Punta de Manabique illustrate the potential for direct and substantial income generation by use of stand-alone PV systems. These communities and systems are not explicitly included in this study because of issues of rule of law, discussed further in Chapter 6: organized crime co-opted control of the peninsula and have since denied access (by acts or threats of violence) to government and NGO employees and other strangers. The current status of the systems is unknown to the local NGO that had been involved in implementing and maintaining the projects, and any repairs to the systems that are beyond the knowledge of local community members will necessarily go undone. As such, Punta de Manabique is an exemplar not only of the potential for PV to benefit rural communities economically, but also an example of how making money with a system is not enough to make it successful.

5.4.6. Observed income opportunities

In communities connected to small hydroelectric systems, new industries are created and people make capital investments. In Guatemala, I observed a carpentry shop, innumerable stores with refrigeration, pharmacies, grain grinders, a bakery, and a *pinchazo* (a tire repair shop) that resulted directly from the implementation of the new energy system. However, stand-alone PV systems generally did not offer the same opportunities. Microhydro systems are sized based on the generation capacity of the water source, where small PV systems are sized based on pre-determined electricity demand. Thus, a hydro-connected community can "grow into" its energy source, while PV systems offer no room to grow.

Income-generating activities that are facilitated by solar home systems can theoretically increase recipients' ability to pay to maintain their systems. However, I observed a very small range of economically productive activities undertaken in the home after dark.

Owners of local *tienditas* that were part of homes that benefited from donated solar home systems reported being able to stay open later and generate more sales because they had electric light. Since these shops operate in isolated, subsistence-level communities, I question whether sales have actually increased as a result of longer hours or if the same sales have been spread over more hours in the day. Without changes in disposable income among members of the communities in which the *tienditas* are located (which is possible because of the donation of solar home systems to other community members, as described in section 5.4.4), the total amount of money spent at the *tienditas* seems unlikely to change. Sales may shift from a shop without lighting for nighttime business to one with PV lighting, if more than one *tiendita* is present in a community, but allowing a store to stay open later does not increase the amount of money that community members living in poverty or extreme poverty have to spend. However, respondents who were beneficiaries of donated solar home systems and ran *tienditas* out of their homes reported increased income because they stayed open longer hours.

Some *tiendita* owners reported saving money by communicating with suppliers via cell phones charged by their solar home systems. *Tiendita* owners who were the beneficiaries of solar panels were more likely than their neighbors to have performed capital-intensive maintenance like battery replacement.[73] It is not immediately evident that the additional income generated by staying open a few hours later at night and the money saved by communicating with their suppliers via cell phone are the only reasons for their greater success rate. As small business owners, they may have more experience managing money, better enabling them to save for anticipated expenses. They generally seem to have greater and more regular cash income than their neighbors due to the nature of their business, as contrasted with the subsistence farmers and occasional laborers who are their clientele. *Tiendita* owners may have access to credit, developed through relationships with the suppliers of the goods they sell, or they may have better access to the stores that sell solar home system components through more frequent trips to urban centers. These questions, little explored in this research, merit further study.

Cell phone coverage was nearly ubiquitous in the communities in Guatemala included in this study. Few or no vendors sold cell phones in rural communities, but many *tiendita* owners sold *saldo*¸ or credit for pre-paid cell phones (by far more common than monthly cell phone plans in Guatemala). Cell phones were owned by few community members before the installation of donated solar home systems, and those who had them often had to walk to the nearest electrified community, sometimes several hours away, to charge phone batteries and purchase *saldo*. Once cell phone charging was made available in the community by the donation of solar systems, more people came to own and use them, as discussed further in section 5.5. Except when asked, few *tiendita* owners mentioned the increase in *saldo* sales as part of their increased income that resulted fairly directly from the donation of solar home systems. However, since *saldo* use increased and most was bought locally, owners of *tienditas* in communities with donated solar home systems very likely saw increased income because of it. Notably, the increased income to shopkeepers

[73] Anecdotally, *tiendita* owners performed or anticipated performing maintenance much more often than other solar home system users, but sampling methodology precludes quantifying how much more likely.

because of the sale of prepaid cell phone credit whether or not the shopkeepers themselves had functioning PV systems.

Other direct income-generating activities enabled or aided by stand-alone PV systems were a fish farm, owned and operated by the local Catholic diocese for the benefit of its parishioners, a homeowner who collected a small fee for charging her neighbors' cell phones, a women's weaving cooperative lit by PV, and three tourist sites.[74] The success of these productive applications varied. The PV at the fish farm was operable and considered useful by respondents familiar with it. The women's weaving cooperative included in this study was also satisfied with its lighting (suggesting that the cooperative was earning enough to maintain the system), but an analogous co-op facility in a nearby community was abandoned and in complete disrepair.[75]

The PV system in one tourist facility was viewed as successful by respondents, but it was not helping them generate income, as described below. I conducted eight interviews with members of three communities with regard to this system. Six interviews were with individuals. For the seventh and eighth, both conducted in the same community, I interviewed a group[76] claiming to represent a large portion of that community and a smaller group of passers-by who joined an interview I began with a community member in a public place. All respondents concurred on the basic facts of the history of the project. A foreign archaeologist (for whom I was given three different names) had come some years before to excavate a Mayan ruin in Cancuén in the department of Petén. Although he employed some local labor, three nearby communities united to request (or demand, as seemed to be the implication) of the archaeologist that they benefit from this excavation taking place on land that was historically theirs – *de facto*, though the communities did not have legal deeds to the property – and that resulted from the ancient works of their ancestors. All concurred that the archaeologist readily agreed, and some seemed surprised by this. To that

[74] A fourth tourist site is included in this study but is not considered to be related to income-generation; it was a PV system in a national park to aid rangers in their duties.

[75] The abandoned system is not included in this study because I had helped to maintain it during my preliminary fieldwork (albeit obviously without success!). Since I had influenced the system in the course of this research, its inclusion is potentially biased.

[76] Between eight and fourteen men participated in the interview. I am not sure of the exact number as they came and went during as their interest and time permitted.

end, the archaeologist aided in creating a legal association made up of members of the three communities and a tourist attraction at the site of the archaeological dig.

Among other things, the creation of the tourist site included the erection of a ranger station, a restaurant, a kitchen and a latrine, the formation of a corps of rangers who were responsible for protecting the area and acting as tour guides, and the establishment of a boat launch in one of the communities to move tourists from the highway on one side of the river to the site on the other. To aid the rangers in managing the site, an NGO (there is some discrepancy among respondents as to which one) provided two PV panels and several two-way radios. The first panel and stationary radio is located at a privately owned store in the community most easily accessible from major roads in the area. The owner of this store also owns the motorboat used to transport tourists from the community to the site. He charges for this service and profits from it as an individual rather than these profits benefiting the three communities through their association. He uses this radio to contact the guide station at the site, where a second PV panel and stationary radio are located, and inform them that tourists are coming.

At the site, the guides collect a fee from visitors. This fee benefits the association rather than any individual. The guides are paid from these revenues and from sales of food or beverages at the restaurant. The guides also have portable radios to aid them in policing and managing the site. All concurred that, at the time of the interviews, the association and its members were not seeing economic benefit from the PV systems specifically or from the creation of the tourist site in general because the economic downturn had resulted in such a steep drop in tourism that revenues were not sufficient to cover expenses.

Members of two of the three communities differed from the third on the question of whether anyone was making money because of the systems. The store owner who dispatched the boat had use of the electricity from his PV system, even when not using the radio. As such, the store had lighting and members of other communities stated or alluded to the fact that he made additional money from his store because of this. They also seemed to resent the monopoly that the store owner had on transportation to the site. They believed he was making money as a result of that enterprise, and guides stated that tourists were surprised and sometimes resentful when they were asked to pay a site fee after disembarking as well as the transportation fee. I can directly substantiate this as I was under the impression that admission to the site was included in the fee I paid for transportation, and was myself surprised at being asked for a second payment. The store owner, with whom I spoke before I spoke to other community members or guides, did not mention that he personally profited from the boat transportation nor that he gained any economic advantages over anyone else in the three communities as a result of the donated PV system.

Among the other seven interviews, there was some discrepancy among responses to questions of who, if anyone, made money when tourists were present. Those involved in the project, such as guides and governing members of the association, presented a very egalitarian picture of a project that would benefit when tourists were present. The two group interviews painted a different picture. These respondents complained that many community members were *de facto* excluded from the project, even if they had nominal rights to participate. There were few guide positions available, and the guides were among the only ones to benefit economically through their salaries. When the restaurant was open, the guides' wives were called upon and paid to cook and serve, increasing the benefit to those households alone. These interviews suggested that the majority of people in the three communities did not see direct economic benefits from this project, even under ideal conditions. However, they viewed the project as successful in that it functioned as planned, and they felt they benefited from it because the association formed to manage the project had been able to bring other donation projects to the community – notably, every household in the community had recently received a donated water tank.

Two other communities in the general vicinity of the archaeological site had constructed tourist facilities appealing to ecotourism and relying upon the remarkable jungle in the area. One had received a single PV system, but the panel had been stolen. A second site had received two systems. One panel had been stolen so the second was kept in storage where it produced no energy. These two systems were not successful by any measure and were not in place long enough to assess what, if any, economic benefit they may have brought to community members.

Too few and varied direct income-generating PV systems are included in this research to draw definitive conclusions about the degree to which income generation itself drives system success. Three tourist sites where panels had been installed with income generation as a primary objective did not see their incomes increase, but one was successful nonetheless. Systems that were installed for household lighting – with no income generating opportunities included in project objectives – increased income for those who had *tienditas* in their homes. This research shows that donated stand-alone PV systems can increase income opportunities in rural Guatemala, but I cannot draw conclusions from these limited data to qualify or quantify conditions under which income generation is likely nor whether income generation improves project success rates.

5.4.7. Loss of income

Any aid intervention has the potential for negative unintended consequences, including consequences to local economics. If a good is available without cost from a donor, why would anyone continue to pay for it from a previous source? There are of course reasons that they might, but an economic argument can be very powerful, perhaps especially to people already living near subsistence level. Money that might otherwise have been spent on candles in the community may be spent instead on battery replacement with a remote vendor. Other unanticipated negative effects are possible in any donation situation. In this section, I discuss those observed and not observed during the course of this study.

5.4.8. Perception of lost income in the community

Respondents generally did not have the perception that solar photovoltaic systems in their communities cause anyone to lose income. Among interview subjects who responded to the question, 80% believed that no one in their communities lost income because solar energy systems had been installed in their communities, as indicated in Table 3. In some cases, this was unambiguously true. For example, almost all schools with donated solar panels had previously used only natural light. No money was being paid for lighting energy either inside or outside the community before PV lighting was added, so no one would logically lose income.

Community income effect		
Income is lost	5	13%
Unsure	3	8%
No income is lost	32	80%
Total	40	

Table 3. Perception of community members' loss of income resulting from PV

However, in communities where solar home systems were installed, most households continued to use other energy sources in addition to their solar home systems, such as batteries for flashlights used outdoors, or candles or kerosene when the solar battery was low, but they used less of these other lighting sources while they had functioning panels. Eight respondents answered the specific question of why they complement or complemented their PV systems with other energy sources. Two said they used traditional energy when cloudy weather prevented their batteries from fully charging. Seven mentioned needing batteries for flashlights outside their homes.[77] These were common themes mentioned implicitly or explicitly in more open-ended discussion and in answers to other questions by many respondents.

Kerosene is sometimes purchased from a *tiendita* in the community and sometimes purchased in larger communities or cities. Candles seem to be purchased in the community in which they are consumed. Despite respondents' own reported reductions in candle use and, in the case of *tiendita* owners, their own reductions in candle sales, most people did not believe that this represented a loss of income for anyone in the community. "People from other communities come to buy candles," said one *tiendita* owner. "Candles are also used in ceremonies. They are always bought," said another respondent. Others pointed to the occasional need for candles due to electrical system failure (such as a drained battery) as evidence that candle sales did not decrease; although users claimed that they spent less money on candles while they had functioning solar home systems, they did not equate this decrease in spending on their own parts to decreases in income on the part of candle sellers.

[77] One respondent gave both reasons.

Tiendita proprietors pointed to their increases in sales during the nighttime hours to show that their net income was positive, not negative, as a result of system installation. A member of a community powered by a small hydroelectric power plant (and as such not included in this study) observed that those who used to sell candles now sell light bulbs. Though not explicitly stated by respondents speaking of stand-alone PV systems included in this study, the sale of light bulbs and distilled water (for batteries) may offset or be perceived to offset lost income due to decreased candle sales. However, shops in communities powered by PV systems may have less access to needed DC light bulbs; the shopkeeper in the community powered by the micro-hydroelectric system sold universally available AC lamps.

Respondents were generally disinclined to make directly negative comments about the systems or projects. Follow-up questions on many topics in this study revealed that superficially positive responses covered decidedly negative thoughts or experiences. In the case of lost income, however, people's responses were consistent. Those who said that no one suffered economically as a result of system installation in general did not change their minds when asked about specific potential income losses like reduced candle sales. Although increases in income were modest at best (as detailed above), donated PV systems were not seen to negatively impact the community financially.

5.4.9. Liquidation of the asset

A donated renewable energy system may itself be viewed as an economic opportunity to a user via resale. In Mexico, very large numbers of solar home systems were donated to households without training or explanation (Ley, 2006). The components of these are now available for purchase throughout Central America and Mexico, but few of the original recipients make direct use of the donated systems (Ley, 2006).

In my research, beneficiaries in the communities included in the disaster relief category were left after one year with full ownership of and responsibility for their solar home systems, without further follow-up or assistance.[78] The next contact they had about their systems was from a "system recycler" who convinced people that their systems would soon be valueless so they should sell them immediately and cheaply. Respondents reported that many of their neighbors, recognizing their own inabilities or unwillingness to maintain their systems or with mistaken expectations about their systems, leveraged the financial value of their donated systems by selling them to the recycler. This same recycler would return to the communities repeatedly during the first few months or year after installation.[79]

While certainly not the intent of the donor organizations that implemented them, this was inarguably a short-term financial gain to the user though arguably a long-term financial loss.

5.4.10 Economic effects of community-based systems

Systems installed for the benefit of the community, including those used for schools and health clinics, offered no direct economic advantages to beneficiary communities.[80] Seventeen respondents reported that, as their systems were used on a community basis (for schools or health clinics, for example) rather than by their households individually, the systems had no economic impact on them personally. No community-based system included in this research replaced a prior energy source: schools and clinics were used only during daytime hours previously, or systems were installed for a new purpose (a vaccine refrigerator was installed in one community), or systems were installed when schools were built. Therefore, the systems cannot be said to have saved users money compared to a previous energy source.

[78] This paragraph is drawn from information provided by respondents and affirmed by a representative of *Fundación Solar*, the local NGO involved in project implementation.

[79] Only five of the twenty respondents in the disaster relief category reported that they themselves had sold their solar home systems. However, the sample was strongly biased towards households with systems still in place. Respondents unanimously agreed that "many" or "most" beneficiaries in their communities had sold their systems. Details of the contexts of these sales are found in Chapter 6.

[80] The provision of electricity to a community institution is not inherently assumed to improve that institution's ability to provide health or education services; this study also does not assume that improved education and health necessarily lead to greater economic opportunity or productivity. Though both assumptions are arguably reasonable and anecdotally appear to be widespread in the donor community, this study does not assume that electrifying community institutions improves community economic prosperity. In fact, anecdotes observed during the course of this study lead me to question whether and how solar electricity on a school building has any relationship to student learning; this topic should be studied further.

5.4.11. Summary: Economic outcomes and success

Household users were generally better off economically after they received donated systems than before, on average incurring lighting expenses with the system that were equivalent to approximately one-third of their previous lighting expenses. This averaging obscures the economic reality that about 10% of the users saw their lighting energy costs increase. Systems included in this study that were considered unsuccessful belonged disproportionately to users whose costs increased. Clearly users who both saw their costs decrease and who considered the solar lighting to be as good as or better than their previous lighting sources had strong economic and utilitarian incentives to keep their systems operational. Those who took on an additional economic burden when they accepted a donated solar home system may have been unwilling or unable to pay this higher cost to meet their basic lighting needs.

However, among unsuccessful systems, 69% of former users theoretically should have seen cost savings by maintaining their systems rather than letting them fail and reverting to former energy sources. There are many reasons for this, as discussed in subsequent chapters. Among strictly economic reasons, access to capital when needed was a substantial barrier: though the net present cost was lower, that did not in any way guarantee that the avoided lighting costs would be available as cash when system maintenance was needed. In theory, representative organizations which collect monthly tariffs should lessen the economic burden on individual users. Although the total amount of money may be the same, monthly payments are perhaps easier to make than is gaining sufficient access to capital to replace a battery.

The real cost savings afforded by donated stand-alone PV systems did not represent a sufficient condition for system success; many economic “winners” failed because capital was inaccessible or for non-economic reasons. However, there is a clear general trend of higher success rates where systems brought economic advantages to their users, despite the few cases in which systems succeeded despite higher economic costs.

5.5. System utility

"…to charge the cell phone. You can't do that with a candle!"

Owner of a successful solar home system

This section examines the uses donated PV systems and the implications of use type on system success. Systems in this study were intended to provide illumination, to power communications systems, or to power equipment in school or clinic settings. However, these cover a wide variety of applications. All respondents reported using their systems in some capacity to provide illumination. Other uses are considered in this section. Specific economic impacts of system use are discussed above and not included in this section.

5.5.1. PV as an alternative to prior energy sources

5.5.1.1. Illumination

Illumination was an application of PV electricity that was used by 100% of respondents in this study. For some, it was the only application. However, it did not always replace a previous illumination source, as described in this section.

Respondents in home and community applications used fluorescent light bulbs, which were chosen by the donor or designer for their low energy use. Lighting fixtures used DC electricity and specially-designed light bulbs which cannot be replaced with traditional low-cost, low-efficiency incandescent bulbs. Solar home systems typically included three lighting fixtures per household, though not all were functioning in all households at the time of my visit. Illumination using PV electricity provides better quality of light than combustion light sources like candles, gas lamps, and *ocote*, according to respondents. Parents view it as advantageous for their children's studying.

Not all lighting applications replaced prior forms of artificial lighting. Electric light in schools was not used during school hours. School buildings are built with adequate natural lighting and classes meet during the day. School lighting was used for community meetings and celebrations at night, during emergencies if the school was used as an evacuation shelter, as detailed below, and by the teacher if she or he lived in a room in the school building. Since teachers are hired by the government and normally are not native to the communities in which they teach, having teacher's quarters in the school building is not uncommon. Anecdotal reports suggest that providing basic comforts and conveniences like electric light to teachers and medical professionals may encourage them to stay in remote communities rather than seeking to apply their skill sets in more urban environments. Whether this approach is effective or not is not is outside the scope of this study.

Many users described solar electricity as *luz* (light) and differentiated that from grid-based electricity. Some users seem to understand PV as capturing actual sunlight and storing it in a battery, and then releasing the light through their lighting fixtures. None of the general users described receiving the highly technical training that would be necessary to explain the processes that convert light through forms of electrical and chemical energy before converting it back to light energy, nor would that training have been likely to aid users in sustaining their systems. Some respondents trained as technicians or with understanding of electricity independent of the PV project had a more nuanced understanding of the technology.

Because all systems included in this research included illumination as one of their applications, it is not possible to draw any conclusions about the effect of lighting as an application on system success. Nor was there a significant difference in perceptions of light quality between users with successful systems and those with unsuccessful systems: all respondents who remarked on light quality praised PV lighting as superior to combustion lighting sources such as lamps, candles and torches.

5.5.1.2. Cellular telephone charging

Cellular telephone charging was an important use of solar home systems. Most other household applications have alternative sources of power: batteries can power radios and candles bring light. Larger applications such as refrigerators cannot generally be powered by solar home systems. However, there are few locations in Guatemala that do not have cellular service, telephones themselves are relatively inexpensive, and *saldo* is easy to find and can be bought in increments starting at less than 1 $US. A cellular phone is useful in emergencies and can be used to keep in contact with family members who live outside the community. Since there is no charge for incoming calls, even someone without the resources to purchase *saldo* can benefit from a phone if wealthier friends and family initiate the calls – all dependent upon keeping the phone battery charged.

Fifty-three percent of respondents with successful systems reported using them to charge cell phones, while only one third of their less successful counterparts reported this as something they did or had done with their systems. Two possible explanations are suggested: one is that people are more motivated to maintain their systems when they have cell phones or other uses (like television) that cannot be met with alternative energy sources. The other is that those with the access to resources to purchase telephones are also more likely to have access to resources to maintain solar home systems.

Among the communities included in the disaster relief program, only one community member who responded to questions about energy use reported that cell phone charging was one of the applications for his household. By comparison, about half of respondents in the post-conflict development project listed cell phone charging as one of their uses or former uses. These are communities that are demographically similar (indigenous communities with similarly low income levels), suggesting that neither poverty nor "culture" precludes cell phone use. Cell phone service was available in or near communities in both programs at the time of this study. However, respondents reported that most systems in the disaster relief program only lasted a few years after implementation. It is not clear whether cell phone service was available in the area at the time the project was put in place. Additionally, since the time that most systems in this group were functional was also a time of great economic need and volatility for the beneficiaries, the purchase of a cell phone was likely not a high priority for most community members. In contrast, members of the post-conflict development group are poor but seemed to be in a relatively stable situation, perhaps affording them the opportunity to accumulate small luxuries such as phones without any substantial changes in standard of living.

Because of the very low incidence of phone charging in the disaster relief group, I revisit the correlation between success and cell phone charging while excluding those systems. Among solar home system users in other categories in this study, 55% of respondents both with successful and with unsuccessful systems mentioned cell phone charging as an application in their homes. The hypothesis that the need for electricity for cell phone charging will increase the likelihood of success of stand-alone PV systems is not supported. Since, outside the disaster relief group, at least one beneficiary still had a working system in each community, it is possible that many people with cell phones rely on a few solar panels to charge them. While I saw evidence of some households charging multiple phones (some for a fee, others free of charge), I did not quantify this.

5.5.1.3. Radio and television

Radios are widely used in the rural Guatemalan communities visited for this research. A reliable electricity supply is not needed for radios, however, since most can be powered by batteries, which are readily available at local *tienditas*. As with cell phones, having a radio does not predict system success: among respondents to this question, 23% of users with successful systems used them to power radios, while 22% of respondents with less successful systems mentioned radio as one of the uses of their system while it was functioning.

Twenty-five percent of users with successful systems who responded to this question had or previously had black and white televisions, as did 14% of users with unsuccessful systems. However, the reasons for considering these systems unsuccessful are notable: they are not non-functional systems, but these users expressed dissatisfaction with the amount of energy provided. They would prefer grid electricity in order to power more and larger appliances (such as color televisions). Also notable is the distribution of respondents with televisions. One is a *telesecundaria*, so the television was bought as part of the donation. One television owner is located in a post-conflict development community, one has flood early warning system power, and the others are all in government loan communities. Among the government loan communities, most with TV's are *Ladino*, and the government loan population in this study is on average wealthier than the indigenous post-conflict development and disaster relief communities. Television users are willing and able to keep their systems functioning, but this does not imply success. Some are able to afford more electricity-consuming devices, and find PV unsatisfactory because of its inability to power them.

Among the government owned and managed systems that were intended only for powering two-way radios to warn of weather-related and other disasters, all respondents used excess energy for domestic applications including lighting, and one admitted to having a television connected to her PV system. The government representative in charge of the network of systems to which she belonged knew she owned and used the black-and-white television. She openly admitted to using the TV, but insisted that she used it for only one hour each day to watch her favorite *telenovela*, the Latin American answer to North American soap operas. Hers was a successful system by the definition used in this research: it was functional, she thought it successful, and her household would not have selected a different form of energy if it had been available. Her system's success made her exceptional among television users – most had unsuccessful systems based on the criterion that they considered them sub-optimal – and made her exceptional among those at her level of poverty – her home and her family's livelihood suggested that she was among the poorest respondents in this study, and wealthier respondents appeared more able to keep their systems functional. The reason for her success is related to the program under which it was installed, as detailed in Chapter 6, showing that, like economics, utility is not a sufficient criterion for system success.

5.5.2. Desired applications

When asked what they would like to be able to do with electricity that their systems could not support, users said they wanted television, which is feasible to connect to a larger solar home system if few other applications are used and it is not run for many hours out of the day. Whether users who wanted television but did not have it were unable to acquire it because of the capital requirements or availability of DC black and white televisions, because they heeded the advice of the project donor or developer,[81] or because their systems were smaller than average and could not support a TV is not clear. Television is clearly a luxury item, and as such differs from other unmet desires, which all relate to women's household work.

[81] Standard solar home systems in Guatemala are not designed to accommodate television loads, though they can be made to do so. Designers and installers recommend against it to manage users' expectations and to maintain system loads within design specifications.

Many users wanted refrigerators. Solar home systems are not sized to power home refrigeration, and relatively large systems must be constructed to power small, high-efficiency DC refrigerators for rural stand-alone applications such as those included in this study. Only one system in this research included a refrigerator, and it was intended for vaccines and other medical supplies in a rural health clinic.

Self-reports of what one would do given the opportunity may differ from actual behavior. However, in rural Guatemalan communities observed at the time of this study that were connected to micro-hydroelectric systems, *tiendita* owners and many private residences had acquired refrigerators. As such, I believe that at least some users of solar home systems would acquire refrigeration if they were able to power it.

Only two respondents used their systems to power blenders and none used them for irons, but these were common unmet needs. The desire for blenders and irons highlights a clear disconnect between the attitudes of donors and beneficiaries. Donors may state explicitly as goals the desire to reduce the physical or temporal demands of household labor on women, and many projects such as community laundry basins and piped or pumped water are implemented with this goal. However, I have never heard of donor programs to provide irons or blenders or the electricity to power them even though the women included in this study clearly wanted them and viewed them as tools to save time on household tasks. A blender is presumably considered a less valid means for improving standard of living or development opportunities among project donors and developers than is, for example, water pumping, even though the primary outcome of both may be to decrease demands on women's time and labor.

5.5.3. Utility and success

I cannot draw clear relationships between the non-economic uses of systems and their success based on the data s for this research. Some applications, such as lighting and radio, are ubiquitous or nearly ubiquitous – and easily used without access to PV – and therefore cannot be contrasted between successful and unsuccessful systems. Other applications, like television, lead to success or failure only on optimality criteria: poorer users are delighted that they are able to watch TV at all, where wealthier respondents saw systems as insufficient because they were forced to watch black-and-white television rather than color.

Other applications, such as cell phone charging, had no bearing on system success. I hypothesize that the need for cell phone charging correlates to a greater probability of success of at least one PV system per community or social group, but this hypothesis is not addressed in this research.

5.6. PV systems in weather-related disasters

"…Everyone should use renewable energy. If they had, they wouldn't have suffered."

- Resident of a community that used biodiesel to survive and thrive during a hurricane and its aftermath

Violent conflict, civil unrest, severe weather, earthquakes, landslides, and other natural and man-made disasters have plagued Guatemala's recent history, as detailed in Chapter 3, so these are among the contexts in which the rural stand-alone PV systems included in this study are situated. Some of the systems were implemented specifically for weather-related and other disaster preparedness and response; others were implemented as a response to a disaster. I had no a priori hypotheses about stand-alone PV systems in disaster situations, but it emerged as a relevant theme, so I posed questions to system users about PV, PV-enabled technologies, and energy-related social networks during disaster situations.

"Disasters" are not simply weather-related events; even unusual or severe events are not necessarily hazardous to people. A hazard is "an interaction of man and nature, governed by the coexistent state of adjustment" in human and natural systems (Kates, 1971). For example, a severe snowstorm in a community that is acclimated to such storms may be inconvenient, but not disastrous. The same storm in a community with little or no experience in or preparedness for blizzards may result in significant loss of life and property: it may be a disaster. The definition of a "disaster" is so subjective that members of the same communities frequently gave different responses when asked if the community had suffered weather-related disasters.

While users saw various advantages and disadvantages to renewable energy systems, a common theme was a preference for a diversity of options: being grid connected with PV for back-up, having flashlights on hand, or having candles as well as a PV panel provides the best opportunity for a safe and successful outcome in a disaster situation. All PV users appeared to have access to other forms of energy – at a minimum, candles were available in every community – but this diversification of sources was not included in the development plans described by either donors or beneficiaries interviewed for this research. PV was expected to replace previous sources of energy, and having to rely on previous energy sources in either day-to-day or extreme situations seemed ubiquitously disappointing but only sometimes unexpected.

5.6.1. User responses

Although hydroelectric projects are not explicitly a part of this research, I visited several rural communities that used them, and their responses are notably different from PV users' responses. These differences in responses give context and meaning to responses of those included in this study and are therefore briefly discussed here.

Among respondents who answered both questions of whether their communities had experienced weather-related disasters and whether their PV systems helped them to cope better with such disasters, 76% said they had experienced disasters. Among those who had experienced disasters, 92% of those whose systems are considered successful for these analyses stated that having their PV systems help them cope with these disasters, compared to only 50% of people with unsuccessful systems who believe that PV helps them better cope with weather-related disasters. Thus a system that helps its users cope with natural disasters is more likely to be successful than one that is not, though causation may go either way. Obviously a system that is destroyed by a weather-related disaster is neither successful nor able to help users during that disaster. Another explanation may be that those who expect their systems to be helpful to them during weather-related disasters may go to greater lengths to maintain them as part of personal or systematic preparedness plans.

The question of the utility of PV during natural disasters was phrased two ways to all respondents: does having a renewable energy system (the PV system) make it easier to cope with natural disasters; and is the renewable energy system better able to withstand natural disasters than your previous energy system? Negative responses to follow-up questions for both fell into one of two categories. People disliked PV or electricity in general because they perceived it as dangerous in the presence of lightning, flooding, or rain, believing that a storm could either damage the system or harm people (see Chapter 7 for details of the impacts of safety standards); or people were dissatisfied that their batteries didn't charge adequately in cloudy weather, leaving them without power in weather emergencies. Some users disconnect their systems during storms to protect against lightning strikes. Users in some flood-prone areas move their batteries to higher shelves in the house during flooding; users of a system at a tourist site remove the entire system (panel, battery, and balance of system) during the off season to protect it from flooding that can sometimes rise to the level of the roof of the tourist center.

Positive responses included statements about the utility of having light during emergencies (such as being able to see water levels rising, being able to evacuate to lit shelters, keeping better track of children and the elderly), some giving specific emphasis to the quality of light produced by electricity versus combustion light sources. Some preferred it to grid electricity (even though the grid had not reached the communities where the panels were installed) because the grid is notoriously unreliable and perceived as unsafe during storms. A commonly stated advantage of panels over candles and gas lamps is that wind and moisture can extinguish flames, or can blow candles over and cause fires.

5.6.2. Biodiesel: a case study in the use of renewable energy in disasters

By far the most successful use of renewable energy in a disaster situation that I observed involved biodiesel. The community involved was the first visited for this research, and the location where the questionnaire was tested and refined. It is a fairly advanced community, with a small hydroelectric plant, two solar panels, and numerous income-generating projects including a coffee plantation, macadamia nut growing and processing, an eco-lodge for tourists, and a water purification and bottling plant. "A foreigner" had donated the equipment and provided training to produce biodiesel from waste cooking grease. After several failed attempts, the community produced its first successful batch of biodiesel on the day the area was struck by a major hurricane. The community and its surroundings were cut off from "the outside world" in the aftermath of the storm, since roads and bridges in and out of the area were impassible. They had no access to traditional petroleum-based diesel fuel, which was normally used to run their small industries. During the aftermath of the storm, the community used its biodiesel to continue to operate fairly normally. The water bottling project also used biodiesel in its trucks, which it sent to surrounding communities. In this way, nearby communities also had access to potable water despite the destruction or interruption of their water supplies by the storm and their lack of access to help from the government, aid groups, or metropolitan areas.[82] The community has since expanded its biodiesel production (although the community must still supplement with petroleum diesel on a regular basis) and is working with a local university to grow an appropriate feedstock since available cooking grease is no longer sufficient and purchasing waste grease has become expensive.

Since this was the only biodiesel project I viewed during the course of this study, it is not possible to say whether biodiesel itself, the characteristics of this community, or some other factor led to its success in a disaster situation. However, community members themselves spoke highly of their biodiesel and subsequently donated hydroelectric energy production. They viewed these renewable energy sources as enabling them to operate independent of donor aid in the aftermath of the disaster, and in fact to become donors to neighboring communities by delivering bottled water. Although the answer is outside the scope of this research, the circumstance beg the economic question of whether the donation of robust renewable energy systems in advance of a disaster costs less to the government or donors than rescue and relief efforts after the fact. A member of the community itself answered the human aspect of that question: …Everyone should use renewable energy. If they had, they wouldn't have suffered.

5.6.3. Disaster early-warning systems

As described in Chapter 3, CONRED (Guatemala's national disaster coordination agency) installed a series of solar-powered two-way radio systems in a watershed to enable early warning of flooding conditions.

[82] This aid to neighboring communities subsequently increased their business as they became paying customers for the water after the disaster was resolved.

Collaborating community members in the upper watershed measured rainfall and those in the middle watershed measured the rivers' water levels, and the government used this information to assess risk of flooding in the lower watershed. When flooding is predicted, the expected timing and magnitudes of the floods are relayed to downstream collaborators, who in turn warn their own and surrounding communities to enable households to take appropriate precautions by securing possessions and livestock and, in severe cases, evacuating low-lying areas. The radio systems have offered other benefits beyond the initially intended flooding early warning program: they have been used in non-weather emergencies and lives have been saved by communities' being able to radio for help in cases of childbirth complications and other health emergencies. One community used its radio to communicate with medical professionals about a spate of digestive complaints. The medic immediately recognized the symptoms as cholera, and was able to help the community address the illness. The respondent firmly credited the availability of the two-way radio for preventing a few isolated cases of cholera from becoming a local epidemic with potentially devastating loss of life.

Users ("collaborators") take a strong interest in their systems and are eager to see them continue functioning, both for their intended purpose of securing life and property in disaster situations and for the added convenience they offer to households that are then able to use excess electricity for electric lighting and other luxuries or conveniences. However, it is easy to be supportive of a program that brings benefits with very minimal costs: CONRED is 100% responsible for system maintenance. CONRED's institutional involvement and responsibility for maintenance may have a stronger bearing on the remarkably high success rates of these systems than the value people place on them in disaster contexts, as can be seen by a comparison with other systems that were used in disaster-related contexts, below.

These systems have aided downstream communities in preparing for minor flooding and communities throughout the watershed in local emergencies. They were not used during one major hurricane because the government had cut funding to the program at the time, leaving many systems operable but with no coordination or support staff – no one was available to provide information or answer calls for help. Another major storm has not threatened the watershed since funding was reinstated. The success of these systems, then, is limited neither by technology nor by user interest and participation, but by level of institutional support.

5.6.4. Enabling of other technologies

According to respondents, PV enables other technologies that are useful during emergency situations. In addition to light, which was described as useful both during weather-related emergencies (for shelter and awareness) and in medical emergencies (to monitor sick patients or to allow pharmacies and health centers to remain open at night), communications technologies were emphasized as important in disasters.

However, systems that were not installed with disasters in mind also provide benefit in this regard. Cell phone charging allows community members to communicate with people outside their immediate area, even if access is cut off. While people in un-electrified communities may bring their phones to neighboring towns to be charged under normal circumstances, disaster conditions may be prohibitive of such travel; local charging allows people to stay connected. Respondents with PV systems use radios and sometimes black and white televisions, and these communications media provide information to isolated communities during disasters, and early warning of imminent storms. I am reluctant to credit PV for the availability of radios, however. Readily available C-cell batteries could run most radios that I saw in communities if no other electricity supply was available. While purchasing batteries is expensive relative to running a radio using a PV system, PV systems do not enable radio use per se.

Entire communities need not be electrified to reap these benefits. One or a few households with electricity can provide cell phone charging and radio information for the whole community, as is the case with CONRED-owned and –managed systems.

Communities electrified by small hydro facilities generally benefit more from the electricity during emergencies, if the system is not itself damaged in a storm, than do users of stand-alone PV systems: more water means more power is generally available from a hydro than from a PV system, which allows use of more technologies. The medic in the clinic in one community with hydro power spoke of the reduction in deaths from respiratory illnesses since the inception of the hydro, which he attributed to two things: decreased indoor air pollution from the use of electric lights instead of combustible lighting sources,[83] and, more importantly, his ability to use a nebulizer for patients presenting severe asthma or other respiratory illness symptoms. The greater availability of electricity also allows the use of televisions and computers, with some people in remote communities having internet access using cellular technology. Both TV and the internet facilitate the flow of information into a community. In one hydro-connected community, leaders attached loud speakers to a radio to broadcast news to the entire community during disaster situations.

5.6.5. Electricity and water

When discussing weather conditions, nearly all hydroelectric users with whom I spoke claimed that rain was beneficial to their systems – increased rainfall leads to increased stream flow, which in turn leads to increased hydroelectric production up to the capacity of the plant. PV users universally responded to the contrary: the clouds that bring rain also reduce sunlight reaching their panels, which leads to lower availability of power. This seemed to lead to system failure based on unmet expectations. Some operable systems failed to meet optimality or perceptions criteria for success in part because of user frustration that energy was least available in darker times of year, when it was needed most.

However, water and electricity can be a frightening combination to some. Some women (but no men) expressed fear of electrocution by their PV systems when rain was falling or during flooding events. In fact lightning strikes during rainstorms did more damage than rain; users in some communities knew of systems that had been damaged or destroyed by lightning strikes, but none spoke of anyone being physically harmed by their PV systems, in the presence of rain, lightning or otherwise. The fear certainly cannot be called unfounded as water does increase electrocution risk and very few systems were installed with recommended safety features such as grounding rods (see Chapter 7). The fear itself proved more harmful than the electricity; one respondent suffered a "year-long nervous breakdown" as a result of her family's PV system being struck by lightning, even though no one was hurt and the only damage was to the system itself.

[83] This hydroelectric system did not eliminate the use of traditional biomass for cooking and heating, which are arguably much greater sources of indoor air pollution than candles and gas lamps or even *ocote* torches.

This fear of electricity and water reported only by female respondents contrasts sharply with the preference for electric light over candles or gas lamps during a storm, reported only by male respondents. To them, the electricity was safer because candles and lamps can blow over and start fires, or simply blow out.

Since people in hydro-connected communities are more removed (physically and, in general, in terms of day-to-day operations) from the electricity generating equipment, they expressed less concern or fear about the safety of electricity during storms, although a few respondents (all women) remained uncomfortable with the electricity-water combination present in a storm.

5.6.6. Summary: rural energy systems in weather-related disasters

Electrification helps rural communities in weather-related disasters only if the electrification system itself is robust enough to very literally weather the storm and if people are confident in it. The production of biodiesel allowed one community to switch its usual role of beneficiary to that of donor to its less-fortunate or (perhaps more accurately) less-prepared neighbors. Contrarily, an ungrounded PV system that was struck by lightning damaged a user's mental health and greatly lessened her neighbors' confidence in PV, especially during severe weather. Although relatively infrequent in any particular community, Guatemala is affected by severe storms every year, resulting in property damage, displacement of populations, and loss of life. If rural electrification systems are not designed to withstand these severe weather events, they are not a help and may become a hazard to the populations they are intended to benefit.

5.7. Conclusion

Economic opportunities are strong drivers of system success, but economic value in real dollars is insufficient to ensure success itself. Institutions and relationships among beneficiaries and between beneficiaries and outside parties, discussed in detail in Chapter 6, have strong bearing on the opportunities to capture economic benefits. The conspicuous lack of financial institutions available to beneficiaries contributes to the lack of access to capital which makes system maintenance prohibitive even in the face of real economic opportunity.

Correlations between utility and system success are not apparent based on this research. However, system uses and users' perceptions highlighted when discussing system utility bear strongly on the definition of success, (see Chapter 2). One system may be successful for a particular user because it provides a basic need or luxury that was unavailable previously, whereas an identical system may be a failure to another user who wants or expects more than that basic functionality.

Uses of energy in communities powered by hydroelectricity highlight a dramatic limitation of PV systems: the former are sized to capture as much of the available resource as possible – allowing users to expand their energy consumption to meet their self-defined needs – and the latter are sized to meet a specific set of needs, most often defined by the donor, and allow little if any expansion in utility. Because this study did not include hydroelectric projects explicitly, these are anecdotal results only that merit further study.

Chapter 6. Results concerning institutions and relationships

6.1. Introduction to results concerning institutions and relationships

In this chapter, I consider how the success of rural PV projects in Guatemala are affected by ownership, accountability, management structure, level of participation, and other management- and governance-related issues, and how, in turn, these institutions and relationships are affected by the introduction of those projects. The questions of interest were defined in Chapter 3.[84]

Unlike grid electricity users, stand-alone PV users generally are expected to provide maintenance for and management of their own means of electricity production. Excepting the government-owned and -managed systems that are in place to serve a specific purpose on the government's behalf (PV-powered flood early warning systems, for example), I know of no donor model or lending programs that provide ongoing funds for maintenance of systems owned by users, and some programs – like the government loan program included in this research – will even re-claim a panel if the beneficiary fails to maintain the system. Users must either be a part of a collective organization to share the responsibilities of project management, or they must themselves provide all necessary management, technical skill, capital, and transportation to keep the lights on. The operation of a single PV system may be simple, but the responsibilities of being one's own electric utility may be complex. These responsibilities exist within the institutions and relationships described below.

The startling implication of these results is that the ability of a system to provide electricity is only part of its value to users, as described throughout this chapter. Users invest in and receive benefit from the social networks and institutional structures that surround their systems, much in the same way as they invest in and receive benefit from the PV hardware itself. Very analogous groups of users can see very different success rates with their systems, based not on any fundamental technical, economic or cultural differences, but because the institutions and relationships that users build or with which they engage as a result of these systems vary dramatically. This observation, not reflected in the hypotheses and research questions, is a recurring theme in the remaining sections of this chapter.

[84] See Appendix A for the relevant survey instrument.

In this chapter, I first summarize previously introduced hypotheses and research questions concerning institutions and relationships and system success, and differentiate between those issues that will be included versus those included in Chapter 5, Results: Economics and Utility or Chapter 7, Results: Characteristics and Consequences. I consider the impacts on system success of project origination and user training, issues of ownership and accountability, and ongoing relationships between donors and beneficiaries. Finally, this chapter examines the role of institutions and relationships in the unintended consequences of these projects, some of which may increase system success rates while still being arguably "bad" outcomes, and the impact of unethical and criminal behavior on the part of members of extra-community institutions.

6.2. Hypotheses and research questions

As described in Chapter 3, the institutions and relationships – the social networks and formal and informal structures within the community, as well as the government, donor and development organizations involved – that surround, create and result from the implementation of rural stand-alone PV donation programs can influence system success, though this is one of the least studied aspects of such programs.

The institutions and relationships linked to community energy systems are closely tied to the characteristics of and consequences to users, non-users and their communities, as discussed in Chapter 7. As examples, the quality of materials used to construct systems is driven by institutional structures that dictate their purchase and installation, and intra-community conflict is influenced by the characteristics of a community and of the program that installed its energy systems, as discussed in Chapter 7.

This research began with the two fundamental research questions regarding institutions and relationships and four hypotheses regarding answers to those questions (first presented in section 3.5.2 of Chapter 3). I repeat those questions and hypotheses below, discussing them in more detail than in Chapter 3.

Research question 1: What are the governance structures related to the systems? Does it matter whether committees are formed to manage projects or savings? Does their legal establishment lead to greater success, or do those established by intra-community trust work as well?

This question is fundamentally about project governance. Are projects governed by institutions or organizations, or is "governance" of the project left to the individual? How aware of project governance are individuals, and how involved are they? The question of legality relied on the implicit assumption that respondents would know whether their committees were legally established or not, and that that knowledge would be consistently represented by members of the same community. This assumption did not hold true. As described in Section 6.4, below, laws and *de facto* rules of conduct are not necessarily coincident.

Hypothesis 1: If people are the originators of their projects (they ask, rather than the donor offers), they will tend to care for them more because they are more in line with beneficiary needs.

This hypothesis is one of project origin. Prospective users may become aware of PV systems and then request them, or they may learn of them only when a donor offers. The diffusion of information about a novel technology is an important part of its dissemination and adaptation (Acker and Kammen, 1996). Word-of-mouth is a common means of dissemination of information about solar home systems in Kenya, surpassing by increasing margins the effects of advertising (Acker and Kammen, 1996). As such, users who see solar panels in neighboring communities, and see the value that they bring, may request them of potential donors. Because they initiated the request – they recognized their own need and had the agency to pursue filling the need – they are hypothesized to be more successful in using and maintaining systems as designed.

Hypothesis 2: Projects are more likely to fail if people are not trained in their maintenance and administration when systems are installed.

Implicit to this hypothesis is the idea that the donor is the only source of training or information about a donated PV system: at the outset, beneficiaries do not know how to maintain a physical system, nor do they have the economic management skills to save for replacement. This underlying assumption, postulated at the outset of this research, is not necessarily true. A few beneficiaries had had some training as electricians in other contexts, purchasers of systems improvised maintenance without any training,[85] and managing household or community-level finances requires a basic level of knowledge or skill in administration – independently of donated PV systems. As such, the focus of this hypothesis shifted to the question of whether active participation in training led to system success, and whether beneficiaries found the training that was provided useful and sufficient.

A related hypothesis originally considered for this research was that projects were more likely to succeed if a designated, trained maintenance person lived in the community or a nearby community. However, the data collected in this study do not allow for testing of this hypothesis, as described in Section 6.6.2, below.

Hypothesis 3: If people are required to contribute financially or in kind to their systems, they will have a stronger sense of ownership and take better care of them.

It seems to be held as self-evident by those who work in development that user contributions to projects increase their value to beneficiaries and improve success rates. In an extreme case, one government official was quoted when speaking of development projects at the end of the civil war (Manz, 1988, p.43): We must force the Indians to work on our projects or else they will never appreciate what we are doing for them. But they are so stupid. Even when they have slaved away building a playground, they still, the very next day, steal the tires we used for swings to make themselves sandals.

Though I did not find the same overt condescension in any of the development professionals interviewed as a part of this research, the attitude that a project will be valued if users contribute persists. What is suggested by the above-quoted government official and by the beneficiaries in this research who sold their solar home systems is that the value of the project intended by the donor or developer is not necessarily related to the work contributed by recipients. Indeed beneficiaries contribute in work or funds in order to gain access to a resource, but they will then use the resource in the way that brings them the most value. The beneficiaries in these two examples did not request swings or solar panels but accepted them as

[85] Users of systems that were privately purchased are not included in the data analyzed for this research; however, those with whom I spoke during the course of this study were demographically similar to the beneficiaries of donated systems. The ability of the system purchaser to improvise maintenance here implies that at least some beneficiaries would have the same capability.

potential resources. These resources they converted into things they needed more: shoes and money for food. Thus the focus of the hypothesis must shift from whether the system is "successful" by the definition used in this research to whether the beneficiary found value in what was donated.

Research question 2: Do donors and beneficiaries maintain a relationship? Does it matter?

The question of whether donor and beneficiary maintain a relationship became more nuanced throughout the course of this research. Other questions arose:

– *What is the nature of that relationship?*
– *What role does accountability between beneficiary and donor play?*
– *How long was the relationship maintained?*

Hypothesis 4: Unintended negative consequences due to donated systems decrease the likelihood of project success.

Sometimes overlooked by donors desiring to improve the lives of the rural poor, donated systems have the potential to negatively affect a community. Specifically, technologies may conflict with religious beliefs, cause changes in cultural norms, or cause or exacerbate social inequity. These consequences are hypothesized to decrease system success. In contrast, unexpected outcomes may be beneficial, as well. If a donated technology creates cohesion in a community or strengthens bonds within families because they spend more time together as a consequence of the technology, these positive unintended consequences may improve probabilities of system success.

These hypotheses and research questions, as well as my own implicit assumptions that I discovered during this study, are discussed throughout this chapter. As I describe below, what I found in my field investigations confirmed some hypotheses, but contradicted others.

6.3. Technical versus institutional issues

Although this chapter is intended to focus on institutions and relationships to the exclusion of technical issues, the distinction between the two types of issues is not as concrete as might be expected, as explored in this section. I start by illustrating this point with an example of a community and project observed in this research.

Don Alcalde[86] is town mayor in a community included in the post-conflict development program. *Don Alcalde* identified a problem with batteries on systems in his community as a technical one. He said they arrived sometimes working, other times not. Originally, when the community was working with the donor on a regular basis, the vendor was honoring its one-year guarantees on the batteries. However, since the donor turned the management of the project over to community committees, the vendor is not as responsive. If they complain of a problem, the vendor is slow to respond, often so slow that the guarantee expires before a battery can be replaced.

As *Don Alcalde* identified, this can be considered a technical problem. Good quality solar batteries will last three to five years if well maintained, and should last around two years if marginally neglected as long as they are not abused or subject to extreme climatic conditions. Batteries that systematically last less than one year fall well short of their design lives.

However, this case illustrates several institutional problems. First, the vendor was responsive to the donor but not to the community after the donor decreased its level of involvement. Vendors may have a vested interest in working with donors who give them repeat business for major projects, but little incentive to put effort into working with communities which are difficult to access and give only paltry and sporadic business. If the donor does not maintain a relationship with the community, the donor will not know that this is the vendor's response in the long term. Further (although I do not believe this to be the case here, given my acquaintanceship with and knowledge of this donor), donors may not care what happens after their mandate of installation is complete; if a vendor is giving the donor the best deal for installation, the donor may care little about the consequences after its involvement is over.

[86] Names of communities and people are changed to protect confidentiality.

The second institutional problem may have to do with the community-based committee. Though community members report their problems to the committee, and the committee either does or is believed to give its best efforts towards resolving problems and working with the vendor, the committee does not have experience in negotiating the warrantee replacement process at the outset of the project. Most things of this nature require paperwork and record-keeping. Most donors probably keep records of bills of sale and dates of installation, where community members often have low levels of literacy and rely very little in general on written records – and therefore may be less likely to keep receipts and paperwork. Often, dwellings in rural Guatemalan communities have dirt floors and offer little protection from the elements; these are not conditions conducive to the preservation of paper even if households made a priority of it. A hypothetical vendor may see more legitimacy in the warranty claim for the replacement of, for example, "one of seven Trojan deep-cycle batteries installed by your company on 15 December of last year" than for "the battery I got when everyone got them, before last Christmas I think."

Guatemalan donors and in-country project developers all speak Spanish, as do representatives of PV enterprises in Guatemala. In indigenous communities, people may speak Spanish as a second language, creating difficulties in communications between the vendor and the community representative. Beneficiaries may not understand what is covered by a warrantee and therefore may make claims that the vendor is not contractually obliged to honor; the vendor may not understand the community's claims and believe that a legitimate claim is in fact spurious.

A third problem in this case has to do with the specific vendor involved. He and his company had been working in Guatemala for many years and had an ongoing relationship with the donor involved, and had been certified for quality by the U. S. government for its work with solar photovolatiacs in Guatemala (Ley, 2006). I was unable to locate him to interview him about donor project installations in which he had been involved. The "off the record" responses I got to inquiries among people in the donor community was that he had either gone underground or fled the country. Despite his prior reputation for quality, he had begun charging customers for first quality components but installing cheaper, inappropriate components instead. Using batteries as an example, he would bill for name-brand solar or marine deep cycle batteries, but install car batteries with their original labels covered. It was suggested that he made some enemies while he made a lot of money. This is clearly a technical problem of component quality, but it is also clearly a problem of the institutions – the vendor and the lack of oversight provided by the developer – and the people involved.

In this case, the overlap of technical and institutional issues is clear. The basic technical problem of low battery quality is rooted in the decisions of the vendor, the relationship between system users and community leaders, communication between community leaders and the vendor, and the nature of the ongoing relationships of the project developer with both the community and the vendor.

6.4. Institutional structures in Guatemala

In this section, I present the background of some of the institutional structures found in Guatemala that directly influence rural electrification. These institutional structures form the context in which my hypotheses and research questions about institutions and relationships are framed.

Although speeding is a punishable offense under the law, it seems to be "common knowledge" that exceeding the legal speed limit by five miles per hour on a U.S. freeway will not result in legal consequences; in fact, it seems rare that people travel at or below posted speed limits under normal conditions on U.S. Interstate Highways. In contrast, exceeding the speed limit by the same amount in a designated school zone may result in a traffic ticket. If these anecdotal observations hold true, they suggest that an understanding of *de facto*, informal rules is at least as important as understanding the letter of the law in travel on U.S. roadways.

In Guatemala, murder is of course illegal. However, only about two percent of murders are prosecuted.[87] During the course of this research, a law was enacted in Guatemala City requiring motorcycle and scooter riders to wear bright, reflective vests with the bike's license plate number clearly readable on the back. While I do not have any formal statistics on compliance, I can recall seeing only two of the hundreds or perhaps thousands of motorcycle riders I saw in Guatemala City who were not wearing the required vests in

[87] See Chapter 3.

the months immediately after the law was enacted. The fact that the more serious crime of murder was under-prosecuted did not translate to the expectation among motorcycle riders in the capital that the presumably more trivial law would similarly be unenforced.

An underlying assumption of this research is that the same distinction between *de jure* and *de facto* rules is present in Guatemala in general. Understanding the letter of the law is less instructive in these analyses than an understanding people's perceptions and knowledge of the law is enforced. Because of this, I include no formal study of Guatemalan civil or criminal law in this study of Guatemalan institutions.

6.4.1. Legal and informal governance structures

Guatemala is governed under a centralized government (U.S. Department of State, 2009 (2)). It is divided into twenty-two departments, which are further divided into municipalities. A municipality consists of a single city or defined community which is the seat of governance, and the population surrounding it (U.S. Department of State, 2009 (2)). Communities within municipalities are less well defined, both geographically and politically. A "community" may consist of some houses within a cluster, while neighbors interspersed may belong to a different community. Agrarian households without near neighbors may be ambiguously considered part of a nearby community for some purposes but not for others. Clusters of houses around a water source, a road or some other geographic division that are some distance from other clusters of houses may declare themselves independent communities with new names, without any formal legal process.[88]

Community-level governance in Guatemala is also irregular. Communities, however they are defined, may or may not have mayors, who, where they exist, have varying degrees of influence.

[88] I observed this twice during the course of this research, both related to the provision of grid-based electricity. The first instance involved a homeowner who had privately purchased a PV system. The national electric grid had reached the easily-accessible parts of his community, while the cluster of houses on a hillside was excluded because of the cost and technical difficulty of running electric wires over the terrain. Because the purchased system was outside the scope of this research, I did not explore this further within his divided community. The second instance involved a cluster of houses with government-loaned panels, set aside from the main community that had access to grid electricity. I was unable to explore the phenomenon here because I found myself followed by members of the Zetas drug cartel and left the area as soon as I became aware of their presence. The apparent phenomenon of grid electricity driving the redefinition of community merits further study, but is outside the scope of this research.

Anecdotally, *Junta Directiva*[89] (JD) is a common term for governance committees in rural Guatemalan communities, whether associated solely with a specific project or as a governance structure of the community. The term does not imply any specific makeup or form of governance, but is simply any "group that directs" a project or activity. On the other hand, a *Comité Comunitario de Desarrollo* (COCODE) is a legally-recognized community-level governing body, the activities of which are limited to development work. It is legally limited in its ability to collect tariffs and handle money, which limits its effectiveness in governing ongoing projects, however successful it may or may not be in bringing new development projects to a community. A *comité* is a legally-defined community-level management organization with specific powers and limitations, but the term is used colloquially to refer to less formal committee structures as well.

6.4.2. Institutional contexts

As described throughout this section, donated stand-alone PV systems in rural Guatemala exist within specific institutional contexts, many of which vary by program, project, community or even household included in this research. While the national Government of Guatemala is nominally the same, the way it relates to specific constituencies and they relate to it can vary, as observed when comparing outcomes among *Ladino* and indigenous respondents in Chapter 7. The national government also holds varying degrees of *de facto* control over territories that are nominally part of Guatemala, with parts of the country effectively controlled by *narco* cartels,[90] as described in Chapter 3 and in section 6.9, below. Further, the branch of government with which respondents interacted in relation to their systems varied, including donations by Ministries of Education and Health, the government loan program through the Ministry of Energy and Mines, the emergency response systems with CONRED, locally elected representatives to national or regional government, and the nominal general support for the post-conflict development and disaster relief programs. In most cases, the government was not the sole donor or project developer, and worked through NGO's. These organizations form part of the institutional context for systems included in

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[89] These definitions are gleaned from informal conversations with community members and development professionals. Specific citations of legal statues establishing COCODE's, *comités* and other forms of governance are less pertinent to this research than respondents' understandings of them.

[90] *Maras* (street gangs) are reported to have *de facto* control over sections of cities, but as these syndicates apparently operate only in urban areas, they are assumed to have little or no influence on rural energy outcomes, and as such are not further considered.

this research as well. I examine the results of the hypotheses and research questions presented in section 6.2, above, in the contexts of the individual institutional structures relevant to the projects included in this research.

6.5. Project governance

In this section, I consider the first research question, concerning project governance, presented in section 6.2. Projects were variously said to be governed by *Junta Directivas*, COCODE's and *comités*, or were "governed" by their users individually. I had initially hypothesized that the presence of a formal system of governance or project administration would correspond to greater project success. However, I was unable to test this hypothesis as both successful and unsuccessful systems were included from communities in which these governance structures were present, and in communities in which these governance structures were absent.

One of the most important functions of community-level governance of projects – and a function found ubiquitously in project governance structures encountered in this research – is managing economic resources to enable repair and replacement of components as needed. Globally, even households that exist on as little as $1/person/day or less rarely spend every dollar earned immediately on food or other very basic necessities, instead managing their money often by accumulating savings, paying down loans, or engaging in other formal or informal financial transactions . Thus the concept of a savings cooperative or a group lending program is not foreign, although its formalization may be less common. As savings was a function found in all governance structures included in this study, I cannot assess whether there is a relationship between system success and this function.

Similarly, the effect of the legal standing of a governance structure on success cannot be ascertained. Most respondents (81%, or 29/36) believed their governance structures to be legally established; I did not consult official records to corroborate this.

Because of research methodology, I am not able to compare the influence on system success of the various governance structures. Rather than examine the presence or absence of project-related governance as a driver of success, I looked instead at the participation of individual respondents in these governance structures. Among users of unsuccessful systems who stated that a governance structure existed for their PV project and answered the question of whether they personally participated, 56% (10/18) said yes. Similarly, 53% (9/17) of respondents with governance structures and successful systems were participants. Thus, active participation in available governance structures does not appear to influence project success.

Qualitatively, I may be able to draw some inferences by comparing the disaster relief program with the post-conflict development program. The disaster relief program had a categorically low success rate. The developer for that program reported that they aided beneficiary communities in convening "energy committees," and 79% (11/14) of respondents who answered the question of whether a governing body for their energy systems existed were familiar with the committees.

Although communities in the disaster relief program initially formed these governance structures under the guidance of the NGO, they were all dissolved within a few months or years after their establishment. When asked why they were dissolved, users seemed more at a loss to provide reasons that they should have been maintained. Any money that had been collected by the committees was returned to those who contributed it and, although it was not explicitly stated, the desire for access to the capital tied up in maintenance savings funds seemed to be the primary driver of their dissolution. Users saw no point to saving collectively when they could save as well individually, and saw no benefit to an energy committee once the savings were gone. One user described having dissolved the energy committee and returned its funds to users "because the crops failed." When asked why they did not re-start the savings fund once their economic situation became more stable, he merely shrugged.

In contrast, in the post-conflict development communities, a multi-level and highly organized governance organization was responsible for system maintenance, and for interaction with the donor, developer and vendor, as necessary. Communities elected representatives who served on the governing board of the project, representing both the community to the board and the decisions of the board to the communities. These representatives collected the monthly tariffs from their communities and delivered them to the board. Trained maintenance men were employed by the board to resolve technical problems for all beneficiaries who were current in their payments. The board's initial agreements with the vendor and project developer allowed some (though not all) parts under warrantee to be replaced if they were defective or malfunctioned prematurely.

This system was not perfect, of course. Respondents in one community dutifully paid their monthly tariff because they had agreed to do so, but thought they were re-paying a loan for the system rather than ensuring themselves access to maintenance, and as such maintenance issues in that community sometimes went unresolved.[91] In another example of a problem within this governance structure, one of the former board members is rumored to have looted the maintenance fund and attempted to use the money to go to the U.S. illegally. Although several respondents alluded to this, no one was willing to explain it in detail on record. I am under the impression that the would-be thief did not make it out of Guatemala and that all or most of the money was returned; I do not know what consequences, if any, he faced.

However, overall, the governance structure in place in the post-conflict development communities seemed to enable maintenance activities and facilitate contact with the developer and vendor, both of whom were able to aid the communities in keeping their systems operational at least to some degree. The formal structure seemed to create a social pressure to live up to the obligation undertaken by beneficiaries of making payments for system maintenance. The representative nature of the structure – not every household was required to be actively involved or particularly knowledgeable about either the maintenance or the administration of PV systems – reduced the knowledge and time burdens on heads of household.

The disaster relief program and the post-conflict development program were both implemented among similar populations – indigenous, very poor and rural – under the direction of the same NGO,[92] but had

[91] The community representative who introduced me to interview subjects took this as an opportunity to clarify that they were, in fact, entitled to maintenance support.

[92] *Fundación Solar*

very different outcomes. The persistence of a governance structure in the post-conflict development communities is a major differentiator, which seems to accompany project success. However, even if the governance structure did lead to success, other factors including relative geographic and social stability (systems were not installed in the immediate aftermath of a disaster), the longer implementation timeframe, and the continued relationship with the NGO may have aided in or been prerequisite to the persistence of successful governance structures.

A final observation with regards to success and community-level project governance comes from the national government-run flood early warning systems program. These systems were governed entirely by a body outside the community, but were categorically the most successful systems included in this research. Thus these data do not appear to support the hypothesis that the creation of community-level governance institutions leads to project success, though the persistence of consistent governance, whether legally established or not, and whether within the community or by an outside party, may increase the chances that projects will be successful.

6.6. Project origin and training

"Any engineer can construct an irrigation system, but using the system to grow food is another matter altogether." (Maren, 1997).

The physical installation of a system does not imply that the system has been "implemented" in the society and culture into which it has been inserted. This section examines the roles of beneficiaries in project origination, whether and how they were "socialized" to accept and use the systems, and the degree to which they received training to build the skill sets needed to manage and maintain the systems once the donor or developer left the community.

6.6.1. Project origination

As stated in Hypothesis 1 in section 6.2, I hypothesized that projects would be more successful in communities which originated projects than those in which the projects were proposed or imposed by outside parties. As explained in this section, this hypothesis is not supported by these analyses.

Respondents were asked whether they were informed and consulted throughout the planning process, independently of involvement in implementation. Seventy of the seventy-nine (89%) responses to that question were affirmative or "more or less": people were informed and consulted throughout the planning process. One did not know. Unexpectedly, the eight negative responses (which ranged from "not much" to "not at all") are not clustered. They are in seven communities spread across six different departments, represent five different categories of projects included in this study, and were all in communities in which other users had responded to the contrary.

The affirmative responses that include some explanation specifically mention activities pertaining to requesting the project (if the project was initiated by the community), or they generally mention "meetings" or "socialization." Meetings and socialization, often conducted by the donor or developer, may take place after the project has been decided upon by people outside the community and funding has been confirmed. Thus the planning process in which the communities may have been involved was the planning of the implementation of projects that had been decided on their behalf. Those answering in the negative may have been alluding to the fact that they were excluded from the process of planning whether the project would happen at all.

I hypothesized that those not involved in the planning process would be more likely to be owners of unsuccessful systems, but this research does not support that hypothesis. Respondents who claimed to have been little involved in the planning process were categorically not the owners of unsuccessful or non-functioning systems. One respondent commented that he opted not to participate because there had been no socialization before he was asked to sign up: he did not have enough information to make an informed decision. Among the seven negative respondents who did participate, five had successful systems, and the two unsuccessful systems were functioning but are considered unsuccessful for purposes of these analyses because respondents considered them insufficient to meet their needs.

Respondents who stated that they were not involved in the planning process seem to have been no less informed or involved than their neighbors, but instead seem to have had higher expectations of the appropriate level of involvement. The respondent who declined to participate clearly recognized that participation created obligations for beneficiaries. Those who did participate appear to have recognized that as well, as they were willing and able to take the actions necessary to keep their systems functional.

Fundamentally, asking respondents how involved in planning they felt appears to be a poor measure of their actual level of involvement, but rather is a stronger indication of their desire to be involved and informed; those who most wanted to be involved and informed may have simultaneously been those who participated most and those who felt their level of participation was least adequate. The relationship between level of participation in planning and system success cannot be assessed from these data as the survey question did not measure level of involvement as was intended. Some of the stories of how beneficiaries came to participate follow.

6.6.1.1. Disaster relief systems

A few people who looked like me showed up with a solar home system project unsolicited, according to one respondent in the disaster-relief program.[93] This response gave very little information about the facts of the project origin, but it provided considerable insight into the relationship between the donor and that particular beneficiary. Some projects arrived from "outsiders," people with no ties to the communities and probably foreigners. The beneficiary's knowledge and memory of the developers was so superficial that he remembered only that they were fair skinned compared to most Guatemalans. From conversations with one NGO employee who was active in the development of the project, my impression is that the relationship was mutual. The NGO had the time and resources to do little more than install panels, not build relationships.

[93] I was asked to confirm that I was not in fact a person who had been there when the project was initiated.

The disaster-relief program, as described above, was implemented in a very short timeframe. The push to rebuild within the one-year funding timeframe meant that "outsiders" were making decisions without thoroughly understanding community needs and wants. It is possible that the communities would have come to the conclusion that electric lighting was one of their basic needs, but they were given the opportunity only to say yes or no to a project conceived without their input. In some cases, the decisions of the development organizations were good: the new stoves were still in use and valued by the communities nearly ten years after implementation. In other cases, the decisions were not as good: the solar home system component of the project was a near complete failure.

Ten of the 20 respondents in the seven communities interviewed about the disaster relief program remembered the name of either the multinational development organization that managed the project in its entirety, or the name of the local NGO that implemented the PV part of the project.[94] Most remembered little else. Five mentioned other aspects of the project, like the provision of seeds and building of improved stoves. Only one believed that the community had initiated the project, and one said that they negotiated to have panels included in the project after the multinational had provided crop seeds and improved stoves.

Only four of the twenty systems met the definition of success in these analyses, despite efforts to find working as well as non-functioning systems in the relevant communities: systems that were still functioning were in such a minority that they were challenging to find. Two respondents were non-participants in the program: they were offered the opportunity to participate but declined. Respondents with successful systems, unsuccessful systems, and non-participants gave equivalent answers to the question of project origin. Most remembered little, but did not view it as something the community initiated. In this case, system success was not influenced by users' perceptions of whether they (as opposed to someone else) initiated the project.

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[94] "*Cáre*," or Care International, and *Fundación Solar*, respectively.

6.6.1.2. Post-conflict development

The first phase of the post-conflict development project was for widows and orphans of the civil war. Some respondents reported that the community initiated the request in the names of widows and orphans, while others gave the impression that the first phase of the project was initiated by people outside the community. Everyone who mentioned the second phase agreed that the community or its representative (the mayor) initiated the request for solar home systems for everyone else in the community after the widows and orphans had received theirs. Responses of those with successful systems did not differ in this regard from those with unsuccessful systems: again, there is no apparent relationship.

6.6.1.3. Government loan/donation program

Of the thirty-five interviews regarding projects in the government loan program, eleven respondents said they requested it, and eight said the municipal mayor (who is located in the central municipality, not the communities in question) requested it on their behalf. Nine reported that someone outside the municipality initiated the project. The remainder did not know or answered ambiguously.

As with other groups of projects described in this chapter, responses were not necessarily consistent: within the same community, different respondents attributed the initiation of the project to different actors. Looking at this subset of 21 interviews (interviews with people in communities that were not unanimous about project origin), we see the results presented in Table 4.

Count of successful and unsuccessful systems	Who initiated		
	Self	Mayor	Other
No success	2 (40%)	2 (40%)	1 (20%)
Success	5 (31%)	4 (25%)	7 (44%)

Table 4. Successful and unsuccessful systems, based on project initiator

Because of the small number of systems included in this subset and the sampling methodology, valid statistical inference is not possible but trends might be observed. There is no clear relationship between success and the perception that the project was initiated by users, by their representative, or by an outsider. Thus, independent of the actual originator of the projects, user perceptions of their own agency in acquiring the systems once again does not appear to influence success.

6.6.1.4. Other systems

For the most part, the remainder of projects included in this study were initiated by someone other than the user. The EWS projects and the community school and clinic projects were initiated by the government, with the former being categorically successful and the latter being categorically unsuccessful. Other productive uses projects, such as tourism projects, are normally directed from the outside: rural community members usually do not have the knowledge and experience to cater to tourist demands at the outset of the projects. These were neither categorically successful nor unsuccessful, and do not lend insight into the impacts of donor (as opposed to beneficiary) project initiation.

Thus, this research does not support aforementioned Hypothesis 1: users' perceptions of their participation in the origination of their projects are not shown to influence project success.

6.6.2. User training

As stated in Hypothesis 2 in section 6.2, I had hypothesized that systems would be more successful among respondents who were trained in the maintenance of their systems. Among users with unsuccessful systems who responded to the question of whether training systems had been offered, 45% (23/42) said yes. Among users with successful systems, 64% (27/42) answered in the affirmative. Thus training does appear to be linked to system success. A closer examination of the data brings a more nuanced picture of this apparent link.

6.6.2.1. Unsuccessful training in disaster relief communities

Iván Azuria of *Fundación Solar* (Azuria, 2006) was actively involved in the implementation of the solar home system portion of the disaster relief program included in this study. He stated that *Fundación Solar* provided training to community members at the time of project implementation. Thirteen of the fourteen respondents from these communities who answered the question agreed that training was provided. However, these systems were nearly ubiquitously failures.[95] Comments on training from the respondents in these communities were illuminating. Among the ten users who commented on the sufficiency of the training, eight said the training they received was not enough. One said she was told during training that she should expect her panel to last four years; since panels of the kind installed in these communities typically last 20 to 25 years, I find it exceedingly unlikely that this was the information given by *Fundación Solar*. It is far more likely that she misunderstood something said in the training, illustrating clearly that the training she received was not sufficient for her. Respondents in this program suggested that they did not understand their systems well enough to be successful with them in the long term, which is part of the reason they were easily convinced or coerced to sell them, as explored in detail in section 6.9.2. "If it (the training) had been enough, we wouldn't have sold," reported one.

Removing the systems in the disaster relief program from the data, the apparent association between training and success is stronger. Among respondents with unsuccessful systems, only 24% (7/29) knew of or participated in any training related to the system, compared to 63% (26/41) of respondents with successful systems.

6.6.2.2. Participation in training

Only the post-conflict development program established structures in which local participants were designated as "maintenance men" and given specific training with that in mind. As this is only one of many categorical differences between this program and the others included in this study, it is not possible to say whether the local maintenance man influenced system success.

Among all systems included in this research, many respondents said the training wasn't universal, pertaining only to committee members, maintenance men or select members of the community: 42% (8/19) of respondents who commented specifically on who was invited to attend training sessions said that the training was reserved for a select group. Less clear was whether the training sessions were open to women

[95] Sampling methodology prevents me from reporting percent of successful systems in any program, but among the 18 respondents from these communities, I was able to find only four with successful systems despite actively seeking them.

in the communities. One woman stated that she attended training sessions only when her husband was unavailable. In a different community, a woman reported that women were not invited. In other communities, people stated that "everyone" participated, sometimes explicitly stating that women were included. Indigenous women and older or more marginalized men, some of whom understand less Spanish, may have been *de facto* excluded from training because of a language barrier.

A participant in a community in the disaster relief program observed that, while women were invited, they rarely participated in meetings or training associated with the project. He stated that their household work tended to take higher priority for them. He also commented on the cost of attending training, as sessions were held in centralized locations and people from other communities might have to take buses to attend. The juxtaposition of these comments suggested to me that women either had less access to funds for travel, or that they prioritized other expenses over attending meetings. These attitudes towards women were consistent with the generally *machista* culture I observed in Guatemala. "Everyone" in many cases meant "all men;" in communities who included women in project activities, respondents often spoke of it as if it were unusual.

6.6.2.3. Training content and participation

When asked about the content of the training, those who attended largely responded vaguely "maintenance" or "use." Those who were more specific generally remembered the most critical and frequent maintenance activity: check the water level in the battery regularly. Most knew that they should use distilled water purchased at a gas station.[96] Some also mentioned cleaning panels or battery terminals, with a few noting specific issues like "the safety of the children" and not confusing positive and negative terminals. One remarked that members of his community were instructed not to chop a battery with a machete.[97]

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[96] Many users who followed the training and tried to purchase distilled water were convinced by vendors that they should use a commercial electrolyte, calling it colloquially "Red Bull for batteries." Trainers had not specifically told users that this was an unnecessary expense as distilled water would function equally well. The idea that a North American energy drink would be well known enough to have meaning as an analogy in rural Guatemalan villages, while striking, is not explored in this research.

[97] In an example of why local knowledge is critical to appropriate training, this was advice that the user regarded seriously but is something that never would have occurred to me to mention.

Training was clearly not understood by all, since some respondents were mistaken about very basic information, as illustrated by the woman who expected her panel to last only four years. People in other communities who received training under the same program did not share that misunderstanding; while the trainers may have been giving the correct information, they did not ensure that it was received, understood and remembered by all attendees.

Users in the disaster relief and post-conflict development programs reported receiving some training in accounting and management as well, in the interest of forming maintenance or administrative committees. The utility of this training is difficult to gauge. In the post-conflict development program, both administrative and technical training were aimed at project leadership committee members, so most users were little aware of it. In the disaster relief program, collective maintenance or administrative committees were rapidly abandoned either because they were viewed as pointless, or because maintenance moneys initially collected were returned to contributors when crop failures left people hungry one to two years after the initiation of the projects.

Training content was not considered sufficient by many, but why users considered it insufficient is unclear. Among users who commented on the sufficiency of the training, 68% (8/13) who were owners of unsuccessful systems said that they believed that they needed more training or were unsure if they needed more training; 63% (9/15) with successful systems said the same. This suggests that the perceived sufficiency of the training is not necessarily related to the level of training actually needed for successful systems. Possibly, those who perceived their training as insufficient were merely those who were more interested in the topic or those who wished to have sufficient training to learn a job skill in the area rather than merely being able to maintain their own families' systems. Those not satisfied with the training wanted training to be available to more people or more understandable, wanted more information on the topic of solar energy and system maintenance, or wanted a review of the original training as people had forgotten needed information in the years since the original training. Three wanted training on topics other than solar energy, with one happy to attend training on any topic offered.[98]

It seems "common sense" that providing documentation of necessary maintenance activities would increase the value of training by serving as a reminder of topics covered. However, the literacy rate in Guatemala is officially 69% (CIA, 2009), but anecdotally much lower in rural communities – calling into question the utility of written documentation. Some organizations instead use pictorial instructions or combined pictures and words to educate rural populations in Guatemala.[99] To my knowledge, the effectiveness of this sort of documentation has not been rigorously tested and has been called into question by some development professionals.[100] While outside the scope of this research, this topic should be studied further.

In summary, Hypothesis 2 detailed in section 6.2 is partially supported by this research. Users of successful systems were more likely to have been aware of training opportunities at project inception or implementation, regardless of whether they personally attended these training sessions. The perception that the training was sufficient was not a driver of system success.

6.6.3. Summary: project initiation and user training and success

Both the most successful program – the early warning systems – and the least successful program – disaster relief – included in this study were initiated by someone outside the community. Some beneficiaries in the other programs played a role in initiating their communities' participation in already existing programs and these data do not allow conclusions to be drawn about the influence of that initiation on success.

People generally considered themselves to have been involved in the planning process if there were any meetings before installation, even if they were not invited to participate until the major decisions had been

[98] This comment suggests many questions about the development paradigm under which systems like these are donated, but is a topic outside the scope of this research.

[99] For example, I observed a poster in a health clinic that used both pictures and words to convey its message about AIDS prevention.

[100] Anecdotal.

made. Reported involvement in project initiation cannot be related to system success from these data as the question of perceived involvement did not measure actual involvement in the planning process.

Most beneficiaries knew about training taking place, even if they themselves did not attend or were not eligible to attend. Those whose systems were successful were more likely to have known about training opportunities. This suggests that publicizing training within the community is important to system success. Perceptions of training being “sufficient” were not drivers of system success.

6.7. Ownership, accountability and donor relationships

Questions about the relationship between system ownership and success emerged as a result of this research. It is accepted as fact that beneficiaries who invest in and have ownership of projects will maintain them, while projects that are wholly donated or belong to someone else will be neglected.[101] While I began this research with this implicitly assumed to be true, this study does not support this assumption. Instead, it suggests that users who are accountable to “someone else” for the operability of their systems have higher success rates than those who are accountable to no one but themselves, as described below.

The question of who owns a project that has been donated to a beneficiary is not necessarily straightforward. In some cases it is clear: some systems are agreed to be the property of the user; others are unambiguously the property of “someone else” such as a government agency. However, hybrid ownership arrangements exist and in some cases ownership is ambiguous or contested, as described in this section.

In this section, I explore the effects of accountability, ownership – and, importantly, perceptions of ownership – under the various projects included in this research, as well as other projects I observed but were not explicitly part of the data collected.

[101] Found in guidebooks for development professionals such as “Solar Photovoltaics for Development Applications” (SAND93-1642), (Shepperd and Richards, 1993) and many others.

6.7.1. User contribution and ownership

In development, it is apparently ubiquitously believed that a contribution by beneficiaries to a donated project will increase beneficiaries' sense of ownership of the project and therefore lead to better project success and outcome. Though I have heard debate about the appropriate level and type of contribution to expect, the consensus seems so complete on the underlying assumption that developers seem to forget that an assumption is being made: that a feeling of ownership in fact leads to success.

However, I examine here the hypothesis that a user contribution to a stand-alone solar electric system in rural Guatemala will lead, whether directly or indirectly, to system success. Contrary to "common knowledge," the hypothesis is not supported by this research.

Among users who responded to the question of whether and what sort of contribution they agreed to as part of the implementation of their systems, 20% (8/40) of users of successful systems said they made no contributions, and 19% (8/42) of users of unsuccessful systems said the same.

Viewing user contributions of money specifically, only 10% (4/40) of users of successful systems contributed capital, compared to 19% (8/42) of users of unsuccessful systems. Looking at capital, materials and transportation cost contributions combined, the picture is much the same: 20% (8/40) of users of successful systems were asked to contribute capital, materials or paid transportation, 26% of users of unsuccessful systems were asked to make those contributions. While the number users asked to contribute money is too small to draw definitive conclusions, they certainly do not support the firmly held belief that paying for something will make users take better care of it.

Some respondents reported that they contributed labor during the installations of their systems: 53% (21/40) of users of successful systems and 36% (15/42) of users of unsuccessful systems reported that they or other members of their communities worked to varying degrees on the installation of their systems. The contribution of labor may have been more of an investment than monetary contributions to the beneficiaries, supporting the idea that beneficiary contribution leads to success. However, it is perhaps equally possible that those who contributed labor learned more about the systems initially and were therefore more able to maintain them over time.

Other small contributions were asked of beneficiaries, including meals for installers and, in one case, the beneficiary's vote in an upcoming election. Three respondents each among successful and unsuccessful systems stated that they were asked to contribute but did not specify the contribution.

This remarkable result merits further investigation: between those who were successful and those who were not, users were asked to contribute to their projects in about equal numbers (~80%). However, those that succeeded were more likely to have contributed labor than those that did not succeed, and the unsuccessful projects were more likely than the successful project to have provided a monetary contribution.

6.7.2. A question of accountability

This research is not structured such that it can explicitly and quantitatively test the hypothesis that ownership in some way leads to success. However, the pervasiveness of the belief and evidence suggested by this research make clear the urgent need to test it.

Some inferences may be drawn about the question, even if no statistical data can be analyzed (each is discussed in more detail in subsequent below that deal with ownership types). Both the most successful series of projects – the early warning systems – and the least successful – the government-provided systems for schools and clinics – were unambiguously perceived by their users to be owned by "someone else." The reasonably successful post-conflict development program and the categorically unsuccessful disaster relief program involved systems that were owned entirely by the users. These dichotomies alone suggest that ownership, if it is a driver of success at all, is so weak compared to other factors that it is not clear whether ownership by users helps or hinders project success.

In contrast to ownership, a clear theme that emerges from this research is accountability. Users in both of the more successful examples above maintained a relationship with the donor that was imposed by the donor, whether welcomed by the communities or not. The donor or perceived owner in both of the less successful programs never questioned users about the states of the systems after initial installation. Accountability to other members of the community, as was the case with microhydro projects I observed during this research but which are not considered explicitly in the data, similarly seemed to accompany project success.

In weighing ownership and accountability as drivers for care or maintenance of a thing, I applied the concept to myself and a substantially expensive item that I use: an automobile. If I rent a car and purchase the accompanying insurance, I have no motivation whatever to care for it. There are no consequences to me if the car is damaged: financial, social or otherwise. However, if I drive my own car, the consequences of damage fall only to me: I have to choose between paying out of pocket, submitting an insurance claim if the damage is covered, or living with a dent in my car until I can afford to fix it. When money is tight, the last option is the one I choose, or I can simply sell the car with the damage. If I borrow a car from someone I know, I am incredibly careful with it. Here, I am faced with personal, social and financial consequences if I damage the vehicle: I will feel bad for having abused the confidence of the person who loaned me the car, I face potential loss of trust or other social capital with the car's owner, and I will have to pay monetarily for the damage, whether directly or through my insurance premiums. Inaction – fix it later when I can afford it – is proscribed here where it is my choice when my own car is the one damaged.

Thus in examining my own case, I realize that ownership is not the strongest motivator for maintaining this substantially expensive and arguably necessary (or at least incredibly convenient) item. If the consequences to me are trivial, I may not make any effort to care for it at all. If the consequences are a loss to me alone, I will remedy the problem if I have the wherewithal, or do without if necessary. It is when I have the greatest degree of accountability that I am most motivated to take care: when I have fewest choices in remedying the situation, when the financial cost is highest, and when it hurts my relationships with others.

In examining the ownership structure of each of the categories of systems in this study in the remainder of this section, I examine the issue of users' accountability as well. I do not propose that respondents' motivations mirror mine, but I propose that knowing the ownership status of a system gives much more information when the consequences to the user of system failure are also known.

6.7.3. Uncontested beneficiary-owned projects

Both the post-conflict development program and the disaster relief program included in this research involved donating systems in their entirety to beneficiaries. These two projects had very different outcomes, with the development projects succeeding at a much higher rate than the relief projects.

In visiting the communities that participated in the disaster relief program, the most startling observation I made was that there was a remarkable dearth of panels visible on houses that had been beneficiaries of a solar home system donation. Respondents in these communities were unanimous in stating that many or perhaps most of their neighbors had sold their panels within one to two years after installation, and many within the first few months.[102] The specific circumstances that surround the buyer for most or all of these systems are detailed in Section 6.9. Here, I note only the influence of ownership on the situation. Community members owned their systems outright without obligation to anyone, legally and ethically allowing them to sell the panels or complete systems.

The choice to sell was enabled by their perceptions of ownership. If the systems were owned by "someone else," selling them would be stealing, legally, and presumably ethically in the communities included in this research as well. Systems or partial systems that have been sold do not meet the definition of success in this research, so this is one way in which ownership may actually depress success rates.

Even users who own their systems can have a sense of accountability, which might influence both selling and maintenance decisions. *Fundación Solar* was involved in implementing both the disaster relief and post-conflict development programs. In both programs, *Fundación Solar* helped beneficiary communities set up savings and maintenance cooperatives to govern the projects. In the post-conflict development program, all beneficiaries were initially invited (or nominally required) to join a multi-community

[102] Respondents were unable to suggest clear or consistent numbers or percentages of systems that were sold.

governance and maintenance structure. Most, but not all communities remained involved and most, but not all members of involved communities are associates of the organization. Conversely, the governance structures established in the relief program were dissolved shortly after inception, as discussed in section 6.5. Rules continued to exist in the former case but not the later, and the near universal participation in the post-conflict development program suggests a degree of social pressure to conform. One of the few people who did not participate in the governance structure in the post-conflict development communities was the lone respondent in these communities who was not aware of the project in advance of its implementation, suggesting that he was already marginalized or isolated and therefore perhaps less subject to the social pressures that might encourage adherence to the rules surrounding the systems.

Further, the NGO that was the primary implementer of the solar home systems in both projects has a long-standing presence in the region of the post-conflict development projects, but not where the relief projects are located. Although few individuals in either program claimed to have access to the NGO, members of the NGO claim that they have maintained an informal communication with the governance/maintenance body of the development projects. There is then an informal and weak accountability to the NGO, just in that the project is at least casually watched, although the NGO has no right of sanction against the project if they do not approve of circumstances or decisions. An elder in one of the communities suggested that the community had hopes of further projects with the NGO. From this I infer that they would be motivated to impress upon the NGO that they are capable of maintaining projects to the NGO's standards.

A broader definition of success might be needed to judge whether systems owned wholly by users were, in fact, successful. As described above, respondents who felt they had 100% ownership of their systems and had no accountability to others as far as the systems were concerned sometimes sold the components of their systems. They obviously valued the cash income from the sales over the utility of the systems themselves. Having an asset to liquidate when they needed cash might be a highly successful outcome for some users – especially among the very poor who may have used this money for food and other more basic necessities – whereas it falls outside the definition of success used in this study, which is fundamentally the provision of adequate electricity into the indefinite future.

Although respondents in these two programs have equal legal ownership of their systems, they have different degrees of accountability to the developer. They also have very different degrees of success.

6.7.4. Hybrid ownership

The Ministry of Energy and Mines was involved in a hybrid loan/donation program, as described in Chapter 3. In brief, MEM installed solar home systems in communities that were expected to be connected to the national electric grid within the subsequent three to five years. Batteries and lamps are owned by users, and users are responsible for their upkeep and replacement. Therefore the economic burdens of ownership fall to the user, just as they would with a donated system. However, the panel – without which the rest of the system is useless since few beneficiaries could reasonably be expected to replace it – is owned by an outside party (MEM) with the prerogative to take it away. Although the responsibilities of ownership are the same for these beneficiaries as for the beneficiaries of donated systems, they are accountable for the state of the system. They may have to answer for its status as often as twice per year, and if it is not maintained, they may lose a critical piece.

Respondents reported that MEM representatives visited irregularly rather than biannually as initially stated, and sometimes gave advice to households with inoperable systems rather than repossessing them. The director of the MEM program[103] expressed a seemingly genuine desire to help beneficiaries make use of their systems rather than punitively repossessing them. However, most respondents seemed to regard the threat of losing their panels seriously.

In other cases, beneficiaries are reported to consider themselves owners of the panels as well. No community reported that Ministry representatives consistently visited them twice per year, and some had not seen representatives since the projects were installed. Though no one would admit to it personally – nor would they direct me to the neighbors about whom they were talking – some respondents reported that they knew of people who had sold their panels. In another community, the Ministry requested the panels

[103] Byron del Cid, Director, PV Rural Electrification Program, Ministry of Energy and Mines

back from all beneficiaries when the national electric grid reached them. The community members refused because there were to be no consequences to the people who had sold their panels before the grid arrived. Though I spoke with only one household in this community (as it was grid connected and thus outside the scope of this research), they insisted that "all" of their neighbors had done as they had and kept their panels. The MEM representative who I asked about the unreturned panels told me that the cases were referred to the Guatemalan civil courts, but that the court system was so inadequate that the cases may never be heard, or would be considered many years in the future. I was left with the impression that the value of a used PV panel was less than the cost of taking action to reclaim it from an unwilling user or former user, but that this fact was unknown to communities where no one had yet refused to surrender a panel when it was demanded.

In this case, ownership is ambiguous. Some respondents firmly believed that the panels associated with their systems were their own, while others expressed concern about maintaining their systems so that the Ministry did not repossess the panel, which it owned. Though the Ministry had the legal right to repossess panels, it seemed to have no power to do so without the consent of the beneficiary.

Some communities in the hybrid program were very analogous to the communities in the full donation programs described above. Both types of households would equally lose the benefit of their systems if they were not maintained, but those with the threat of punishment – of having their system taken from them – succeeded at seemingly much higher rates. Startlingly, it was not the mere loss of the benefit that was the motivating factor: there was some other value that users gained from not having their systems repossessed. It may have been pride or social standing that was at risk: users would be embarrassed in front of their neighbors and the government agency if their systems were taken away. Or there may be some perceived value in having as opposed to using a solar home system.[104]

[104] As an analogy, I own sterling silver flatware, almost all of which I have received as gifts rather than purchased myself. I use it not more than two or three times per year – and then when my usual stainless would function equally well – and store it to avoid tarnish rather than having it on display. In addition to its use as silverware, I maintain a certain pride of ownership due to a family culture that values such things, and view it as a highly portable asset that could be liquidated in an emergency. Its value to me exceeds the utility of the teaspoons or the cash value of the silver: there is value in possession.

This hybrid ownership program provides two primary insights. The first is that the accountability that users felt towards MEM seemed to motivate them to keep systems in working order. The other is that the degree of accountability and perception of ownership differed in some communities, even though they were participants in the same program governed by the same rules.

6.7.5. Absent owners

Both the most successful and the least successful systems in this study were perceived by their users to be owned by "someone else," namely various Guatemalan government agencies.

As detailed in this section, the success of systems owned by "someone else" depended largely on the accountability users felt towards the owner. If users felt that they would be punished by the owner (by having the system removed, for example) if they failed to maintain it, or if users felt they could rely on the owner to offer some sort of support or advice for system maintenance, systems often succeeded. On the other hand, if systems were owned by "someone else" and maintenance was seen to be the responsibility of the absent owner, systems failed.

6.7.6. Implications

The remainder of this section reviews the implications of system ownership on the success of the different categories of systems included in this study.

Some cases agree with conventional wisdom on user ownership: "un-owned" systems can be un-cared-for systems. The fourteen government-donated school and clinic PV systems were chosen as a convenience sample rather than a purposeful sample: I did not seek out successful or unsuccessful systems of this type, but included those that I could locate in the areas in which I was traveling. Among these fourteen, only three are considered successful by the definition used in these analyses. Most were not functioning, and there was the common expectation that "someone else" was responsible for their upkeep. Employees of the Ministry of Energy and Mines, which is generally responsible for rural electrification using PV, were not aware of their existence or locations, so clearly did not take responsibility for their upkeep. The ministries of health and education, which users reported as the originators of the projects, did not offer resources to users to maintain the systems, and so presumably expected either the communities or the energy ministry to maintain them. Community members or parents of school children did not express the expectation that they themselves should contribute to the upkeep of the systems, and no institution or organization had been formed to ensure savings for maintenance.

The only category of systems that was 100% successful in this research was the series of flood early warning systems (EWS) owned by the Guatemalan government's disaster preparedness division, CONRED, as described in Chapter 4. Users had no ownership and almost no responsibility for maintenance. Although not 100% of systems were functional at the time of my visit, those that were not working had been reported to the maintenance group and were in queue to be repaired. Collaborators had played no role in planning or implementation, except to agree to participate. Users had responsibilities associated with having the systems, and gained community-wide benefits as well as personal benefits from having the systems in place.

These systems were owned by someone outside the community to whom users were accountable on a daily basis. This both allowed users to report problems immediately (or the absence of their daily reports alerted the system owner to problems) and required them to account for the states of the systems. Batteries in these systems lasted less time than would be expected for the type and quality installed (typically one to two years for batteries with expected lives of three to five years). This is likely due to battery over-discharge and failing to re-fill it with distilled water (one user collected rainwater for the purpose), and may illustrate a downside to the arrangement: without any incentive to maintain the battery and knowing that it will be replaced promptly under any circumstances, users are not motivated to maximize battery life, even if they are educated in how to do so.

The relationship with the system owner seems to drive success in cases of absent owners. Is "someone else's" system also "someone else's" problem, or are those deriving benefit also accountable to and supported by the absent owner? These examples show once again that it is not legal or *de facto* ownership that drives system success, but instead the institutions and relationships that support or fail to support system users.

6.7.7. Ownership and maintenance responsibility

Maintenance responsibility was generally thought by respondents to belong to system owners, except in the two cases described in this section. The first is under the hybrid ownership paradigm of the MEM-sponsored systems. The Ministry owned the panel and the user owned the balance of system components, including the battery. Users were responsible for the maintenance of the systems, including the PV panel, and the Ministry was unwilling to replace it if it degraded or was damaged.[105] For practical purposes, this still means that the system owner has responsibility for maintenance: the regular maintenance required for a PV panel is trivial and major maintenance is trivially rare, while battery and light bulb replacement are ongoing maintenance issues.

The post-conflict development project represents the only other divergence between users' sense of ownership and their responsibility for maintenance. The successful governance structures that persisted in the post-conflict development communities, described below – and in which most beneficiaries still participated – were responsible for system maintenance. Users who paid their monthly tariffs felt entitled to avail themselves of the services of the organization, but expressed the sentiment that their physical systems were their own and not collectively owned.

6.7.8. Institutional arrangements between donors and beneficiaries

The relationship between project donor or developer and beneficiaries differed among the categories of systems included in this study. On an ordinal scale, program success correlates to the length and frequency of donor involvement: projects that are dropped in place by donors who then disappear tend to fail, where regular or frequent donor contact tends to bolster project success. This correlation cannot be quantified for these analyses because sampling methodology does not allow me to calculate the percentage of systems

[105] Conversation with Byron del Cid, Ministry of Energy and Mines.

that are successful or unsuccessful under a particular category or program; this observation is discussed qualitatively in this section.

Projects owned and managed by the government in support of an early warning system required (and achieved) an ongoing relationship between the households where the systems were located and the government agency. This ongoing relationship ensured that the government knew when system maintenance was needed. The “donor” in this case also took responsibility for system maintenance; the system was not a financial, an administrative or a technical burden to the user. Users at the same time had a high degree of accountability to the donor for the few responsibilities they had – and to the communities depending on their information to prepare for flooding events. These systems were categorically the most successful observed during this study. Although sampling methodology was not appropriate to calculating percentages of systems operating in each category, every government-owned and managed system included in these analyses was operable or concrete steps were being undertaken to repair it. This category had both the strongest relationship between the project developer and beneficiaries, and the best success rate seen in this research.

The most categorically unsuccessful projects were those implemented under the disaster relief program, in which the donor and developer were required to complete all work within a one-year time span, from conception to implementation. Beneficiaries and the project developer concurred: there was minimal contact between developers and beneficiaries before and during implementation, and when the projects were installed and the relationship ended. This lack of relationship worked to the disadvantage of the beneficiaries. Users in different communities had very different understandings of the value, capabilities and limitations of their systems, some of them necessarily incorrect. Beneficiaries and developer both attested that limited socialization and training had been provided, and the developer maintained that the training was consistent between and among communities. Had there been an ongoing relationship with or follow-up by the donor or developer, misconceptions and problems could potentially have been resolved before systems were irreparably unsuccessful (most often because they were sold, in this case). Note that the ongoing relationship is not necessarily a financial relationship: the provision of information might be as important as the provision of funds for system repair. This seemingly obvious differentiation is more nuanced than it might initially appear. An ongoing relationship with a project developer or donor is necessarily a financial relationship on the part of the developer, as the developer must devote resources to employee time, volunteer logistics, communication with the community, or other expenses. The beneficiary, on the other hand, may view a financial relationship as being limited to whether the developer provides material or monetary support directly to the project or beneficiary. This topic merits further study, and is outside the scope of these analyses.

The post-conflict development program was more successful, and was implemented over a longer period of time with more ongoing involvement from the project developer than was the disaster relief program. The same Guatemalan NGO (*Fundación Solar*) assisted members of a group of communities to apply to the program that allowed the development of their solar home systems and helped to create a highly-organized collective maintenance organization made up of representatives of each community involved. The gradual addition of communities and households within communities to the program allowed the NGO to maintain contact with the original beneficiaries for a longer period of time than would typically be budgeted for such a project by staying involved with and introducing new communities into the collective maintenance organization. Even after the end of the formal relationship, representatives of the NGO continue to advise the local collective maintenance organization occasionally while they continued to work on unrelated projects in the area. *Fundación Solar* has had a presence in this area of Quiche for over a decade, usually through the local presence of one or more employees originally from the area. Though seemingly not as successful as the government loan program described subsequently, this category of systems was relatively successful.

In the government loan program, representatives of the Ministry of Energy and Mines maintained the right to inspect the systems they installed at any time because they maintained ownership of the panel, the most expensive part of the system. Although the Ministry did not have the resources to visit each community semiannually as intended (and some communities had not been visited by the Ministry in many years at the time of my visit, if they had been visited after installation at all), there was an ongoing relationship between beneficiaries and project developers. Beneficiaries in some communities expressed a sense of accountability to the Ministry, understanding that misuse or neglect of the system would result in loss of the panel. Although this program with its ongoing relationship between donor and beneficiary is estimated to have a better success rate than any other program studied except the government-owned and managed program, stronger relationships between individual communities within this program and the Ministry did not correlate to better success rates in those communities: the communities that qualitatively seemed to have very high rates of operability were the same communities that claimed never to have had their systems inspected by the Ministry.[106] There are several possible explanations for this. One is that the Ministry may have made more effort to visit communities that were likely to have problems or the communities themselves may have requested more assistance from the Ministry. Another possible explanation is that the least-visited systems in this program that were included in this study were coincidentally also those held by the wealthiest beneficiaries.

The Ministry of Education and the Ministry of Health donated systems for rural schools or clinics and provided no follow-up on those systems. Beneficiary communities generally did not have the knowledge or the means to maintain these systems, nor did they have the ability to contact the project developer. Community members attributed responsibility to "the government," the Ministry that installed the systems, or the Ministry of Energy and Mines, but not to the community itself.

When asked specifically about their personal relationships to the project developer, among respondents who answered, there was not an appreciable difference between those with successful systems and those with unsuccessful systems (56% and 60% respectively at least knew how to contact the project developer). This is likely an artifact of sampling methodology rather than evidence that the ability to contact the project developer is unimportant: both successful and unsuccessful systems were sought in communities included in this study, and responses within a community were fairly homogeneous.

[106] The communities in question, located in Cancuen, were, relative to the population included in this study, very affluent, which these analyses show to be linked or seemingly coincident with success (see Chapter 5).

Thus, for reasons of beneficiary accountability, ongoing donor support and perhaps other reasons, closer relationships between beneficiaries and donors led to better system outcomes.

6.7.9. Summary: Ownership, accountability and donor relationships and success

In this section, I summarize the results related to ownership, accountability and donor relationships. I begin with an example that typifies these results.

Don Típico is a homeowner in a community included in the disaster relief program. According to both the NGO and *Don Típico*, a local NGO implemented the project using hardware from a local vendor and performed trainings both on the physical maintenance of the systems and on administration and financial management. The community created a maintenance cooperative under the NGO's guidance, but at the end of the one-year project timeframe, everyone involved in project development left and never followed up.

Don Típico reported that their savings cooperative quickly fell apart, a fact echoed by everyone interviewed from the towns that benefited from this project. Systems fell into disrepair mainly due to lack of battery maintenance, which may be because users did not know how to maintain their systems or because they lacked the funds to do so (see Chapter 5). The majority of beneficiaries sold all or part of their systems.[107]

Don Típico readily affirmed that he and other beneficiaries had received both technical and administrative training. He affirmed that the training had been useful to him. When asked if the training had been sufficient, he replied "if it had been enough, we would not have sold them and we would still have light."

Fundamentally, those who own their own systems must manage them according to their own priorities. They face the consequences of their decisions, but do not face artificial or external sanctions for them. Paradoxically, system owners accept the loss of system use because they do not choose to maintain it, but

[107] Due to the sampling methodology, I am not able to say what percentage of beneficiaries sold their panels. However, in each of the communities that were electrified under this program, it was difficult to find households that had not sold. In one community, other community members reported that the only family who had not sold was unavailable at the time of my visit.

users of systems owned by others seem less likely to accept the loss of the physical system hardware by making the same choice against maintenance. Either would be left in the dark.

Institutional relationships between beneficiaries and donors or developers appear to be related to system success, independently of the above-mentioned issue of accountability. Communities with the least successful systems had short relationships with project developers that terminated after rapid implementation processes. The longest relationships – notably ongoing relationships without formal termination – seemed to lead to the highest system success rates. This relationship need not be one of continuous donation (i.e., the donor need not pay for maintenance or replacement of system components), but the exchange of information, ongoing accountability, and anticipation of future work with the same donor may be factors that lead users with established relationships with donors to have more successful systems.

The definition of success in this research is narrow: it requires the beneficiary to continue benefitting from electric power. As such, ownership or the perception of ownership, which affords the prerogative to sell, is a source of system failure. Whether users see themselves as owners or not, the institutions and relationships surrounding systems – from perspectives of both support and accountability – are far stronger drivers of success than is ownership itself.

This research does not show whether tangible contribution by beneficiaries creates ownership or the perception of ownership. However, it clearly does not support the hypothesis that beneficiary contribution to the project – especially cash contribution – leads to greater system success. While more investigation is needed to more fully explore this relationship or lack thereof, the prevalence of this underlying assumption in development work in general makes this an important result of these analyses.

6.8. Unintended consequences

In this section, I detail the results related to Hypothesis 4, detailed in section 6.2, regarding the effects of unintended consequences on system success.

Anecdotes from development professionals suggest that donation programs can cause conflict within a community, especially if community members are given unequal access to the project or the project is insufficient to meet the needs of everyone involved. Among projects with which I am familiar but that are not included in this study because they fall outside its scope, two communities that participated in a PV battery charging program in Nicaragua experienced problems when the first phase of the project included only one third of households. The households were chosen by community leaders to include their families and friends rather than on any objective criteria. The issue was "resolved" when a hurricane destroyed all of the systems that had been installed. In communities in both Nicaragua and Guatemala, micro-hydro systems have been installed by donors who failed to consider class stratification within the communities. Ability to pay an access charge or to contribute requisite labor hours to participate in the project has increased the divide between the "haves" and the "have-nots" in communities that may be easily considered homogeneous by outsiders. In a Guatemalan community where a substantial contribution of either labor or money was required to connect to the microhydro, one woman in a particularly poor household lamented she could not participate because God had cursed her with only daughters; she had no sons to either contribute the labor or earn the money.[108]

A grid-powered electric system (also not included in this research) that was to pump water to a clothes-washing station for members of two communities who previously washed laundry in an ecologically sensitive lake in Guatemala suffered repeated failures due to social issues. Initially, competition between communities for use during peak hours caused a great deal of conflict, as did use of the water for other-than-intended uses (leaving insufficient water for laundry), and the presence of men who used the site socially to interact with (and frequently interrupt) women doing laundry. Though these problems were thought to have been resolved by setting up a system of rules to which all agreed and providing training, only a few years passed before the system was again non-functional because the pipe from the water source to the laundry basins had been chopped with machetes past the point of repair. While this might be said to

[108] Project leaders stated that women could contribute time to lighter labors than men, but few chose to do so. This respondent was either unaware that she or her daughters could work, or found it unacceptable, or the nominal inclusion of women was poorly actualized.

be a technical failure (lack of piping) or an economic failure (insufficient money was available to replace the pipe), the problem is inherently social. Even if the resources to replace the pipe were available, the motivation to do so is small until the underlying problems that led to the vandalism are resolved.

I hypothesized that negative unintended consequences would decrease the likelihood of success of rural stand-alone PV projects. When asked about negative impacts of the systems included in this research, most respondents said there were none. Of the nine respondents who said the system did have negative impacts, none were claiming that the system caused bad things to happen, but stating that the systems did not produce enough electricity to meet their needs and wants. Answers to more specific questions lead to the conclusion that donated stand-alone PV systems can have negative impacts on a community level follow.

6.8.1. Cultural and religious conflict

With a single exception,[109] no respondent reported knowing of any religious conflict associated with systems in this study. This may be an artifact of people's general reluctance to talk about religion in public forums, particularly with outsiders and perhaps more so with people in the development community (Lunn, 2009). Anecdotes from project developers and observations of other energy systems suggest that it is a small – though not trivial – problem in Guatemala, where Catholics, Evangelicals and practitioners of traditional Mayan religions live side by side.

I found evidence of religious conflict associated with projects not included in this investigation because of resource constraints or because they fell outside the scope of the study. An interview with a project developer before the outset of the study indicated that it may be an important factor (Ley, 2006). She confirmed the facts of the case during a 2008 interview:

A U.S. government agency and a Guatemalan NGO were collaborating on the installation of solar home systems in a rural Guatemalan community with strong ties to a Mayan religion. Modern Mayan religions are descendent from pre-colonial religious beliefs. These religions are not homogeneous in their belief

[109] One respondent said the donated system was used only for religious festivals, which was not corroborated by other community members.

systems or leadership (there is no Mayan equivalent to the Catholic Pope). However, a shared belief across most or all is a deification of or deep reverence for the sun.

At the outset of the project, community civic leaders were included and consulted in planning, but religious leaders were not. The leader of the Mayan religious group in the community objected to the project when it was presented to him with the rest of the community. He argued that a thing such as a solar panel would hurt the revered sun, and he and his followers refused to participate. The issue became divisive in the community, with some strongly lobbying for the project and the benefits electricity would bring and others lobbying against on religious grounds.

Dialogue between the NGO, community civic leaders, and community religious leaders eventually led the religious group to allow and participate in the project, but not before religious concerns were addressed and the physical relationship between panels and sun was clarified. The underlying issue was much less that PV is fundamentally spiritually offensive to Mayan religion than that religious concerns were excluded from the origination and planning of the project. The religious leader's exclusion meant that initially he did not have grounds to judge whether the project was a threat to his religion, and this exclusion was unequivocally a threat to his religious leadership.

The then-head of the Guatemalan NGO involved in the project has since researched, written, and presented on the intersection of Mayan cosmovision and western technology (Azuria, 2006). From a developer's point of view, better understanding of this will lead to more successful projects (whether by using technologies acceptable to the community or by working in communities where the available technology is acceptable) and fewer negative consequences (like conflict within a community and project delays that divert developer resources from other projects). However, I believe this case demonstrates that developers without profound understanding of the religion or religions of the communities in which they work can help mitigate potential conflict by addressing the question to community members at the outset: if this community is to be electrified, what are community members' beliefs about the available options, and what information do they need to make informed decisions? The result may still be that the developer's ideas (or those of some but not all of the community) are unacceptable, but inclusion in decisions and understanding of options may minimize the possibility of rejection based on lack of information or exclusion, and lessen conflict within the community.

Conflict is not limited to religions outside the western mainstream. Another example of religious division in a project analogous to those included in this investigation (and visited during the course of this research) is the case that I've called the Catholic Hydro. Padre, a Catholic priest from the U.S., moved to a poor, remote, and indigenous area of Guatemala in the 1970s. Since then, his efforts have been focused on helping people maintain their linguistic and cultural identity while simultaneously embracing his religion and the modernization allowed by development projects under his direction. He performs mass in the local Mayan dialect and has translated substantial portions of Catholic texts. While I do not know that he has encouraged it, he has not objected to traditional religious practices such as the ritual sacrifice of chickens and turkeys at the outset and completion of Church development projects. "JR," a layman Catholic from the U.S. who moved to the diocese shortly after the priest and has been living there almost continuously since, assured me that the priest has an extremely loyal following.

JR serves as the technical expert and labor foreman on many of Padre's development projects, including the micro-hydroelectric project in a previously unelectrified town in the diocese. Since the initial construction of the hydro, the national electric grid has reached the community, but few of those connected to the hydro have chosen to switch to the grid. In detailed interviews with four community members and casual conversation with others in October 2008, only one stated that he believed there was conflict related to religion because of the project. When asked for more information, he declined to elaborate. The three others formally surveyed said there was none, and no one else mentioned it.

In a formal interview, JR explained the history and details of the project and his role in it, but did not claim any religious conflict existed because of it. After the interview was over and the recorder was off, he mentioned again that about one third of the community was connected to the hydroelectric project – and noted without elaboration that about one third of the community was Catholic.

Religious differences apparently kept the Evangelical Christian majority in town from benefiting from the electricity produced by the hydroelectric project before the grid arrived. Whether that was self-selection, a desire not to be associated with or indebted to the Catholics, or whether it was exclusion on the part of the Church or some combination of the two is not evident. Further, it is not clear whether the tangible benefits of being connected to the hydro (such as reduced energy cost) outweigh the disadvantages (electricity availability varies with stream flow, and is normally insufficient for some productive-use applications like carpentry tools) or if loyalty to the priest or church keeps Catholics from switching to the national electric grid now that it has arrived.

Although these two examples point to the potential for religious conflict in rural PV projects, it was not found in any community included in this study. It may not be negligible as a cause of failure of rural renewable energy systems, but it is not a strong driver for the failure of systems surveyed.

6.8.2. Inequity and conflict within communities

Donated solar PV systems have the potential to either increase or decrease inequity within communities, as explored in this section. Because the poor spend a disproportionate share of their income on energy sources, the poorest of the poor may benefit most from a reduction in energy cost, thereby reducing inequity within a community. Contrarily, if the cost structure[110] associated with maintaining or subscribing to an energy system are prohibitive to the poorest members of a community, then inequity is increased as the poorest are forced to continue to use sources that are, in the long term, more expensive.

I visited two sub-communities that were geographically removed from the majority of houses and buildings in the main community. In these, the national electric grid had reached the community and been extended to households close to the road or center of town, but more removed households were excluded. In each of these, I spoke with only one outlying sub-community member, who expressed frustration, and the tension between the outliers and the main groups was evident. Although the power company was blamed for the

[110] See Chapter 5, for a discussion of access to capital and other potential financial barriers to system ownership.

decision of which households would be electrified and which would be excluded, people in the outlying households suggested that they had been abandoned by the community at large once the grid had reached the majority.

In one of these communities, one household had privately purchased PV and was looking for donations to bring PV to the rest of the community, seeming confident both that the power lines would not reach them in the foreseeable future and that the main community leadership would not take an active role in advocating for them. In the other case, the outlying cluster of households had assumed an independent identity and a new name (not legally recognized), and requested and received panels under the Ministry of Energy program. The two households I visited that were in this situation had successful systems (the system purchased by the household is not included in the data in this research because it does not meet the selection criteria, but was remarkable that despite its age and very poor quality, it was still producing power), suggesting that the lucha fought by these splinter groups inspired them to work harder for the success of their electric systems. I wished to explore this hypothesis further by speaking to other beneficiaries in the group of households that had received panels in the second case, but I had come unfortunately to the attention of the drug cartel that controls the area and judged discretion to be the better part of research in this case. The hypothesis that an excluded group can have better than average success merits exploring in future research.

Almost a quarter of respondents (16/68) who answered the question as to whether everyone in the community had equal access to the project said no. However, answers to follow-up questions were more nuanced. Fifteen respondents said that some households who were eligible voluntarily chose not to participate, with most simply saying "they didn't want to," sometimes without elaboration.[111] Mistrust of the donor was a common reason reported for self-exclusion: people hear promises that never come to fruition from prospective donors, and so must choose carefully whether they wish to contribute energy, time, labor, or money to any particular project. Five mentioned cost as a barrier, some phrasing it as an

[111] Some respondents gave multiple answers.

exclusion (“if you couldn’t pay (the 30Q contribution), you didn’t get panels”) and others phrasing it as a choice (“not everyone wanted to pay”).

In other cases, seven respondents reported that some households had systems while others in the same community did not because houses without systems were built or occupied after the donor made the initial lists of beneficiaries. Many of these were said to be the households established by young couples who had newly moved out of their parents’ homes. However, in the disaster relief program, two respondents reported that people whose homes had been destroyed by the hurricane were excluded because there was no home on which to put the panel.

No community reported that the original donor had included more households after the initial list was made, or that the same donor had developed a second round of projects for new residents. Communities that asked donors to do this reported being ignored, with a single exception: in one community, MEM failed to bring sufficient hardware for all of the families it had originally listed. Members of the community went to the capital and petitioned MEM, which ultimately brought the remaining systems.

The consequence of donors not implementing additional systems in communities in which they have previously worked is a generational inequity that develops over time. As children grow up, most will leave their parents’ homes and start households of their own. These new households lack the advantages of the solar home systems donated to their elders. One of the children of the original system beneficiary can continue to benefit if he or she takes over the parents’ household, but the systems are too small to provide light to more than one house, even if the houses were very close together (and thus suffered fewer line losses).

Exclusions such as these that were either considered the fault of the donor or the option of the non-participant did not appear to cause conflict among community members. Two respondents who themselves opted not to participate did not express resentment and claimed that their self-imposed exclusion posed no problems for the rest of the community, even if it meant that they themselves went without light. However, in some cases, potential users were actively excluded from the project at the community level. Specific examples follow.

In one community, poorer households were excluded because families had been away working the sugar cane harvest at the time the donor made the initial lists. Respondents expressed resentment, but it was unclear whether the object of the resentment was the group of beneficiaries within the community, the donor, or life's injustices in general. It was not reported to and did not appear to cause or exacerbate conflict within the community.

Some people were actively excluded from projects, and the circumstances surrounding the exclusions were not fully disclosed. In one community, a man I call *Señor Iresponsable* vaguely said that he did not participate because the then-community leader knew he would lose the panel, so he was not included. He said this as if affirming the leader's claim that he was not responsible enough to keep a system, but did not wish to elaborate. A woman in the same community stated that a second round of battery donations (which contributed substantially to the success of the systems) favored some community members over others, which either caused or exacerbated tensions.

In another community, *Señora Fuera*, a woman excluded from a weaving cooperative that had solar lighting, said with apparent bitterness that the women in the co-op knew she was too busy and so they didn't bother to ask her to participate. The head of the weaving cooperative saw me talking to the excluded woman and, appearing angry, interrupted to end any conversation between us. The conflict between these two women (and perhaps others) was clear, but is unlikely to have been caused or substantially aggravated by solar energy.

In both of these communities, the exclusion of these community members did not adversely affect project success: the weaving cooperative seemed highly successful in all regards, including the energy system, and the rate of success of systems in *Señor Iresponsable's* community seemed to be on par or a little better than the rates in other communities that received panels under the same program.[112] It is possible that exclusions actually increase the percentage of successful systems in a community. If *Señor Iresponsable* in fact had a lower probability of caring for his system, then his inclusion would have lowered the percentage of successful systems there. If the inclusion of *Señora Fuera* would have caused conflict within the cooperative, it and its energy system might have failed.

Since the excluded parties seem to be members of poor or otherwise marginalized minorities, they may not have the power to disrupt the functioning of the program or systems, regardless of their resentment. Though these exclusions might increase the number of successful systems relative to the number installed, the social cost of doing so may be very high. The societal impact of increased inequity is outside the scope of this study, but cannot be ignored.

6.8.3. Inequity and conflict between communities

Because this study examined only communities in which stand-alone PV systems had been installed, nothing can be concluded about any tensions that may have caused between beneficiary communities and nearby communities which were excluded from the project. However, one project observed in this research did create tension between members of adjoining communities, as follows:

One project was related to an archaeological dig that was simultaneously an active scientific excavation and a tourist destination. The inter- and intra-community conflicts and alliances that have arisen from this arrangement, which were mitigated at the time of my visit perhaps only by a downturn in tourism that left little to fairly or unfairly divide, are worthy of study unto themselves, although outside the scope of this research.

"Several" years ago, three communities surrounding the archaeological dig petitioned the primary scientist in charge of the excavation. They claimed that the dig was a part of their cultural heritage and found it unfair that he, a foreigner, should benefit from it and they should not. According to community members,

[112] Because of sampling methodology, precise rates of success by community or by program cannot be assessed.

he readily assented and helped establish the tourism aspect of the site. It was structured such that the scientists could continue their work unabated while the community members served as park rangers for the site, transported tourists by boat from a location easily accessible by road to the site on the other side of the river, and opened a small restaurant to serve tourists. The scientist paid for or arranged for funding of the initial capital investments while the community members contributed labor and later paid the salaries of rangers and other participants through admissions fees and revenues from the restaurant. The interest of this research in the project are the PV systems that are used to power lights in buildings intended for visitors and the two-way radios that the guard/guides use to communicate in their work.

Conflict and resentment developed quickly within each community as only a few community members were selected to serve as guides and rangers, and therefore received financial compensation for that aspect. The wives of the rangers were those called upon to cook for tourists, as the need arose, further reinforcing the income streams to few households at the expense of others.

However, resentment between communities was apparently greater than any in-community conflict. This resentment stemmed from transportation to the site. A road easily navigable by vehicle ended at one of the communities. A store owner near the entrance of the community had a stand-alone PV system installed on his home/shop. Nominally, this was to power the radio to alert the rangers and guides that visitors were on their way, and it was used in that capacity. However, it was also used by the store owner to power his household and shop. People in other communities expressed resentment that he should be the only private individual to benefit from a solar panel intended to help three communities. This shopkeeper charged visitors for a boat ride to the archaeological site. According to members of other communities, his was the only boat and motor available for this purpose, so he held a monopoly on site access. Once being dropped off by boat at the archaeological site, tourists are asked to pay for admission to the site. Rangers expressed frustration that the boat owner consistently failed to make this clear, leading tourists to believe that the boat fare also included site admission. Upon arrival, tourists are immediately frustrated at being “charged twice” for access.

Overall frustration among members of these communities was high. First, an economic downturn had reduced tourism to the degree that there were few proceeds to distribute among all participants. Second, community members who were not employed by the project resented that their neighbors benefitted where they did not. And third, all respondents from the two communities that did not have boats to transport tourists expressed resentment that one individual, the boat and shop owner, benefitted so disproportionately to everyone else involved both through fares collected for transportation to the site and through personal use of a PV panel that was intended to benefit the community.

The PV systems themselves, both that attached to the shop and those used in the ranger station and other tourist buildings, are considered successful for purposes of this research: they function, the solar energy equipment specifically is seen as successful by its users, and the systems are sufficient to meet the needs for which they were installed. However, whether this tourism project – well intended to allow indigenous people to benefit from their cultural heritage even as the archaeological excavation benefitted the scientists involved – should be considered successful is questionable, and beyond the scope of this research.

6.8.4. Creation of social networks

Thirty respondents answered questions about the creation of social networks within the community: whether and in what way the projects may have influenced these networks. Twenty-six said that social networks had been created or strengthened as a result of the solar PV systems. These responses were evenly divided between one of two (or fell into both) general categories: the availability of light is useful to individuals within the community, and this in turn creates opportunities for improved social networks within the community; and the process of creating or administering the project or the use of the light contributes directly to a sense of unity or an ability to work together. Specific examples of the latter include using the light to enable community meetings at night, the ability to work together to seek more development aid, and creating the impetus to form other institutions like an "emergency committee" to help in the event of future natural disasters, but more often included generalities about a less tangible sense of unity. "It wasn't like this before (the PV project), everything has changed. We were very divided and now we work more united. There is strength."

Eight of the thirteen responses that dealt with the creation of social networks as a result of individual benefit and nine of the thirteen responses that spoke directly of unity were from users of successful systems: these data do not show that one perspective is more related to system success than the other. Among the four respondents who claimed no social networks were created as a result of the projects or systems, two were users of successful systems and two were not.

This result – an apparent lack of relationship – stands in stark contrast to observations I made of micro-hydroelectric systems in the same areas of Guatemala while conducting this research. Even the smallest hydro systems I observed did not serve a single load, but were connected to microgrids or to the national electric grid. The result of this physical interconnectedness seemed to be an institutional and social interconnectedness in many cases. It is not possible for an individual to make maintenance decisions without affecting his or her neighbors, as is the case with stand-alone PV systems. This research does not explore in depth the institutions that surround rural hydro systems in Guatemala, but even cursory observation of them shows that they are necessarily quite different. Physically independent systems offer the opportunity for independent operation and independent decision-making. Collective institutions surrounding energy systems are often a choice for PV system owners, but they are a necessity for microhydro users.

The institutions surrounding rural stand-alone systems in Guatemala may offer little insight into the institutions involved in other forms of rural electrification that require physical electrical connections among users. This distinction is important because it suggests that these results regarding institutions and relationships are specific to stand-alone systems and should not be inferred to be generalizable to interconnected rural renewable energy systems.

6.8.5. Summary: Unintended consequences and success

Unintended consequences can decrease or even increase system success in sometimes surprising ways, and may cause harm to communities or individuals without decreasing system success rates. Potential negative environmental and health consequences of improper battery disposal are an example of the later: systems do not fail more often, but a child getting lead poisoning is certainly not a desired outcome. This is discussed in detail in Chapter 7.

In energy projects not included in this research, religious affiliation has been responsible for exclusion from participation, which may or may not influence success rates. However, religious conflict was not reported by users in this study, and as such cannot be considered to influence system success here.

Inequity within communities can be exacerbated when some community members are included and others are excluded from projects. This exclusivity may increase the success rates of systems within a community if those who are least able to maintain their systems (through lack of financial resources, community support, or other reasons) are excluded while those best able to sustain their systems are included. This outcome calls into question an original implicit hypothesis of this research that higher rates of system success equate to more successful programs. Donor mandates and project goals must determine whether improving success rate by exclusion is a desirable outcome.

Depending on the outcome considered, unintended consequences may be positive or negative overall, and may increase or decrease the likelihood of systems being successful. Negative outcomes such as increases in inequity or environmental contamination do not necessarily decrease the probability that systems will be successful.

6.9. Institutional ethics

I had no a priori hypotheses about the ethics of institutions and the decision makers within them. However, they emerged as an important result with regards to the institutions and relationships that surround donated PV systems in Guatemala.

Unethical or questionably ethical actions taken by donors, developers and vendors can ultimately lead to system failure, to the detriment of intended beneficiaries. While examples of this have been included in previous sections of this chapter – vendors who install cheap components while charging for first quality, for example – the cases reported here more fully illustrate questionable business decisions and their consequences.

6.9.1. Power inequity between parties

The solar energy systems considered in this study are all donated or partially donated. However, this does not preclude the need for business transactions and binding contracts. People's failure to live up to their legal or ethical obligations can have an adverse effect on the success of donated solar energy systems.

Some legally binding contracts are written to one party's advantage over another's. In an agreement among equals, this can be attributed to the better negotiating skills of the party on the winning side. However, not all agreements are between parties with equal legal knowledge or representation. I had planned to include a series of communities with solar panels installed under a specific program in this study, but they ultimately had to be excluded. The proximate cause of their exclusion was that members of some of these communities were rumored to be using their machetes to chase off strangers who were interested in their solar panels. However, the situation that brought people to wield weapons against anyone with an interest in solar energy is complex.

I was invited by the head of the local NRECA[113] office to assess the success of a program that included six communities. Four they viewed as successful or satisfactory; two were viewed as utter failures. They invited me to examine the program and assess the differences that allowed some communities to succeed but allowed others to fail. The national head of the organization was very accommodating to me and my research. He readily answered questions and instructed his staff to allow access to records of this project and others in which the organization had been involved.

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[113] The National Rural Electric Cooperative Association (NRECA) is a U.S.-based organization that was established in the 1930's to help U.S. farmers and other rural consumers gain access to electricity (NRECA, undated). It has expanded its activities to other countries, including Guatemala. However, in this capacity it works more as a foreign development organization facilitating donations and loans, rather than organizing rural communities to form electric cooperatives as they did in the U.S.

From the perspective of the organization, the project was straightforward and was to have been economically sustainable. The organization coordinated the donation of all of the hardware needed to install solar home systems in six communities. Community members agreed to pay for the installation of the systems. The organization acted as intermediary to arrange a loan from a commercial bank for the amount needed to cover installation. Because of its central location in the capital, the organization chose to work with an NGO local to those communities, with the expectation that someone local would be better able to arrange installations, collect loan payments, and otherwise interact with the communities.

Reportedly, two of the communities had not been making their loan payments. In accordance with the original agreement, the local NGO was to go to the communities and repossess the systems of anyone delinquent in their payments after a contractually-mandated period of time, but the panels remained in place and the installation loan was in default.

The head of the international organization said that their mistake had been in their choice of a local NGO. He described the organization as "eco-terrorists," among other colorful things. The NGO had had final word in selection of communities that were to benefit from the project; they had ignored the head of the international organization when he told them repeatedly that some of the communities chosen did not have the minimum economic resources necessary to repay the loan. They, perhaps more than the community members who were not making payments, were to blame for the default of the loan and the unknown state of repair of the systems.

The organization was the keeper of the original contracts that the community members signed. The contracts were approximately two pages long, written in a formal, legal style. One contract existed for each beneficiary family. Some of the contracts were signed by beneficiaries with their names. For others, they were sealed with a right thumbprint, which is accepted as a binding signature for those who cannot write well enough to sign their own names (I believe it is legally binding, but I do not know whether by statue or by common law).

This contract is well within the limits of Guatemalan law. The parties are defined and the rights and responsibilities of each party are enumerated. It has legal signatures from all involved. The international organization wrote all of the contracts, and its signatory was the person responsible for explaining the terms of the contract as they were written to the other parties. The members of the local NGO are middle-class Guatemalans and seem to have reasonable understanding of legal and financial operations, but no one among them is an expert in these fields. Some of the community members couldn't read what they signed at all.

The head of the organization provided the contact information for the local NGO in question, assuring me that they would help with the logistics of visiting the communities.

The same factual history and timeline of events was repeated by members of the local NGO, who agreed to meet with me, but regarded me with a great deal of suspicion because they associated me with the international organization. They offered a somewhat different perspective on the history.

The leaders of the NGO had personally guaranteed the loans using their own creditworthiness and their personal assets as collateral. The community members had agreed that they would make payments, but some stopped when their systems developed technical problems, believing they shouldn't have to pay for something that doesn't work.

According to the members of the NGO, their credit was ruined and their assets were threatened. They had agreed to this arrangement because they claimed that the international organization told them they had nothing to worry about, that their participation in the financial transaction was a formality.

They also stated that the international organization should simply forgive the loan. The loan, however, was a debt to a commercial bank – arranged by the international organization – not a debt to the international organization itself. Thus the international organization did not claim to be unwilling to forgive the debt; it claimed to be unable.

In keeping with the contract, efforts were made to re-claim panels from people in communities that were not making loan payments. [114] Presumably the panels were to be sold to pay off the debt incurred, or perhaps installed with another household that would assume the debt. The local NGO shared (as the international organization did not) that those who tried to collect the panels were escorted out of the first community they visited by men with machetes. Subsequent visitors were met with similar receptions. Community members clearly felt they had ownership of the systems, regardless of what the legal contract says.

The international organization – the most powerful party – had controlled the construction of the agreement. The local NGO felt its role had been misrepresented by the international organization. I did not visit the communities to discover whether they felt the same. The organization assumed no risk itself in the arrangement; once the loan was in place and the systems installed, it had no legal obligations to the project. While the actions of the international organization are apparently legal, I question the ethics of the agreement as it was implemented. I do not propose malice, but instead suggest a degree of negligence. The individuals from the local NGO who risked their own assets did not understand those risks, and claim to have been deceived about them. Again, I did not visit the communities, but I postulate that if the literate, middle class members of the NGO did not fully understand the agreement, community members with very basic (at best) formal education would have little chance of understanding a two-page contract written in legal jargon.

Both the NGO and the international organization were interested in the results of my investigation, to be used to reinforce their claims in the legal battle in which they were engaged at the time. Although community members with machetes made it impracticable to include those communities in my investigation, I excluded even communities which are operating successfully (and non-violently) under this program. I did not believe I could guarantee the confidentiality to my interview subjects if there could be some threat of the information they provided being subpoenaed.[115]

[114] Apparently members of the NGO, though perhaps members of NRECA. I got conflicting stories from NRECA and the NGO.

[115] Anonymity of responses was not possible for some community members, such as those who might describe their leadership roles in the community or with the project, or those who had unique uses for energy, such as store owners.

Solar home systems whose ownership status is ambiguous cannot perhaps be said to be successful or unsuccessful. Some of the systems are known not to be working; that was the original reason for non-payment. Those who are chasing out people with an interest in their solar home systems are unlikely to invite outsiders in to repair them. The systems that are functioning, owned by people who are themselves current with their payments and are enjoying the benefits of electric light, cannot be called successful if their impact is that their owners have to draw their machetes in solidarity with their neighbors.

It is possible that many of the systems in those communities were operable and served users' needs. Perhaps they view themselves, and by proxy their systems, as successful because they have managed to keep them without paying for them when someone tried to take them away. Perhaps they view the entire project as unsuccessful because they are forced to physically defend what they feel is their own property. Regardless of the success of these systems from the point of view of beneficiaries, they are a sore failure to the process of PV for rural electrification in Guatemala as the situation is an object lesson in mistrust: actors from the community level to a multinational organization which have the same apparent goal of energy for rural development and who agree on approach and conditions still expose themselves to perhaps unacceptable risk by working together.

6.9.2. Deceptive business practices

Solar home systems were installed in a series of communities as part of a larger hurricane reconstruction program, which failed on a number of levels. It is described in detail in Chapter 3, and its economic, social, training, and institutional failures are discussed throughout this study. An exacerbating factor in the failure of the individual solar home systems to serve their intended purpose of providing household electricity was an unscrupulous PV vendor.

The solar part of the program was implemented too quickly, according to a representative of the NGO that developed the project.[116] The NGO was given a one-year timeframe to bring the project from

[116] Information from the developer's perspective was provided by Iván Azuria of *Fundacíon Solar*.

conceptualization to completion. The vendor chosen by the NGO to provide and install the solar home system hardware had a long history of working in PV in Guatemala – including with this NGO – and was considered reputable. The vendor knew that the NGO had to complete its work in a very restricted timeframe; consequently, there was to be no follow-up more than a few months after the final installation.

Beneficiaries of the disaster relief program were trained on a basic level about their systems. They were told what maintenance would need to be performed, what would need to be replaced, and when these things would happen. People in these communities participated in the training sessions and found them useful. However, they did not find them sufficient; of the seven respondents in the disaster relief program who answered the question, six believed that they did not receive enough training. That they were insufficient is reinforced by two factors. First, people within a community had a shared understanding of what they were to have expected from their solar home systems, but that understanding sometimes differed between communities. Second, some of what they believed was wrong. For example, the good quality solar panels that were installed for this project carry 15 to 25 year warrantees, but some beneficiaries believed that the panels would wear out and be useless in 3 or fewer years.

Some of their mistaken understanding seems to have come from the person to whom many beneficiaries referred as “the recycler.” Within a few months after the completion of the project (after which no follow-up from the NGO was expected), the recycler came to the communities. People interviewed gave a variety of answers when asked how long after installation, which may be attributable to people’s vague recollection of a date to which they may have ascribed little significance, and to the fact that he visited and re-visited these communities multiple times.

The recycler offered to buy solar home system components from beneficiaries. Some sold only their panels, while others sold batteries and charge controllers as well. His first offer, which was accepted by many beneficiaries, was 100 *Quetzales* (about 13 $US) for systems that can be sold retail for as much as 500 $US in Guatemala. To convince people to sell their systems cheaply and quickly, he told them that their panels would last only a few months or years, or that their entire system would be worthless in a year once the battery died, so they would do well to sell to him immediately. He returned to the communities multiple times, each time offering a higher price than the previous. The highest price anyone reported commanding for his system was 500 *Quetzales* – about 65 $US.

A then-employee of the NGO that developed the solar home system part of this program claimed that the recycler was an employee of the original vendor. The timing of the start of the "recycling" efforts and the recycler's apparent ready knowledge of what was installed in the community implicate the vendor; however, new solar panels in communities located beside a highway are publicly viewable (though some communities were then less accessible than they are now), and solar home system design is fairly standard. Between the time that this project was implemented and the time of this study, the vendor has been accused of various other unethical (and sometimes illegal) business practices, and is no longer active in the Guatemalan PV markets. The vendor may be implicated in the PV "recycling" effort based as much on his reputation as on known circumstance specific to this project, but circumstantial evidence suggests his unscrupulous business practices were a major cause of failure for systems donated for disaster relief.

It is a beneficiary's prerogative to sell that which has been donated to him or her. And these beneficiaries' readiness to sell suggests that even a small amount of money was worth more to them than electric lights and radios in their homes. However, this buyer deceived the sellers outright, and pressured them to sell without access to independent information. If the buyer was also the original vendor, then his inside information gave him more opportunity to exploit the vulnerabilities of this population, especially their misunderstood needs and lack of training.

6.9.3. Organized crime

The absence of consistently applied rule of law was hypothesized to be an exacerbating factor in system failure. However, among the stand-alone PV systems included in this study, none had been damaged by vandalism. A panel that was part of a tourism project and a large array that powered a school were stolen, but no home included in this study had lost panels to theft. Thus, though unethical and possibly illegal actions by vendors and developers (described above) may have contributed to system failures, petty criminal mischief had little influence on community-owned systems and none on systems held by private families. Organized crime, however, was seen to force an end to follow-up by vendors, developers or project maintainers – presumably increasing the failure rates of the systems in affected areas – as described in this section.

The Guatemalan Ministry of Energy and Mines had previously installed solar home systems as part of the government loan program in the areas now controlled by Los Zetas. The relative success of those systems is unknown. I attempted to view some of the systems but was followed by men believed to belong to Los Zetas to one of the communities. When leaving the community, the same truck was waiting for us and "escorted" us out of the rural area back to the main road. The community we visited was said to be located very near a clandestine air strip used for drug trafficking,[117] one of the countless temporary and permanent air strips used for drug trafficking in Guatemala. After a single interview, we left the community and did not return to it or three other communities in its immediate vicinity that had government-installed panels.

When I reported this back to my contact at the Ministry the response was that the Ministry was unaware but would likely avoid the area, effectively abandoning any follow-up on the systems. Leadership changes pending at the time of this study within the branch of the Ministry responsible for these projects may mean that follow-up has been or will be attempted, but I find it unlikely as long as *narcos* are *de facto* or perceived to be in control of the area. I cannot assess the success of these systems, but the exclusion of the donor – whose relationship with beneficiaries I found to be relevant to system success – leads me to hypothesize that they are less successful than they could be absent the presence of *narco* trafficking interests.

Another case of rule of law (or absence thereof) potentially driving system success is that of Punto de Manabique, a peninsula on the Caribbean coast of Guatemala that acts as a barrier "island" protecting the

[117] Per waitstaff and local patrons in a restaurant, hotel employees and a washer woman in a nearby larger town, whose anonymity is important enough to leave the town nameless.

mainland from tropical storms and hurricanes.[118] The unique ecological characteristics and biodiversity of the area have earned it the status of "protected area" in which logging and other intensive land use activities are prohibited. Several stand-alone solar PV systems were installed in the communities within the protected area. These included a solar-wind hybrid system that was damaged during a recent hurricane, and two solar-powered refrigeration projects.

One of the solar-powered refrigeration projects, which was part of a larger ecotourism project, was burned to the ground by *narco* traffickers. Apparently, *narcos* were interested in keeping tourists out of the area, which has long been used as a corridor for shipping drugs by sea. I remain unsure of the motivations since those close to the project and in the community are understandably unwilling to talk about it – if they even know what the true motivation was. Both ethical considerations (putting community members at risk) and considerations of personal safety kept me from visiting the community or asking too many questions of the NGO's and government agencies involved. Clearly, drug trafficking has again been an obstacle to successful stand-alone PV systems in Guatemala.

An article in Guatemala's largest newspaper *La Prensa Libre* (15 February, 2009, cover story, no byline) reported that the land within the protected area was being misused by loggers and cattle ranchers, and named five prominent families who were alleged to be involved. It is a known secret that "*ganadero*" (cattle rancher) can be a euphemism for drug trafficker. The backlash resulting from this article was dire; members of the five families mentioned were rumored to have been killed as accusations and counteraccusations were made about who leaked the information; other non-community members interested in the project received death threats if they visited or were believed to be planning to visit the area.

The status of the hurricane-damaged solar-wind hybrid system is apparently unknown outside the community. People from the NGO's have either not gone to check on repairs or are unwilling to admit they have been out to the peninsula. Another of the PV systems was on a scientific research station which has

[118] Information about the *Punto de Manabique* projects comes from two developers, one local to Guatemala and another from a donor nation, who helped implement or had recently been responsible for the projects. For their protection, they remain anonymous.

probably not hosted many scientists recently since the NGO that runs it is not currently making trips to the peninsula. The community-based systems may or may not be functioning currently. Members of the communities on the peninsula have been moving to the mainland in significant numbers since the *narcos* have been buying their property by offering money if they sell or threatening them with death if they do not, a dilemma colloquially referred to as *plata o plomo*, literally translating to "silver or lead."

Drug production and trafficking are able to thrive in specific social, political, and historical contexts (Keefer and Loayza, 2010) like those found in Guatemala. Those involved in drug trafficking are motivated to reinforce those systems that enable their work, often reinforcing the very characteristics of a country that hinder development (Keefer and Loayza, 2010) It is to be expected and unexceptional then that drug trafficking is an obstacle to the long-term success of rural stand-alone PV systems in Guatemala, but the evidence I have to support the conclusion is weak at best: it is based on innuendo and hearsay.[119]

6.9.4. Summary: Institutional ethics and success

Beneficiaries of donated stand-alone PV systems in Guatemala are categorically at a disadvantage compared to donors, developers, vendors and criminal syndicates in terms of power, economic resources and knowledge. This disparity presents the opportunity for outright abuse or simple negligence in meeting the needs of beneficiaries by the more powerful institutions. In extreme cases, beneficiaries must sometimes resort to "desperate" measures such as physically threatening people with machetes in order to assert their own agency in such inequitable relationships. Both the misuse of power on the part of more powerful institutions and the extreme responses sometimes manifested by beneficiaries detract from the success not merely of individual PV systems, but of the programs that install them and the goals of rural electrification in general.

6.10. Conclusions

The institutions and relationships that surround, create and result from the implementation of rural stand-alone PV donation programs can profoundly influence system success.

[119] Several individuals involved in development in rural Guatemala related stories of their own or their peers' experiences with *narcos* to me. The specifics of these cases are omitted for their protection.

Rural electrification in Guatemala takes place against a backdrop of weak legal institutions which enforce laws inconsistently, and *de facto* rules that are enforced socially and, sometimes, by the criminal syndicates that are in control of parts of the country. At the community level, governance of donated stand-alone PV systems is based on trust and community networks as there is little expectation of legal recourse in the event that rules are broken. As such, the legal establishment of such structures has little bearing on their success.

The presence of governance structures seems to relate to project success, although individuals actively involved in project governance do not seem to have more successful systems than their neighbors. The relationship between governance structure and success is complex, however, as governance structures were implemented with hardware in nearly all cases; those that maintained these structures also maintained their systems.

Both the most successful and the least successful systems observed in this study were in programs initiated by an outside party, rather than by the community itself: this research does not support the widely-held hypothesis that a project initiated by the beneficiary would be more successful than one imposed or suggested by outsiders. However, those with successful systems were more likely to have known of available training at the time of implementation, supporting the hypothesis that training provided by the donor is important to system success. The level of contribution that users were expected to make at the time of donation seemed to have no relationship to system success.

The most remarkable results presented in this chapter have to do with system ownership. The underlying, near-ubiquitous assumption that systems will be more successful if users have ownership of them was clearly not supported by this research. Two potential reasons that full system ownership may actually decrease system success rates are these: owners have the prerogative to sell their systems, and owners have the prerogative to delay maintenance until such a time (if ever) that it suits them. Further, those with successful systems were no more likely than those with unsuccessful systems to have contributed capital as a condition of participating in the project.

In contrast, those who do not own their systems outright but are instead accountable to the system owner for its state of repair appear to be more motivated to succeed: selling and delaying maintenance on something that is not yours but for which you are responsible are not options.

Independent of any sense of accountability to the system owner or donor, longstanding relationships between beneficiaries and project donors or developers lead to categorically more successful systems. The full mechanisms of this are not clear from this research, but the exchange of information – advice on system maintenance and where to purchase replacement parts – may play as significant a role as does the exchange of capital – when the donor continues to pay for repair and replacement.

Negative unintended consequences can actually lead to higher rates of system success. The exemplar of this is that inequity in a community can be increased if the poorest or marginalized members of a community are excluded from a project. However, if the excluded households are those who would in fact be least likely to have the means to maintain their systems, the total percentage of systems would likely increase.

Criminal organizations such as drug traffickers have been responsible for system failures through direct destruction of systems or, more commonly, through prohibition of maintenance or other outside support. The same factors that allow organized crime to decrease system success rates also prohibit detailed documentation of this supposed phenomenon.

Finally, the power disparity between rural villagers and the institutions that surround them can lead to failure. Donors, developers and vendors may deceive beneficiaries or negotiate in bad faith, possibly leaving beneficiaries in a worse position than they may have been without the project.

Chapter 7. Results concerning characteristics and consequences

The results of this research begin with defining success, as detailed in Chapter 2. Chapter 5 examines the uses of donated rural stand-alone PV systems and their economic implications for beneficiaries, showing that economic considerations in particular have a strong influence on system success. However, it is also clear that economic advantage is neither necessary nor sufficient for system success. Further, although the institutions and relationships that surround systems have an important bearing on their success, they too are insufficient to fully assess success. This chapter examines characteristics of users, the communities in which they live, and the systems themselves to highlight the influences of these characteristics on system success. Here I also examine the consequences of system implementation under normal and emergency conditions.

7.1. Introduction to results concerning characteristics of users, communities and systems

Characteristics of users and the communities in which they live influence where energy systems will be installed and how successful they will be. At the same time, the presence and success of a community energy system impacts the characteristics of a community. Fewer people might leave an electrified community to find work in the cities, if the presence of power affords greater comfort and economic opportunity. A community that uses electricity as a way to draw tourists necessarily opens itself up to the influences of "outsiders." The ability to charge cell phones or power television reduces a community's cultural remoteness.

Chapter 6 explores results associated with institutions that surround the systems and the relationships between stakeholders. In this chapter, I discuss system characteristics including the type of technology implemented and the quality of the design, installation and physical hardware. Users and the communities in which they live are discussed in terms of their demographics and geographic characteristics. This chapter also includes discussion of changes to these characteristics, such as unintended negative consequences to local environment or culture.

Section 7.2 reviews the hypotheses and research questions related to characteristics that are introduced in Chapter 3. The following section describes the commonalities and differences between communities included in this research, and the possible effects of those differences on system success. Section 7.4 describes the characteristics of users included in this study, and differentiates those characteristics from the characteristics of the communities in which they live. Section 7.5 includes results on the physical characteristics of the systems themselves, including the potential for influence by codes and standards. Finally, this chapter reviews the unintended consequences of the physical installation of rural stand-alone PV systems.

7.2. Hypotheses and research questions

As described in detail in section 3.5.3 of Chapter 3, the success of off-grid energy systems in rural developing world locations is influenced by the characteristics of the systems, the communities in which they are located, and the users themselves.

The characteristics and consequences of community energy systems are closely tied to the institutions and relationships that surround these systems, as discussed throughout this chapter and in Chapter 6. As examples, the quality of materials used to construct systems is driven by institutional structures that dictate their purchase; intra-community conflict is influenced by the characteristics of a community and of the program that installed its energy systems; and the success of energy systems is driven by and drives the level of accessibility of a community.

This research began with these six basic research questions about system, user and community characteristics, each discussed in further detail below:

1. *How is project success influenced by the characteristics of the communities in which projects are situated?*
2. *How is project success influenced by user poverty, ethnicity, religion and age?*
3. *What other characteristics of users influence success?*

4. *Are systems with high quality parts and robust, standard design more successful than those using inexpensively replaceable parts and locally adapted design?*
5. *Are systems maintained under a highly structured regime more successful than those in which maintenance is improvised as needed?*
6. *Have local ecosystems, environment or landscapes been adversely affected by the systems' presence?*

These questions, and associated hypotheses, are examined in detail in this chapter.

7.3. Results: Community characteristics and success

This section focuses on characteristics of the communities studied that are relatively independent of the characteristics of community residents, covered in detail in section 7.4 and independent of community governance, discussed in Chapter 6, including physical geography and infrastructure. The differentiation between these as characteristics of the physical community and characteristics of community members or community institutions is not as obvious as it may seem, as discussed throughout this section. For example, the question of how many kilometers a community is from an urban center is easily objectively measured. However, that is of far less consequence to community members than is the question of how many hours or days it takes to reach the city, which is in large part a function of available forms of transportation – which depend, among other things, on disposable income (a user characteristic) and whether roads have been maintained, as prioritized by community or outside institutions.

In my sampling methodology I sought users of both operable and inoperable systems in each community. I did not make exhaustive lists of successful and unsuccessful systems in these communities because success could not be defined without gathering substantial amounts of information – operability is neither necessary nor sufficient to define system success.

7.3.1. Commonalities

By definition, if all communities studied in this research share a particular characteristic, it is not possible to assess whether presence or absence of that characteristic impacts system success. In this section, I summarize shared characteristics observed in this research.

All communities in this study share some characteristics by design. Systems found in the communities must meet this study's selection criteria, which means all were beyond the reach of the national electric grid when the systems were installed. These communities were all poor at the time of installation, which had led them to be candidates for donated systems. I did not ask explicit income questions, but it was apparent that they remained poor after the donation: most houses had dirt floors, for example.

This study includes predominantly communities that are easily accessible in a vehicle. It categorically excludes any community that is more than three hours (for me) walking distance from a place that a truck can be parked. The factors that lead to the success and failure of PV systems installed in locations more remote than these may be very different. This is an unfortunate bias that is found in many both formal and informal assessments of energy-related development projects. Little funding is generally included in project or program budgets for assessment, forcing evaluators to sample from projects that can be reached quickly. In consideration of personal safety, I was unwilling to walk to a remote location where I would be forced either to walk back after dark or seek lodging, as an unexpected stranger, in a rural community.[57]

The differences between communities are far more in number than their similarities, although the differences may be subtle. The remaining subsections of this section explore those differences.

[57] Although I visited very isolated communities via helicopter during preliminary research, I did not formally gather data during those trips. I lacked the resources to travel via helicopter during the bulk of my field research. Anecdotally, members of indigenous communities seemed to strongly mistrust those who arrived unexpectedly via helicopter. In one community where we were forced to make a landing that had not been pre-arranged, we were cheerily greeted by seemingly every man in the village carrying his machete. This mistrust is a likely consequence of their association between helicopters and military activity during which many indigenous were killed in the civil war. See Chapter 3 for details.

7.3.2. Location, location, location

Both the location of a community in Guatemala and the location of a household within a beneficiary community can influence the success of renewable energy systems, and successful systems can make communities and households less remote, as discussed below.

An important distinction may be made between communities located in the north of Guatemala, which was hardest hit by the civil war, and communities located elsewhere. However, these differences are closely linked to poverty, ethnicity and other user characteristics, and are discussed elsewhere.

7.3.2.1. Community accessibility

A seemingly independent community characteristic like "remoteness" or "accessibility" may not in fact be independent of the institutions related to an energy system: project developers sometimes choose to build roads to or install telephones in communities in which they work. This was clear in the case of Chel, a community in which a solar-powered satellite telephone was installed and a graded road was built to aid in the construction of a micro-hydroelectric project, which has been described at length in Chapter 2. A telephone does not decrease the distance in kilometers from a community to roads or municipal centers, obviously, but it allows contact with those outside the community to coordinate travel or the delivery of supplies: isolation decreases, accessibility improves. In an analogous example from the literature, access to the isolated community of Manantiales, Cuba, was greatly facilitated when the road to the community was upgraded to enable the installation of a micro-hydroelectric system, just as the roads to Chel made it more accessible.

The circumstances surrounding these two power systems here suggest that even physical location cannot be considered an independent variable in a post-facto assessment of rural renewable energy systems. And accessibility, in terms of a decrease in community isolation, is certainly affected by the presence of energy systems, even as accessibility impacts whether systems will be installed and how successful they will be.

Communities and users can be remote or inaccessible in two ways: either the communities are simply a long way away and hard to reach, or users are detached from the resources that physical access can afford.

Every PV system eventually needs maintenance that cannot be accomplished with what is available in a remote community in Guatemala. At a minimum, batteries must be replaced every three to five years (if well cared for; more frequently if poorly maintained). No community visited for this study had a vendor who routinely carried batteries that could be used in a small stand-alone PV system. As such, those responsible for systems must either be able to get to larger towns that sell batteries that can be used for solar systems, or they must be able to contact someone who has that access and would be willing to help.

To judge the accessibility of a system, I consider two things: whether the respondent knows who to contact or where to go when they encounter maintenance issues (routine or otherwise) that are not within their capabilities, and how long it takes users to reach a location where they can gain access to parts or expertise.

7.3.2.2. Knowledge of access

I hypothesized that knowledge of where to go and to whom to speak in the event that the system needed maintenance beyond what could be obtained in the community would increase the rates of system success. I ascertained this by asking three questions: a) whether they knew where they could go to buy replacement parts such as batteries, b) how to contact the original project developer, and c) who they could contact if they had problems with their systems. Success relates to having only some of this knowledge, as explained below.

Success did not depend upon being able to answer all three questions in the affirmative. Among the 47 unsuccessful systems about which users provided this information, [58] only two users (4%) of systems considered unsuccessful by the definition used in these analyses answered in the affirmative to all three questions. Similarly, among the 67 successful systems about which users provided this information, only 3 (4%) answered in the affirmative to all three: knowledge of all three does not predict system success.

[58] Not all respondents answered all three questions.

However, users of successful systems were more likely to be able to answer at least one question in the affirmative: 13% of respondents with unsuccessful systems answered “no” to all three questions, whereas only 3% of respondents with successful systems answered “no” to all three.

In looking at each question individually, knowing where to go to buy parts or find assistance is a predictor of success. Among successful systems, 79% of respondents knew where they could go. Among unsuccessful systems, only 47% knew. This is an intuitive result in that even routine maintenance like replacing a battery is dependent upon knowing where batteries can be bought.

Most users did not know who to contact if they had problems with their systems. Only 43% of successful system users and 39% of unsuccessful system users responded that they knew who they should contact. This suggests that the availability of a maintenance person or a connection to a maintenance person has little bearing on system success.

Among successful users, more than half (52%) knew how to contact the original donor. Among the unsuccessful, only a quarter (26%) knew. Ongoing involvement of the donor, therefore, may have an influence on system success.

7.3.2.3. Physical remoteness

Because of the sampling methodology in which I sought to find both successful and unsuccessful systems in the same communities, actual distances from individual communities to municipal centers are not telling of anything.

Programmatically, distance does not seem to be a driving factor in system success. Comparing again the disaster relief program to the post-conflict development program – both programs for very poor indigenous communities in northern Guatemala – the latter was vastly more successful than the former for reasons discussed in above. However, communities in the less successful disaster relief program were much more easily accessible. Many had paved roads or highways that passed through or near them. The post-conflict development communities were much more difficult to access and further from municipal centers. Most included in this study were accessible by graded dirt road, but others are only accessible by dirt track that can be driven in a 4 wheel drive vehicle, or by walking or mule.

One explanation is that people who live close to roads and cities (and therefore the national electric grid) expect to be connected to the grid in the near future. As such, any investment in the PV system is a short-term investment. Because replacing batteries is capital intensive relative to users' resources, short-term investments do not make economic sense. However, evidence does not support this hypothesis in these cases: people in the disaster relief program did not talk expectantly about the arrival of the electric grid, and many asked if I knew how or where they could get panels donated again.

Another possible explanation is that easy access from the community also means easy access to the community for outsiders. Three tourism projects with donated PV systems are located in close proximity to one another. One is an archaeological tourism site, and the PV array is not easily accessed except by boat. That system is working well. The two nearby ecotourism projects are accessible by paved roads, followed by a short walk. Neither is successful as one PV array was stolen and the other was taken down to keep it from being stolen as well. Also supporting this hypothesis is the "PV recycler" who visited the disaster relief communities. Whether he was the original vendor of the systems or not, that he could easily make repeated trips to the communities increased the number of systems he was able to purchase at below-market prices (see section 6.9 below).

Finally, the fact that there were trained system maintainers in and near the post-conflict development communities may have made distance to urban locations moot for other users (as far as the successes of their systems are concerned), if the maintainers are responsible for all travel associated with system repair.
The government loan program worked only in communities that MEM anticipated would be connected to the national electric grid within five years of the installation of the solar home systems. While this connection has failed to happen within the expected timeframe in many cases, communities that are to be electrified are necessarily close to the then-current boundaries of the national grid, and therefore often

roads. Qualitatively, the government loan systems exhibited wide variability in their success rates, although they were categorically more successful than the disaster relief systems.

Finally, the locations of the government-owned early warning systems were chosen specifically for their ease of access. While they are categorically very successful, I find that this is driven by institutional arrangements not geography, as described in Chapter 6.

Thus physical remoteness – distance from roads and municipal centers – is not seen to be a driving factor in system success. This does not discount the possibility that it impacts success, but other factors overwhelm it in this study, and the sampling methodology is not appropriate to assessing its more subtle impacts.

7.3.2.4. Perception of distance

Respondents from the same communities sometimes had very different perceptions of how long it takes to get to the nearest municipal center where a replacement battery might be purchased. In one community, answers ranged from one hour to a full day. However, many people answered “a day” more to signify that it took away a day’s work than that the trip took 12 or 24 hours.

A further confounding factor is that physical accessibility is driven by wealth. Among systems in the government loan program, I was unable to find someone with an unsuccessful system or someone who was not a participant in the program to interview in a community in the wealthiest department included in this research. Respondents’ estimates of times to reach the municipality from that community ranged from two hours each way to the whole day. I believe this represented differences in means of transportation since it clearly could not represent difference in distance. Driving home an hour or two with one’s purchases could certainly be defined as much easier access than walking the same distance carrying a heavy battery, with the man who traveled by horseback falling somewhere in between.[59] However, the presence of trucks in the community allows greater access to all community members, as those with vehicles can be asked to transport passengers or goods (whether for free or for a fee) when they are making trips themselves.

[59] A horse is a status symbol and indicative of wealth more than ownership of a truck in rural areas.

Since respondents in some communities had differing perceptions of how remote they are, I examined whether perceptions of distance correlated to system success within a community. In three cases, people with unsuccessful systems perceived themselves to be one to two hours further away from municipal centers than did their neighbors in the same community with successful systems. In one case, a respondent with a successful system perceived himself to be a full day from a location he could buy batteries where a respondent with an unsuccessful system in the same community said the distance was only 2 hours (the successful respondent perceived himself to be farther away in this case, as compared to closer in the previous cases). The inconsistencies may have several explanations. People may have imprecise memories of exactly how long travel takes, people may have different means of access, or people from the same community would not go to the same location to purchase batteries or other replacement parts for their systems. In the case where one person said a few hours and another a full day, it may suggest that the person with the shorter travel time takes a boat across the lake to the municipal center, while the person who takes a day to make the trip walks around the lake on the shore. Or it may suggest that the person with the longer travel time would not go for only a few hours, but prefers to spend the entire day or stay overnight rather than invest the time and money in travel for a single errand.

These do not lend particular insight into the perception of distance and the probability of system success.

7.3.3. Micro-urbanization

The location of a community or houses within a community may change because of an energy system. As an example, a community I visited in Mauritania, West Africa, in 2002 (not included in this study) had relocated because of energy: community members re-built their previously dispersed houses under electric power transmission lines that had recently been installed, in hopes of being connected to the electric power grid.

In Guatemala, two communities visited during this research exhibited a phenomenon I call "micro-urbanization." Community-level electric power grids were built to connect households to small hydroelectric projects. In these, as in other hydro communities, households are either given an allotment of grid extension distance to which they are entitled (all houses within a given number of meters from the planned distribution grid are connected) or are required to pay per meter for grid extension to their households.[60] Both arrangements favor in-town living and living as close to the town's main streets or square as possible. In the two communities mentioned, population density at the town center had increased markedly since the installation of the microgrid, according to residents, since people in the outlying areas were denied or could not afford access to power. Disparities between those in the towns' centers and those in the surrounding areas increased, as those without electricity generally pay more for lower quality light and cannot make use of the other appliances so often wished for (blenders, refrigerators) even if they can afford to purchase them, further encouraging people to move to town if possible. A government employee interviewed during the course of this study acknowledged the phenomenon and expressed a different concern: who is growing the food if all the farmers move to town?

Relocation of households or communities was not observed to result from the solar PV systems included in this study. Because of their physical independence, the added burden for a remote solar-powered household is small compared to the burden for a household potentially connected to a micro-grid. Beyond having to carry batteries when they are replaced or distilled water for routine maintenance farther than their more centrally-located neighbors, it is no more costly in money or time to have a remote solar home system.

A sample of two communities is inadequate to draw any general conclusions about this apparent phenomenon, but it suggests that different means of electrification have different social and economic consequences, even if the quantity and quality of electricity delivered is the same. Further research is merited.

7.3.4. Other donated community infrastructure and projects

The infrastructure and proposed infrastructure were assumed to be characteristics of the community, in which case answers about donated projects would be the same among respondents within a community.

[60] Since households or communities connected to the national electric grid were not the focus of this study, I do not know whether or how much people must pay for connection or if the phenomenon of moving closer to power lines exists with the national grid as well as micro-grids.

However, this was not always the case, suggesting that understanding of donations is a characteristic of users, as discussed below.

Dependent upon this assumption, I had hypothesized that a community with more donated projects would be more likely to see success in the solar energy project. A community with more donated projects might have a better ability to work with donors, more experience in maintaining things that are brought in "from the outside," or more resources to perform maintenance. This hypothesis was strengthened by my experience in the first community I visited, not included in data analyses because the survey was refined during work in this community, making the answers possibly not validly comparable to those obtained in subsequent communities, and because hydroelectric power and biodiesel comprised the main energy sources for the community. This community had lobbied for and successfully acquired numerous development projects from outside sources, including the two energy systems, an unsuccessful biogas digester project, a plant for purifying and bottling water, machinery for processing locally-grown macadamia nuts and coffee beans, and others. Although not every donated project was a success to the community – for example, a biogas digester failed due to a lack of feedstock in the form of pig manure after selling many of their pigs to market – the community either had intrinsic characteristics that made it generally good at getting projects and seeing them succeed, or each project's success had taught the community skills that contributed to the subsequent success.

In the communities explicitly considered in this study, respondents expressed less congruence on what projects or infrastructure had recently been donated. For example, three of the five respondents from the community of La Bolsa answered the question of what other projects had been donated recently to their community. Two respondents said potable water, which was not mentioned by the third. A primary school, latrines, and ovens were listed by one of the respondents but not the other two. This may suggest that respondents only identified projects that were relevant to themselves as opposed to other community members, that they did not give the question serious thought and therefore forgot things, that they had different definitions of the terms "projects" or "recently," or some other reason. However, this inconsistency makes it impossible to judge whether experience with other donated projects is related to the success of donated PV systems.

Qualitatively, the number of development projects in a community does not seem to have any relationship to the success of panels in that community. Communities in the disaster relief program were given *estufas mejoradas*,[61] seeds for planting marketable crops, and other donations at the time of the solar home system donation. These communities had few successful systems, with respondents stating that most of their neighbors had sold their panels. They also reported that the crops planted from the donated seeds failed, but that they still used and appreciated their *estufas mejoradas*. Few, if any other meaningful conclusions can be drawn from this data about the relationship between donated infrastructure or other projects and system success.

7.3.5. Summary: community characteristics and success

In this section, I reviewed the commonalities among communities included in this research, as well as their differences as far as location, "urban-ness" and their levels of development as suggested by other community projects.

The "remoteness" of a community is affected by electrification, whether through PV, mirco-hydroelectric, or the national electric grid. Developers of the electrification project often take steps to improve access in order to make their own work easier (or, in some cases, possible), and these roads and telephones may remain behind after the developer has gone.

Conversely, accessibility is a factor considered by project developers when selecting communities in which to work. Communities that are difficult to access demand a greater portion of available funds be put into logistics, so many developers may opt to use available resources to electrify more households closer to roads rather than fewer households in more remote locations.

[61] Literally "improved stoves," it is the general term for concrete or cinder block fireplaces designed to demand less firewood than traditional more open fires.

The same resource constraints and logistical difficulties that dissuade developers from working in very remote locations also make research difficult or impossible. Every community in this research is one that could be visited between sunrise and sunset of the same day, including time in transit. If this level of accessibility is viewed as a cut-off point for many developers as well, more remote projects may share very different characteristics.

Systems were more successful when users knew how to contact the donor, a topic explored in greater detail in Chapter 6. They were also more successful when users knew where to go to access replacement components, especially batteries. However, knowing who to contact for maintenance assistance was not shown to relate to system success. This may be because users have not sought maintenance because they believed they could not afford it or because they had not encountered a failure that could not be repaired locally, or some other reason.

7.4. Results: user characteristics and success

The people included in this research do not constitute a homogenous group. They can be classified or categorized by many characteristics: rural rather than urban; northern versus southern; indigenous versus *Ladino*; poor versus extremely poor; etcetera. Even those who are rural, northern, indigenous Q'eqchi' living in extreme poverty do not make up a homogeneous group. They may differ by dialect, dress, social status, economic resources (however small), gender, household size, religion and many unquantifiable factors like personality, ambition, affinity towards unfamiliar technologies, and life experience, which can influence how a person perceives and ultimately sustains a donated solar home system.

The populations studied in this research are discussed in detail in Chapter 3. This section discusses characteristics of users that relate to system success, and equally importantly points to characteristics that have little or no bearing.

7.4.1. Ethnicity

Systems installed in indigenous communities seemed to fail at higher rates than those in *Ladino* communities.[62] The proposed reasons for this are many, as described below.

Discrimination against ethnic Mayans is rampant in Guatemala. They are more likely to live in poverty and have less education and opportunity than their *Ladino* counterparts. However, defining who can be categorized as a minority is problematic. Issues of culture and blood line, and how "pure" in each one must be to be categorized as a minority or not a minority are far beyond the scope of this study.

Communities seem to be relatively ethnically homogeneous, as judged by clothing. Excepting a few among the elderly, men in Guatemala all wear modern clothing. However, women in rural communities often wear attire that is traditional to their particular ethnic background. Patterns and types of skirts, sashes, aprons, and blouses vary dramatically throughout Guatemala, though all four components are normally present. But within individual communities, either I observed only one or perhaps two traditional styles with only "outsiders" like teachers or clinicians wear modern clothing in some communities, or I observed all women in modern clothing in others. Though I did not keep explicit record of it, women wearing traditional clothing corresponded with a traditional Mayan language being spoken within the community. Assuming that the simple combination of language and women's attire is enough to call a community indigenous or *Ladino*, the single characteristic that is used here to define ethnicity is the language spoken in the community. Goldin et al. (1993) suggests a larger percentage of *Ladino* residents in a community correlates to a worse economic and developmental outcome for indigenous residents of the same community, due largely to economic resources such as land being concentrated in the hands of *Ladinos*, and to increased "native agency" in communities without strong *Ladino* populations (Goldin et al., 1993;). Because this study did not randomly sample community members or households, the ratio of Mayan to *Ladino* people in the communities studied is unknown, but this combination of the two were not superficially observable in

[62] Because of sampling methodology, I am unable to determine the percentage of failed systems in each community or community type.

the communities studied.[63] This study specifically excluded communities on private land (such as groups of indigenous workers who live on a *Ladino*-owned plantation) which eliminated the most dramatic cases of intra-community inequity.

The legacy of the civil war has left the indigenous population not just economically poor, but also uneducated and intimidated. Few schools were functioning in the area during the war, entire communities were uprooted and relocated, and traveling even across town was extremely dangerous. Further, the Mayan populations in Guatemala place low value on education for their girls, and even young boys during the war were at constant risk of conscription by either the rebel or the government forces. During the war, many indigenous communities were occupied by government troops who viewed all indigenous as rebels or rebel sympathizers. Thus the price of taking initiative or a leadership role was often death.

Three categories of projects included in this study – disaster relief, post-conflict development, and government-provided school lighting – focused exclusively on indigenous populations. They could equally be said to focus on very poor populations or any of a number of other characteristics that they share with each other but not necessarily with other beneficiaries included in this study. As such, I focus the question of the influence of ethnicity on solar home systems installed by the government throughout the country since this program included both indigenous and *Ladino* communities. Among these, twenty-four respondents lived in communities that spoke only Spanish (and are therefore classified as *Ladino*) and fourteen lived in communities in which at least one indigenous language was spoken. These interviews took place in five departments, two of which were made up of *Ladino* users (Zacapa and Chiquimula), and three of which contained indigenous communities (Alta Verapaz, Baja Verapaz, and Izabal). Alta and Baja Verapaz were particularly hard hit by the civil war, and Alta Verapaz and Izabal were hotbeds of drug and human trafficking activity at the time of this study (see Chapter 3);[64] like racism and poverty, violence and instability are part of what it means to be indigenous in Guatemala.

[63] Excepting as mentioned above, outsiders such as teachers or health care workers who did not own a substantial portion of communities' assets.

[64] The Department of Petén, largely excluded from this study, is the main department in which traffickers work; Alta Verapaz and Izabal are the departments that border it.

The post-conflict development projects took place in a department that is 90% indigenous, in which 84% of indigenous people live in poverty and 27% live in extreme poverty (INE, 2006). The disaster relief projects were implemented in a department where 89% of the population is indigenous and 87% of indigenous live in poverty. However, the latter department differs from the former in that almost half of the indigenous population lives in extreme poverty (49% versus 27%), showing it to be markedly poorer.

The Guatemalan National Institute of Statistics (INE) claims that the total population is 38% indigenous. Fifty-one percent of all Guatemalans live in poverty, 15% of them in extreme poverty. The populations included in the post-conflict development and disaster relief programs are significantly worse off than average. By comparison, 36% of *Ladinos* live in poverty, 8% in extreme poverty. However, this ethnic disparity fails to take into account rural versus urban living conditions. Seventy-one percent of all people in rural areas of Guatemala live in poverty (24% extreme poverty), which is slightly better than the two above-mentioned departments. In summary, extricating the effects of ethnicity from poverty and extreme poverty or from urban versus rural habitation is complicated and beyond the scope of this study. While not all *Ladino* respondents appeared wealthy, the wealthiest respondents were *Ladino*; while not all indigenous appeared extremely poor, the poorest respondents were indigenous.

Further, levels of education and knowledge of Spanish were higher among *Ladinos*. If written instructions are left with beneficiaries for the maintenance of their systems, those with the highest levels of literacy will be those who benefit most. Those who cannot read instructions, contracts, or warranty materials may be less likely to value them and keep them safe. Even with the assistance of one who can read Spanish, system owners will be unable to request warrantee service if they cannot provide documentation of the warranty.[65] Internalized attitudes may also play a role. *Ladinos* talked about "progress" and "moving forward." The indigenous – especially those in the areas hardest hit by the civil war – were conditioned during the civil war to avoid asserting themselves, especially where the government is concerned, or risk being killed.

[65] Although beyond the scope of this research and perhaps little documented in the refereed literature, anecdotally it seems that those with lower literacy levels value documentation less than those with greater literacy – even when the documentation is pictorial and does not require reading skills. A study of this would be valuable to those in development who put resources into creating non-verbal documentation; does such documentation actually aid those with low literacy, or is the need to look to a piece of paper for instruction an obstacle in itself?

Although attitudes towards self-determination seem to be strengthening, many people still live in communities where they were once forced to live, communities that were planned and built by the military. With the peace accords signed in 1996, the government committed to doing more to build up and develop these communities. The paternalistic attitude taken by the government towards the indigenous may do little to inspire people to assert themselves and may lead to the false expectation that many people had that "someone else" would maintain their systems and replace their batteries for them.

None of the communities showed a consistent understanding of the roles played by their municipal or department governments in obtaining the panels. However, members of *Ladino* communities in both departments reported the aid of political influence in getting or maintaining their systems – something not reported in the indigenous communities included in the same solar home system program. Some respondents in one of the *Ladino* departments reported that a powerful political figure represented their district in Guatemala City at the time of implementation, and they received the panels despite having had a recently prior donation of panels from another source. Those who reported this were by far the wealthiest respondents included in this study, judging by home construction[66] and the ownership of trucks and cows.[67] In the other department in which respondents were *Ladino*, many respondents reported that a recent political candidate had purchased new batteries for the solar home systems in a largely unsuccessful effort to win their votes; he was not elected and those who mentioned it did not feel obliged to vote for him because they had accepted the replacement battery. Both of these situations suggest that at least some of the *Ladino* beneficiaries have value to political institutions above that of the indigenous beneficiaries in the same program. *Ladinos* in these communities were treated as a constituency by their representatives and would-be representatives who had either influence in the capital or money to attempt to buy elections. Conversely, the government works with the indigenous in post-conflict areas to meet an obligation. The disaster relief program included in this research would have been a clear opportunity for a government

[66] Some of these homes had drywall interiors (unlike any other homes visited in this study), most had multiple rooms and all had installed flooring rather than dirt floors. In many indigenous communities, homes were single rooms with clapboard or stick walls and dirt floors.

[67] The word for cow used in Guatemala, *gana*, has the same root as the verb *ganar*, which means to earn or to win. Cattle is equated with wealth.

official to win the favor by emphasizing his or her involvement in it, but none apparently found the communities to be a valuable enough constituency to invest the time.

The first group (the wealthy respondents) had what appeared to be the highest rate of operable systems I observed among communities included in this government loan program.[68] Systems in the community that received the recent battery donation from the political candidate were considered successful or unsuccessful based on the same criteria as others. However, batteries were donated to users who had failed to maintain systems on their own; absent the windfall batteries, the community may have shown a much poorer success rate.

In conclusion, *Ladino* beneficiaries of the government loan program were more successful than their indigenous counterparts in maintaining operable systems. However, many of the systems of the wealthiest of these respondents are not considered successful on the basis that they are sub-optimal for user needs: their capacities are too limited to meet the power demand that these wealthy users have in order to run blenders, televisions and other appliances that they have or believe they can afford.

The generally greater success of *Ladino* users may relate to wealth as *Ladino* users had more money to maintain their systems, to political influence as they were more likely to have had politicians intercede on their behalves, or to attitude as indigenous users had been conditioned to expect specific projects outside their control rather than being an engaged part of determining their needs and maintaining what was given to them. The lack of success among the wealthiest *Ladino* beneficiaries was related not to their inability or unwillingness to maintain their systems, but to the fact that their needs and means had “outgrown” their systems.

7.4.2. Gender

Gender-specific results are largely anecdotal. Women interviewed were quick to turn to their husbands to answer questions, and husbands who arrived mid-way through interviews quickly took over answering.

[68] Sampling methodology prevents quantitative conclusions about success rate in one community versus another.

This leads to difficulty in attributing responses to one gender or another. Among those responses in which gender is identified, more than twice as many respondents were men as women.

The same number of respondents said that there was active participation by women in system governance activities as said women were not involved. A few communities had specific women's governing committees (JD's[69]), which were generally subordinate to the main JD (made up entirely of men in those cases). In communities in which women attended general meetings but were not involved in decision making, some individuals answered that yes, women were involved while other participants in the same programs answered no, that this does not constitute involvement.

The few explanations offered as to why women did not participate were largely pragmatic rather than ideological objections to women in leadership. One female respondent said that women had been excluded because they cannot read and write or speak Spanish, which is limiting in dealing with donors and recording events or signing agreements. Women's lack of involvement (either in leadership or as beneficiaries at all) was attributed frequently to the constraints on a woman's time: the practical matter of a woman keeping house was a priority over meetings or development projects according to men and women alike.

The fact that women immediately conceded answering questions to their husbands and practical matters that keep women from being involved belie a *machista* culture. This wasn't addressed outright by anyone, but the head of household was the person most involved in the project – and the head of household is a man unless the woman is a widow.

Some men outwardly supported women's participation, but still concede that the culture is not conducive to it. "Women can do what we do as men. They formed a committee but it wasn't a priority for them; they had their household work…" explained one man. Another man, *Don Compartiendo*, boasted of women's freedom to participate in all of the projects in his community (mostly not energy related), and indeed many

[69] See Chapter 6 for detailed descriptions of these institutions.

women were involved, a few in leadership positions. However, the women who were active were unmarried: they were either widows or young women who had not yet found husbands.

In a conversation about the economics of the community, *Don Compartiendo* stated that the communally-owned store would extend credit to community members to buy food. However, he was concerned because people were over-extending themselves. The credit was intended to hold people over if need be when buying staples, but people were using it to buy processed and packaged foods. He said that though his household could afford it occasionally, he disliked pre-packaged foods. He preferred the meals his wife cooked with herbs she gathered from the mountainside herself. I asked if the availability of pre-packaged food might allow women more time to avail themselves of the opportunities to participate in the projects. He merely reiterated that the people who were using credit to buy them were living beyond their means.

Successful systems were more likely to include women in management or governance. Among successful systems, 56% were governed under structures that included women. Among unsuccessful systems, 56% were governed under structures that excluded women.

Women and men had different perceptions of system safety. Women noted being afraid of lightning strikes, and fearing the combination of electricity and water during storms. One woman suffered what she described as a year-long nervous breakdown after lightning struck her panel while she and her family were in the home. No one was physically hurt, but she and her neighbors wanted nothing to do with solar energy. Conversely, a man in another community said that the damage to his panel, which was shattered and bent at the edges, resulted from a lightning strike.[70] However, he was happy with it because it was still producing some power and providing him with lighting. Men generally said that PV was preferable and safer during storms and disasters because candles and other traditional lighting sources can blow over and either blow out or start fires. Women tended to prefer traditional lighting during storms, and some disconnected their systems to prevent damage to the system or the household should lightning strike. Women's valid concerns about system safety could be addressed with more robust design (see Section 7.5), just as men's concerns

[70] Physical inspection of the system suggested that it was damaged by impact with a solid object, perhaps a cocoanut that fell during a storm, leading him to believe that lightning caused the damage.

about candles blowing over could be addressed with better housing construction (less drafty houses), although it is not clear whether that would allay the fears of either, nor where the resources to improve either housing or system construction could be found.

7.4.3. Age

This study included only men and women of at least 18 years of age. If the ages of respondents were questionable, they were asked whether they were at least 18 years old, but no record was made of respondent's ages. In three cases, respondents were excluded and no written record was made of them because they were less than 18 years of age. A seventeen year old was with a group of women who were interviewed for this study, and as such her exclusion was somewhat artificial: there was likely very little difference between speaking with her and speaking with her friends, some of whom were likely only a year or two older. In two other cases, children sought to be involved. In one household, no adult was present but two girls who appeared to be young teenagers offered to respond. I did not conduct the interview. In another case, a mother participated in the initial part of the interview, but then asked her adolescent daughter to respond to remaining questions. As the mother was present, I spoke with the daughter briefly, but did not take voice or written records of her responses. All four under-aged would-be participants were female, which is consistent with the fact that young boys (older than toddlers) seemed to be in houses infrequently during the times of my visits, which were during daylight hours either on weekends or during the week. Since no data on ages or genders of children was collected – and rumors of foreigners kidnapping babies for the adoption market made asking many questions about children dangerous – this observation is not quantifiable, but suggests that boys have either liberties or responsibilities away from home while their sisters are expected to remain near their mothers.

The only comment on record about age was from an elderly man. In speaking of why he did not participate in the governance of the energy project in his community, he said that people over 60 years old were not allowed to hold leadership posts in the community. This suggests a youth-centered culture in that community that seemed common, but not ubiquitous in Guatemala. No conclusions can reasonably be drawn from this single observation, but suggests another possible cause of exclusion from benefiting from donated PV systems that merits further study.

7.4.4. Summary: user characteristics and success

All respondents in this study shared some characteristics based on selection criteria for inclusion. All had some familiarity with PV technology. All were poor, and lived in rural but not excessively isolated communities. No conclusions about system success can be drawn based on these characteristics because there is no group to which to compare them. And yet, every respondent was an individual and as such different from every other, making comparisons of success difficult or impossible without creating classifications of people, like ambition or levels of literacy or standing in the community, about which I lack both the data and the expertise to judge.

Comparing system success on the bases of gender or age of respondents is not valid since all respondents appear to have lived in households with both men and women, and many households were multi-generational. However, people related to systems differently based on gender, although no such differentiation was observed because of age. Women regarded electricity with more fear or mistrust, while men were more confident in its benefits. In the communities included in this study, youths did not show markedly more enthusiasm or confidence in the technologies than did their elders. This suggests that people were adapting equally regardless of age rather than elders being less willing to give up their traditional forms of lighting in favor of something less familiar.

Systems in communities that are dominated by ethnic minorities are less frequently operable than those in *Ladino* communities, but this does not imply causation. *Ladino* communities were often made up of wealthier, more literate residents who were valued as constituents by political leaders, though many considered their systems insufficient to meet their needs. Many of the indigenous communities were in locations that were under the control of the army during the civil war and, due to historical as well as current political circumstances, may expect more ongoing participation of the government than it is providing.

7.5. Results: systems characteristics and success

This section deals with characteristics of the design, installation and components of the physical stand-alone PV systems. I had hypothesized that these system inspections would yield the most and most valuable information. They in fact told only a small part of the story, as described below.

I performed some sort of physical inspection of sixty-four systems. However, I was often unable to view the entire system: households were uncomfortable inviting me inside to see components, public buildings were locked, panels were inaccessible, or inclement weather made climbing on metal roofs to examine panels inadvisable. Results in this section reference those systems where the information was accessible. Some respondents answered questions about multiple systems, so there is not a one-to-one correlation between systems examined and people interviewed.

7.5.1. Codes and standards

I hypothesized that adherence to internationally-recognized codes and standards for quality and safety would lead to more successful rural stand-alone PV systems. The Ministry of Energy and Mines (MEM) in Guatemala has provided training by international experts to some of its employees on the U.S. National Electric Code (NEC) standards for stand-alone PV systems, which the Government of Guatemala has adopted but not implemented (Ley, 2006). However, MEM employees with whom I spoke wanted further training on the topic as it seemed that they had never applied (and thereafter forgotten) the NEC.

This study does not show the impact of these codes and standards on the success of rural stand-alone PV systems because no observed systems met NEC standards. Government agencies that installed systems tended to do so with internal consistently, but not consistently between different government agencies: MEM systems were installed like other MEM systems and CONRED systems like CONRED, but MEM and CONRED systems did not follow the same design or installation principles. Lightning protection was insufficient in every system examined, with all systems lacking recommended grounding and few including mandated DC disconnects.

In addition to design standards, standards of quality for individual components are issued by the U.S. Underwriters Laboratory (UL) and CE (certified as consistent with European standards), which are organizations that certify that electrical and other products are consistent with industry or government standards. These certifications do not by any means guarantee product quality: UL tests only for safety and CE relies on self-reported data. However, they are suggestive of increased attention to standards which, in turn, should result in higher quality products. Absent the ability to perform rigorous testing on components for this study, these seals are used as one proxy for component quality. Further measure of component quality is more subjective and depends upon my judgment of the degree to which components function adequately and stand up over time. Discussions of each component and the standards associated with it follow.

7.5.2. Quality of components, design and installation

"Our nuts get stuck in the machinery…"

Operator of a poorly designed and installed micro-hydroelectric system on a macadamia nut plantation.

More successful systems were hypothesized to be those with higher quality components, those installed properly, and those designed as closely as possible to industry standards. However, as with most of my results, the qualities of components, design and installation in a given system are not always simple to assess. Further, I focus on the "operability" criterion for success in this section as it has the most obvious and direct relevance.

The three primary components common to good design practices in systems like these are the solar panels, the battery, and the charge controller. The "balance of system" components include wires and effectively everything else needed to make a system operable. Balance of system components are difficult to assess by their physical natures and because they are less consistent between designs. Thus I chose to focus on the quality of the three primary components only. Relevant design criteria are included with components where appropriate.

7.5.2.1. Change controllers

The quality of charge controllers was straightforward to assess: they were ubiquitously poor. This may have little influence on the success of projects because the charge controller is normally a technically simple device that may not need a high level of skill or careful manufacturing processes to ensure its success. However, these data do not contain an adequate group of high-quality controllers against which to test this hypothesis.

Five charge controllers failed in ways that were apparent from physical inspection such as burnt resistors (visible when the charge controller was opened), evidence of burning visible without any disassembly, or direct statements from users that controllers burned. Two of these reported that the problems were common in their communities.

All but one were in communities in the municipality of Gualán and provided under the government loan program. Among the twelve Gualán systems for which charge controller information is available, six are Solsum brand model 6.6x, which is CE certified, five had no trademark, and the last was ASC brand, model unspecified. Some ASC models are UL listed while others are not. None of the four visibly and reportedly "burnt" charge controllers were Solsum models; they were all among those in which the certification status is unknown. Thus it would be logical to infer that the Solsum controller or controllers with CE certification are of better quality than those without. See Table 5.

	Solsum, CE listed	Not Solsum, unknown
Not burnt	6 (50%)	2 (17%)
Burnt	0	4 (33%)

Table 5. Number of damaged charge controllers, by CE listing status and brand, Gualán

However, this gives an incomplete picture. Although the other charge controllers were not visibly damaged, ten of the twelve had been bypassed. There are several reasons for bypassing charge controllers. The first is that it does not function properly. The more common reason, however, is that it is believed to be failing because of a misunderstanding of how systems work. Since a charge controller is designed to prevent over- and under-charging of the battery, it will cause a system to stop providing energy to lights and other applications when the state of charge of the battery is low. As batteries' usable capacity decreases over time, the charge controller will restrict the flow of energy after shorter periods of use towards the end of the battery's life than at the beginning. It is therefore possible to connect an application directly to the battery, bypassing the charge controller entirely, in order to extract more energy from it at a given time. However, this allows over-discharging of the battery and consequently shortens battery life. Looking then not at whether the charge controller is known to be damaged but rather at whether the charge controller is actually in use, the brand and its certification seem to make no difference. See Table 6.

	Solsum, CE listed	Not Solsum, unknown
Not bypassed	1 (8%)	1 (8%)
Bypassed	5 (42%)	5 (42%)

Table 6. Number of bypassed charge controllers, by CE listing status and brand, Gualán

Finally, among these systems, all but one was operable. While it did not use the Solsum charge controller and the charge controller was bypassed, this single system is not telling of any trend.

This is too small a sample from which to draw definitive conclusions, but it suggests that certification may improve system safety since burnt charge controllers or their resistor might pose a safety hazard. It does not suggest that CE certification has any bearing on whether the systems remained operable over time, in the case of the government loan program in Gualán.

Industry standard design, quality installation and manufacturers' recommendations dictate that a charge controller should be present in a stand-alone PV system with a battery. Notably, the design of all systems inspected for this study included charge controllers initially, so I can infer nothing about the effect inclusion of a charge controller by design on system operability. However, they were often bypassed or had been removed. I inspected the charge controller (or connection between the battery and other components when charge controllers were absent) of ten inoperable systems. Among these, five were missing charge controllers or had bypassed them and an equal number had charge controllers connected. Sixteen of the thirty-six (44%) operable systems for which I was able to inspect the charge controller or battery had no charge controller connected to the system, though it was often present and bypassed. Twenty of the thirty-six (56%) had charge controllers in place. A greater percentage of operable systems had charge controllers than did inoperable systems, suggesting that the presence of a charge controller improves the likelihood that a system will remain operable. However, the difference is slight.

7.5.2.2. Batteries

The shortest-lived component of a stand-alone PV system is normally its battery. As discussed in Chapter 5, users often do not replace batteries because they find the cost prohibitive, either in real dollars or because of the relatively large amount of capital needed all at once. In this section, I explore the influence of battery quality on system operability. I also explore the connection between battery replacement and overall system success.

Two basic types of batteries were found in the systems inspected for this study: deep-cycle batteries and automotive batteries. Deep-cycle batteries are the industry standard as they are technically better suited to the slow re-charge and deep discharge operation of PV systems, but are more expensive. There are various differentiations in deep cycle batteries, including sealed versus unsealed, lead-acid versus lithium ion, and those intended for marine versus terrestrial uses. Because these differences were sometimes difficult to ascertain and because industry standard design does not dictate one as clearly superior to another, deep-cycle batteries are considered a single category.

The second types of batteries found during inspections were automotive batteries. These also vary considerably, but are all designed to be optimal for the quick, deep discharge necessary to start a vehicle and quick re-charging once the vehicle is running, not the slow discharge and charge cycles of a PV system. These are also considered a single category of battery, and are considerably less expensive than deep-cycle batteries.

I had hypothesized that successful systems would be more likely to be those with appropriate, deep-cycle batteries, but the hypothesis is not supported by this research. Among systems for which I was able both to inspect the battery and ascertain whether the system was operational, the number of deep-cycle batteries was nearly identical to the number of car batteries, in both operational and non-operational systems. See Table 7.

	Inoperable	Operable
Deep Cycle	2	20
Automotive	3	19

Table 7. Number of automotive and deep-cycle batteries among operable and inoperable systems[71]

Battery replacement is essential to the long-term success of a system. Given that the economic obstacles to system sustainability seemed to be related less to the real cost of systems and more to the need to amass sufficient capital to replace batteries, keeping a system operable could be hypothesized to be more likely with the lower-cost, albeit lower quality, automotive batteries. Considering only systems where users specifically reported that they had or had not yet replaced batteries and the most recent battery was available for inspection, only four owners of inoperable systems reported that they had previously replaced batteries: two had deep-cycle batteries in place; the other two had automotive batteries. However, among users whose systems were operable, thirteen reported that they had replaced their batteries at least once: nine of these (69%) had purchased automotive batteries while four (31%) had purchased the recommended deep-cycle batteries. The reason that replacement automotive batteries are more common among successful

[71] The number of batteries inspected among inoperable systems was very small in part because batteries were often missing from these.

systems might be attributed to their lower upfront cost, their greater availability, or users' lack of knowledge or understanding of why a deep-cycle battery is technically (and, in the long term, economically) preferable. The result suggests that replacing previously-installed batteries with automotive batteries does not preclude system success and may support it.

Excepting specialty "sealed" deep-cycle batteries not seen in this study, batteries require basic maintenance including adding distilled water to their wells. Among the twenty-eight respondents who specifically said that they or someone in their households were responsible for maintenance of the system, all knew that adding water was an important part of basic system maintenance,[72] which yields no insight on whether understanding of this basic maintenance step is related to system success.

7.5.2.3. PV panels

In this discussion of PV panels, I include issues of panel quality, maintenance, orientation and inclination, shading and mounting structure. Meeting industry standards with each was hypothesized to support system operability. All programs included in this research specified the installation of monocrystalline or polycrystalline PV panels, considered to be of superior quality to the amorphous silicon or thin-film panels that are the alternative.[73] However, not all panels installed by vendors met this specification. The post-conflict development program relied on a vendor who they thought to be reputable for the installations of some systems.[74] While many of the systems he installed appeared to be of acceptable quality, he installed sub-standard equipment in at least three communities. Specifically, all three systems inspected in the town of Encuentros Amajchel and one system that I inspected in each of the proximate communities of Amajchel and Nueva Amajchel were installed with amorphous silicon PV panels. Qualitatively, these communities did not seem to have poorer success rates than neighboring communities in which all panels were crystalline. The amorphous panels are rated at much smaller wattages (on the order of 12 W to 15 W) than

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[72] Six respondents used an acid solution marketed for batteries rather than water because they were told by battery vendors that it was necessary. It is not likely to affect system performance, but increases the cost.

[73] This is consistent with specifications reported by donors or developers familiar with the projects, and evidenced by the fact that most panels were of the crystalline variety. Crystalline panels typically have warrantee periods of 20 to 25 years, versus 10 years for thin film panels.

[74] The source of this information is Iván Azurias of *Fundación Solar*. One additional panel in the community of El Estor was also amorphous. However, I was unable to find a respondent with sufficient knowledge of or access to the system to speculate on why this might be.

the crystalline panels in the same and adjoining communities (40 W to 50 W), leaving these households with less energy than their neighbors. Only one of the five noted the discrepancy, stating that he had expected a 50 W panel but received one of only 12 W. Though he expressed his disappointment that the expectation had not been met, he stated that the systems had not caused any conflict in the community, which presumably includes resentment among those with smaller systems. By most users' estimates, these systems had been in place approximately six to seven years; although the inequity in the size of the system created no apparent conflict, negative consequences may or may not result from the shorter system lives. Community relationships and conflict are discussed in detail in Chapter 6.

While the general type of panel specified was of superior quality, crystalline panels themselves vary widely in quality. Among the panels examined, 48% had a visible trademark. However, I suspect some of the trademarks to be fraudulent because this is reported to be a widespread problem in Guatemala (Ley, 2006), because some panels that bore a trade name lacked the technical specifications or certifications found on the boilerplate of these manufacturers, and because some panels that bore a trade name showed signs of being of significantly lower quality than other panels attributed to the same manufacturer. Because 52% of the panels were missing a trademark or were situated such that I could not view it and because the veracity of the trademark is suspect in the remaining cases, I can draw no conclusions about the importance to success of using name-brand rather than less expensive or "pirate" panels.

For fewer than 10% (6 out of 62) of systems I was able to physically examine, I observed damage to or degradation of the PV panel itself. One of these, mentioned in Section 7.4, was mechanically damaged by a lightning strike or falling object, but was still functioning. Another was an amorphous silicon panel, which have shorter expected lives than do crystalline panels, which was not functioning nor did users have plans to replace or repair it. The four remaining systems showed discoloration of the PV surface, which is evidence of degradation of the component. All of these were functioning at the time of inspection, albeit likely at lower efficiency than an undegraded panel under the same circumstances, and were part of successful systems. Thus, these analyses do not support the hypothesis that name brand, higher quality crystalline panels are associated with more successful systems.

I cannot test the hypothesis that grounding to protect against lightning strikes leads to better system success as none of the main programs included in this study (disaster relief, post-conflict development, government loan or flood early warning programs) included grounding in the design or installations of their systems. The four systems inspected that had some form of grounding (although not to U.S. NEC standards) were all successful by the definition of this research, but the sample is too small to draw any conclusion. It is likely evidence that they were better planned overall, and as such may have various reasons for their success.

Proper panel orientation (azimuth) and inclination were also expected more frequently in successful systems. Inclination, measured as the angle between the panel and the horizontal, is normally equal to the latitude of the location where the system is located,[75] so Guatemala's latitude of 15.5˚ N suggests an inclination of approximately 15˚ is appropriate. However, inclination can vary by as much as 15˚ without significant loss of system performance. Thus for these analyses, any inclination between 0˚ (flat) and 30˚ was considered to be within the bounds of standard design. Only two systems exceeded this tolerance, and both were successful. Again, this small sample size yields no meaningful information about the effect of inclination on success.

Azimuth may be important, however. In the Northern Hemisphere, panels should be installed facing due south, plus or minus not more than 30˚. Seventy-eight percent of successful systems for which orientation and inclination were recorded were within this range, oriented between SSE and SSW. Conversely, only thirty-eight percent of unsuccessful systems faced south – markedly fewer. There are two possible explanations. The first is that the decreased energy production resulting from improper panel orientation gives less incentive for people to care for their system or leaves them less likely to perceive systems as successful. The other possibility is that an installer who orients systems with azimuth of greater than 30˚ is likely inexperienced and may have made other mistakes in implementation, whether with the physical installation or in orienting users.

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[75] Design and installation recommendations in this section are from "Solar photovoltacis for development applications" (Shepperd and Richards, 1993), unless otherwise noted.

Among systems donated by the government for use in schools, panels were seen to be deliberately installed facing sunrise. A community member who participated in installing the system at the school in his and nearby communities explained that facing sunrise was the "best" orientation, according to the instruction he had been given by the project developer. Too few school systems were seen to succeed to draw useful conclusions about the influence of panel orientation on system success in this case.

Other panels may have been installed in sub-optimal orientations for security reasons, such as installing panels on the side of a roof that faces away from a road or thoroughfare to prevent theft or vandalism. A system installed on a now-defunct women's weaving cooperative was among these. Even though community members knew that the panel would capture more sun if mounted on the south-facing slope of the roof, they chose to mount it facing north to minimize the risk of the panel being damaged by children throwing stones at it as they walked to and from school. This system was not included in this study because I had helped to maintain it prior to the initiation of the study and concluded that my earlier influence would make it an inherently biased data point. The system fell into disrepair after the cooperative was abandoned, but the reasons for the dissolution of the co-op are outside the scope of this study.

Panels should be installed with a minimum airspace of six inches between the panel and the rooftop or other mounting structure to allow sufficient air cooling, as panel efficiency decreases when panels are too hot. In fact, seventeen percent of successful systems lacked this clearance but all unsuccessful systems for which I was able to view panel mounting structure adequately had sufficient airspace. Though it is unlikely that decreased efficiency would lead to increased success, there may be some common factor that would both lead to system success and to the easier, although technically suboptimal, mounting of panels directly on rooftop surfaces.

Dirt, dust, leaves or other accumulation on panel surfaces can reduce their ability to produce energy. Thirty systems examined had panels subjectively ranked as clean, mostly clean, dirty, or very dirty. All seven unsuccessful systems and eighteen of the twenty-three successful systems (78%) had panels that were dirty or very dirty, suggesting the simple maintenance activity of wiping panels periodically was not happening very frequently. This may be because people are unaware of the importance: among all users who answered questions about training or maintenance, only 26% of respondents with unsuccessful systems and 34% of respondents with successful system stated that they knew that they should clean panels regularly. Additionally, users would logically feel little or no motivation to clean or perform other maintenance on unsuccessful systems, if they were not functioning and not intended to be repaired. However, “dirty” panels were found at about the same rate for successful and unsuccessful systems.

Shading decreases panel output disproportionately to the area of the panel shaded; because the solar cells in a panel are wired in series, shading of a portion of the panel will affect the output of the entire panel. As such, shading on panels was expected to correspond to less system success. This hypothesis is also unsupported by this research, with 13% of unsuccessful systems and a statistically indistinguishable 17% of successful systems having partial shading on panels during some portion of the day.

7.5.3. System longevity

This research considers the years since a system was originally installed. Some respondents had very precise answers, while others had more general ideas (one system was installed on April 10, 1999; another in a nearby community was installed “more than 5 years ago, probably 15 or 16 years”). Some respondents did not remember or were not in the community at the time of installation.

Projects were generally installed in communities at the same time or nearly the same time, so the sampling methodology of choosing successful and unsuccessful projects in each community does not allow a direct comparison of longevity. However, some conclusions can be drawn from the data available.

This study took place ten years after the hurricane that prompted the disaster relief program. In four of the seven communities covered by that program and included in this study, I was unable to interview anyone with a successful system. People gave conflicting reports of whether any panels remained in the communities at all. In the remaining three communities, although I was able to talk to users whose systems were functioning, they were the exceptions rather than the rule.

Conversely, in three of the five communities in the wealthiest area included in this study, I was unable to interview anyone with an unsuccessful system. Respondents claimed that all systems in their communities were functional, excepting those on the houses of a few people who had moved away (although it is not clear if the panels remained with the houses or were taken by former residents). Communities in this region also reported that their systems had been in place for approximately 10 years, with one community reporting that their systems were more than 15 years old.

Both the least successful and the most successful collections of systems in this study were approximately 10 years old. Since batteries are expected to be replaced every three to five years, a system owner will have had to incur that expense twice or three times in ten years. Users in the wealthiest communities were able to sustain their systems through those periodic expenses repeatedly, while those in the disaster relief communities largely reported not having replaced the battery even once.

While systems may be said to fail in the first few years, as in the case of the disaster relief program where many people sold their still-functioning systems within a year of installation, systems cannot be said to be sustainable for their users until after the first major maintenance expenses are met. Thus, system longevity is a result of system success, not a predictor of it.

7.5.4. Summary: System characteristics and success

Characteristics that were the same for all systems included in this study cannot be analyzed for their impact on success. The regulatory environment for codes and standards does not vary by department, but is the same for all of Guatemala, rendering untestable the hypothesis that the presence and enforcement of codes and standards would lead to greater system success. Similarly, since all users who claimed responsibility for the maintenance of their own systems knew to add water to their batteries periodically, I cannot test the hypothesis that this level of basic knowledge and corresponding action would improve system success.

The relationship between system design and installation and success is slight. Shading on panels, type of crystalline panel, and appropriate mounting are not shown by these analyses to relate to system success. However, panels installed at an inappropriate azimuth were less successful; this may be because an installer who does not know in which direction to face the panels may have less expertise in PV in general and may have made multiple mistakes.

Two important, albeit slight, apparent relationships exist between system success and system characteristics.[76] All systems included in this study appear to have been designed and installed with charge controllers, which users often bypass. Systems with charge controllers in place were slightly more likely to be successful systems, as hypothesized. Contrary to my a priori hypothesis, however, systems that include automotive batteries rather than appropriate deep cycle batteries may be more likely to be successful systems. This suggests the hypothesis that the lower capital cost of an automotive battery outweighs the advantages of a better quality, longer lasting deep cycle battery. Specific issues of charge controller presence and battery quality merit further research.

7.6. Unintended consequences

Here I include the physical consequences of donated stand-alone PV systems on the environment. When asked specifically about negative environmental consequences, most people either said there were none, or they didn't know. Two respondents said that there were negative consequences. One said that the panel draws lightning strikes. Another said that "they say" using the panel generates heat "and it affects humanity." For purposes of this research, the system owned by the latter respondent is considered a success, and that owned by the former is not. Unfortunately, this is not enough information to draw any conclusion about the impact of perceived environmental externalities on system success.

Since very few users saw any negative consequence to having a PV system installed, it might be concluded reasonably that developers need not consider this strongly in project planning. However, it also suggests that developers do an insufficient job in educating users about the potential environmental harm caused by

[76] Research methods preclude robust statistical analyses on these data, as explained in detail in Chapter 4.

improper disposal of lead-acid batteries since no respondent volunteered that as potentially harmful. The lead from spent batteries persists in the communities' environments and can cause harm to human health when batteries are not properly disposed of. Although system users' understandings are the topic of this research, lead contamination is an example of an area where developers can and should assert that they know better than the community. Developers are introducing a toxin into the community without adequately conveying the risks associated with it.

When asked specifically about battery disposal, eleven users said they sell or give them to recyclers or buyers, which is the safest thing to do. None said they bury the battery far from a water source, which is recommended by some donors if beneficiaries are unlikely to have access to a recycler. Many people still had their first battery in place, and did not know what they would do with it at the end of its useful life. Almost all others either throw them away with regular trash or store them indefinitely. One gave it to his children as a toy (!). One uses the lead from dead batteries to make bullets.

It could be hypothesized that proper disposal of batteries would be associated with better training, and therefore better system success. No such relationship between battery disposal and system success is apparent.

Other environmental consequences were reported by users of hydroelectric systems (not included in this study), though not by the PV users who were the subjects of this research. An indirect environmental consequence of hydroelectricity for some communities is reforestation. Some hydros – typically those with more organization and institutional support – participate in upstream reforestation projects that reduce the chances of landslides that will damage the hydro project in a severe weather event and reduce sedimentation and other pollution of the water course that can damage or decrease the capacity of the hydro equipment over time. This added tree cover protects not only the hydro, which may be one of its primary intentions, but provides numerous other benefits (and perhaps costs) to the communities in the watershed. Speaking specifically in the case of weather-related disasters, preventing landslides protects crops and communities that may have been in their paths and protects the river or stream as a water supply, as well as protecting the hydro as an energy source. On an ongoing basis, community members have better access to firewood and other forest products.

Reforestation is not associated with solar energy, and trees may be cut back or cut down to eliminate shading on panels; tree planting might benefit communities' immediate environments, but it does not benefit PV.

7.7. Conclusions

In this chapter, I have considered the characteristics of communities, users and systems that may contribute to system success, considered the unintended consequences of the physical systems, and highlighted the close connection between characteristics and the institutions and relationships that surround these donation projects.

The physical and communications-related isolation of a community is a factor that may have great bearing on the success of systems in that community. However, the limitations of this research precluded me from exploring this. Though there are varying degrees of "remoteness" among the communities in this study, they all had to be relatively easily accessible for me to be able to include them.

However, some features of "remoteness" were captured. System success was greater in communities where respondents knew how to contact the project donor or developer, suggesting that they were not cut off due to distance or lack of communication. More respondents with successful systems knew where and how to access replacement components more frequently than those with unsuccessful systems, suggesting a knowledge of, if not familiarity with, larger towns and cities.

Multi-generational, mixed gender households made it impossible to infer differences in success based on age, gender, marital status, or many other demographics. The causes of failure in *Ladino* and indigenous communities may have been different, with more indigenous households' systems being regarded as unsuccessful because they were technically inoperable (and without foreseeable repair), while *Ladino's* systems were more frequently regarded as unsuccessful because, while operable, they were sub-optimal and did not meet respondents' needs.

Characteristics of system design, installation and hardware varied in their relationships to system success. Some, such as the implementation of codes and standards or knowledge of appropriate battery maintenance, were ubiquitous among systems which could be reasonably compared, and thus yielded no insight. Some characteristics of improper installation, such as wrong azimuth, seem related to system failure. This is not likely causal, but possibly both the inappropriate installation and the ultimate system failure result from inexperienced and improperly supervised vendors or developers. Other hallmarks of purportedly poor or non-standard installation, including panel shading and direct roof mounting, were not shown in this research to be related to success.

Charge controllers, which are often bypassed by users, were present with slightly more frequency in successful systems than unsuccessful systems, which is consistent with industry standards and apparent general assumption among project developers.

Importantly, appropriate selection of deep-cycle batteries was hypothesized to be a predictor of project success. Contrarily, this research shows that successful systems are more likely than unsuccessful systems to contain inappropriate automotive batteries. While not presuming causality, it may be possible that users who are able to amass sufficient capital to replace batteries will opt for batteries with lower upfront costs rather than those with higher capital but lower lifetime costs.

Respondents did not perceive negative environmental consequences, so no comparisons can be made to assess the relationship between this and success. A scientifically well-established potential consequence is lead contamination from improperly discarded batteries was unknown to respondents. While this says nothing of system success, it suggests a systemic weakness in the development paradigm under which these systems are installed.

As illustrated by issues of "remoteness" and battery quality in this chapter, many of these characteristics of communities, users and systems are inextricably enmeshed with the institutions and relationships that surround them, as discussed in the previous chapter, Chapter 6.

Chapter 8. Conclusions

This research was started with a seemingly straightforward question borne out of the frustration of someone who has participated in international development: why must donated rural renewable energy systems in the developing world fail so often? The challenges in answering it begin with the fact that the question itself is not straightforward. What constitutes a "donated" rather than a purchased system when nearly all donors require some level of contribution from beneficiaries? Which rural renewable energy systems can be categorized together, and which will show entirely different characteristics? Which populations are involved? And indeed, how does one even define success and failure?

Among the original goals of this research was to create a statistically valid set of results based on a random sample and consistent survey techniques. This goal was not met. It was sacrificed instead for deeper conversations with deliberately selected individuals, yielding less data but a greater depth and breadth of knowledge – but not statistical significance.[77]

To capture the perspective of those who use and benefit (or not) from these systems required a translation of my questions about success, energy, money, institutions, time and many other factors into questions that made sense to those whose perspectives I wished to understand. Although language was certainly important, the gulf was much broader than trading Spanish for English. That which is reasonable and rational to me can be unacceptable, irrational or even deadly to them.

In this concluding chapter to my research, my goal is to translate back what I have discovered and failed to discover to the language from which I started, the language of developers and their supporters who wish to benefit the poor while protecting the environment. I did my best to listen to the poor in rural Guatemala who someone tried to help by donating stand-alone PV systems. This is what they had to say.

[77] See Chapter 4 for details.

8.1 Success[78]

Characterizing systems as successful or unsuccessful can be complicated, and is more than a simple question of operability. A system may be successful even if it is not currently functioning, or may be unsuccessful even if operating as designed. Three characteristics emerged from this research as important to defining system success:

– *Operability, where a system is either in working order, active steps are being taken to return it to working order, or it was operable during its useful life and has been replaced by something preferable.*
– *User perception, where users see the system as successful, find it useful in their activities, and brings something good.*
– *Optimality, where it meets users' needs to the degree that they would not replace it with something "better" if they had the chance.*

This definition of system success is neither necessary nor sufficient in that some development projects that have had unconscionably negative results could still be seen as successful here, and some that fail to meet one or more have provided real benefit.

Among the greatest challenges to identifying systems as successful from the perspectives of users is that users may have motivation to portray their systems as successful to anyone they associate with the development community. Perhaps they will seem ungrateful, ignorant or incapable of maintaining successful projects if they are willing to point to a system as unsuccessful. However, some themes are recurrent in users' views of success. Many spoke of agency: they were able to achieve something in getting and maintaining their systems. Others spoke of outcomes: they were the grateful beneficiaries of the decisions of others.

Perhaps the most difficult question in the definition of success is one not addressed by this research at all. This study was constructed with the presupposition that a greater percentage of successful systems was

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[78] See Chapter 2 for details.

synonymous with a more successful project or program. That definition of success comes at a cost. Those users who are most likely to have successful systems are those comparatively less likely to have needed the donation, so achieving a higher percentage of successful systems can mean exacerbating inequity and excluding the poorest and most marginalized households and communities. Higher rates of "failure" should perhaps be expected for programs that are "successful" in helping the poorest of the poor. This implies that program evaluation should use measures and descriptors of "success" that are broader than mere technical functionality, and broader than the definition used in this research.

8.2. Money[79]

All users included in this study were unquestionably poor, some more than others of course. The reality of the economic hardships faced by users and the monetary costs necessarily associated with the systems made money a recurring theme. Whether speaking of costs or benefits, everyone had something to say about money.

Most beneficiaries of the donated systems studied in this research saved money in real dollars by having the systems, with economic benefits accruing over time. The reduction in expenditures on candles, kerosene and other forms of traditional lighting more than offset the cost of replacement of the PV system batteries every three to five years. These real cost reductions mean the economically rational decision would be to save a portion of the money not spent on traditional lighting sources every month and spending those savings on battery replacement when needed. However, this was frequently not done. The economic rationality argument presupposes a "reasonable" discount rate, and an expectation that if replacement batteries were not saved for, the system would no longer function. However, those living in poverty and extreme poverty, perhaps more importantly, perpetual uncertainty and insecurity may have discount rates that approach infinity. What is the value of a dollar in three years when you do not know whether you will be alive a year (or a day) from now? This economic rationale also presumes that "willingness to pay" and "ability to pay" are synonymous. The decision to buy food rather than saving for battery replacement when subsistence crops fail is a rational decision, regardless of long-term economic impact.

[79]See Chapter 5 for details.

Access to capital was a greater barrier to system maintenance than was real cost. Batteries are expensive. When saving for them is undesired or simply unrealistic, users must amass a considerable quantity of money at one time. This is hardest for the poorest system users, who rely on subsistence agriculture and barter rather than cash more often than their relatively wealthier neighbors.

Not all supposed beneficiaries in fact gain cash benefits from using their PV systems. Some households, as well as community buildings like schools and clinics, incur additional expense in maintaining PV systems as compared to traditional energy sources. Some recipients of donated PV systems realize economic benefit by selling the system rather than from long-term cost savings on household energy expenses.

Opportunities for earning additional income from donated PV systems were few – such as additional sales realized by shopkeepers who were able to conduct business after sunset – and incremental income was small. Any lost income at the community level – from reduced sales of candles, for example – was also small, and was considered inconsequential even to those who sold candles.

Thus, the largest economic benefits of these donated stand-alone solar electric systems in rural Guatemala were realized by the "rich among the poor," both because they were most able to access the capital needed for system maintenance (and thereby maintain the energy cost savings that were lost to their neighbors who could not afford maintenance), and because they were those most likely to realize the few additional income opportunities. Importantly, this research does not show that the donation of these energy systems will necessarily aid in poverty alleviation for all beneficiaries – although it may for some – and may in fact contribute to economic inequity within communities.

8.3. System Use[80]

The systems included in this study were used for lighting. The light was viewed to be of better quality than light from traditional sources, and in many cases had benefits such as enabling children to study at night and strengthening family bonds by allowing people to more easily see one another and communicate. Another common use of energy was cellular telephone charging. If even one person in a community had electricity, this allowed at least a few people to charge cell phones, which in turn gave the community much more ready access to people outside the community. By virtue of a single system and telephone, the community becomes less remote. The addition of radio and television in some households with PV systems further brought the community in closer contact with happenings outside of the community. This greater access was not ubiquitously found to be good: some disliked the distraction of television and its interference with time the family could spend together.

Almost everyone wanted more energy than their PV systems could produce. People wanted refrigerators, and women specifically wanted blenders and electric irons, whether or not they would have been able to afford these appliances if the energy for them were available. The desire for blenders and irons is remarkable in that they are easily considered "conveniences" where other energy applications (such as water pumping, for example) are considered necessities. But whether it is time saved chopping food or time saved carrying water, the effect is the same for the women involved: time is saved. This begs the question to the development community: do we consider sufficiently the desired end result, and do we achieve that in ways that are most useful to beneficiaries and most cost-effective to donors? I have yet to hear of a solar home system that was sized to meet a demand that included a blender.

System usefulness affected success in an unexpected way. I did not find that systems were more or less likely to be successful because of the types of uses to which they were put. However, those who could afford to purchase more appliances than their systems were designed to power were likely to consider their

[80] See Chapter 5 for details.

systems sub-optimal, where those who could not have purchased color televisions or refrigerators even if their systems could power them were more likely to find PV to be an optimal solution.

8.4. Institutions and relationships[81]

The political context of Guatemala negatively affects development and poverty alleviation, including in the area of rural electrification. The state is in large part corrupt and ineffective and, perhaps equally detrimentally, is believed by its people to be so. Bribery, embezzlement, drug trafficking, money laundering and even political assassinations are believed to be rampant among the elite. Schools, food assistance and other social services are plundered by the officials responsible for administering them while people sometimes literally starve to death. Confidence in the justice system is so low that murder and similarly severe crimes are increasingly punished by lynch mobs. The legacy of the civil war and the impunity with which crimes against humanity were committed have left many people, especially among the indigenous, deeply distrustful and fearful of the government. Extreme poverty and racism persist. The covert and sometimes overt control exerted by drug cartels and other crime syndicates over large parts of the country mean that, in some places, there is no functioning government and people are subject to the "justice" of terrorist organizations like Los Zetas.

However, much of that is, to a degree at least, removed from people's daily lives, and more local and involved institutions can help rather than hinder the people included in this study and the success of their systems. Continued involvement of the donor or development organization was strongly associated with system success. Two reasons emerged in this study for this association that suggest that this correlation was a cause and effect relationship. First, the donor was available to help with advice, technical assistance, negotiation with a vendor for warrantee service, and in a few specific cases, material assistance for maintenance.

The second reason dealt with accountability. When users were accountable for the state of their systems to an outside party, such as the panel owner in hybrid-ownership arrangements, an inter-community project

[81] See Chapter 6 for details.

governance structure, or the donor in cases when the beneficiary hoped to continue to receive development assistance from the donor, users applied more of their resources and efforts towards upkeep of their systems than did users in analogous situations who did not have this accountability. That beneficiaries can be held accountable to donors highlights the power inequity that invariably exists between the parties, which can be (and occasionally is) abused.

The idea that accountability leads to system success is a dramatic break from the established wisdom in the development community about project ownership. It is nearly universally believed that users who have a sense of ownership of their systems, especially if they have committed their own financial resources to the project, will have greater motivation to maintain their systems and have better success rates. This was not found in this research. In addition to the lack of accountability to anyone but one's self, those who owned their systems could and sometime did exercise the prerogative to sell the components.

Local governance structures or maintenance cooperatives were created with the implementation of the PV projects in most communities included in this study. Most of these governance structures fell apart quickly. In contrast to micro-hydroelectric plants which connect to houses via a microgrid, PV systems were physically independent from one another. Where physical interdependence required or at least strongly encouraged cooperative administration and maintenance, physical independence did the reverse. If every household must contribute enough to a maintenance cooperative to maintain its own system, why should the household not save money on its own? This is what economists call the "free rider" problem of joint action.

However, local governance structures and savings cooperatives were successful in some communities included in this research. Communities in which local project governance structures were successful also saw a greater degree of success among systems in the community. There are many potential reasons for this, one of which might be that the institutional burden is removed from the household: a lone household with a PV system must be its own electric company, making all decisions and incurring all expenses independently.

In addition, user involvement in project origination, planning and implementation also did not lead to system success. The availability of adequate technical and administrative training, however, was found more among users of successful systems than users of unsuccessful systems. This was true whether the training was informal one-on-one training at the time of installation or if it took place in more structured group lessons. Whether training was available to users or not, all were interested in further training sessions.

The final conclusion about institutions and relations concerned how intra-community relationships were affected by these projects. These effects were important. Some users spoke of a greater sense of community that emerged from working together to create or implement the project, or from being able to spend more time with neighbors at night as a result of having light. People did not see religious or cultural conflict resulting from the projects, even in the few cases where some people were excluded either by self-selection or for reasons thought to be the fault of the donor. However, in a few other cases where people were instead excluded from the project by members of the community, resentment was obvious though the consequences of that resentment are unclear. Notably, exclusion can in fact improve project success rates. If those who are least likely to successfully maintain a system are excluded, then the percentage of successful systems will increase. Here project donors and developers must carefully consider the goals of their programs before engaging in a project with this type of exclusion: the resulting increased success rate comes at a social cost.

8.5. User and community characteristics[82]

Some characteristics of users and communities can be linked to system success while others cannot be related to success by this study due to methodological limitations.

Perhaps the most significant conclusion of these analyses about user and community characteristics is that these characteristics cannot be considered independent and exogenous variables when analyzing system success. Interactions with vendors and donors, institution building, and the introduction of the technology

[82] See Chapter 7 for details.

itself all feedback and change the characteristics of the beneficiaries and their communities. Additionally, communities are often chosen as beneficiaries based on characteristics that are convenient to developers or which donors believe will lead to system success, which introduces a selection bias in the analyses of success based on those characteristics.

The concept of a community's "remoteness" is an example of a characteristic that cannot be considered an independent variable in these analyses. Firstly, donors and developers often chose communities that are easily accessible as beneficiaries of donated stand-alone solar electric systems. Accessible communities reduce logistical and transportation expenses and problems, allowing more beneficiaries to be served with the same resources. Projects may include the improvement of community access for the benefit of project development personnel and the transport of project-related materials. Additionally, in order to reduce resource demands and safety concerns during the course of this research, the communities included in this study were limited to those that were relatively easily accessible. The addition of PV systems in remote communities allows better communication – primarily via cell phone – which makes communities less isolated, even if it does not reduce the actual time required to travel to or from a community. In aggregate, then, the seemingly independent variable of community accessibility or remoteness is instead interdependent with the project itself.

Indeed the concept of remoteness cannot be measured in kilometers from a city or even kilometers from a passable road. Remoteness instead is very much a function of means of transportation, which is in turn a function of wealth. Someone who must walk all day to reach an intended destination – and then return walking with a heavy piece of equipment – lives much more remotely than does someone who owns a truck or a horse and can cover as long or longer a distance in less time and with less effort.

The predominant ethnicity of members of beneficiary communities was related to ongoing system operability, with *Ladino* communities showing overall greater success in maintaining their systems than communities populated primarily by indigenous peoples. This result raises more questions than it answers. The *Ladino* communities were in aggregate wealthier than indigenous communities, and wealth was independently found to relate to success. *Ladinos* also categorically have more education, are more likely to speak Spanish fluently, and seem to be regarded as constituents rather than subjects by their political leaders. Indigenous populations have been subjected to a paternalistic government culture which, for centuries, has prohibited initiative and self-determination upon pain of death. Thus simply having learned not to take initiative in anything may have hindered indigenous peoples from taking the initiative to maintain their systems; they were more likely to express the expectation that "someone else" – namely the project donor – should be responsible for the physical and economic maintenance of their systems. Notably, wealthier *ladino* beneficiaries were more likely to have systems that failed based on the condition of optimality: although their systems were functioning as intended, they did not succeed because they did not sufficiently provide for beneficiaries' energy needs.

Beneficiary households were multigenerational and mixed-gender, in largest part, and that precludes any analyses of success based on age, gender, family status, or other demographics that would vary within a community. Women took less active roles in projects, including their initiation and governance, and were less likely to agree to be interviewed for this research if a man were available to respond. In many cases, women were not welcome to be a part of project administration. In cases where women were permitted to be involved, men and women agreed that women were less involved because a woman's work at home took precedence for her time.

8.6. System physical characteristics[83]

This research does not strongly support the firmly held belief in the development community that higher quality design, installation and components should lead to greater system success.

No systems in this study met the National Electrical Code standards for PV installation. The NEC has been adopted by Guatemala, but never implemented or operationalized, even by the Ministry of Energy and Mines, which was responsible for its adoption. Similarly, although many PV panels were stamped with UL

[83] See Chapter 7 for details.

or CE certifications,[84] many of these stamps appeared to be forged and at least one distributor in Guatemala procures panels from a U.S. company that is under investigation for fraudulent use of the UL certification. As such, the effects of compliance with these codes cannot be assessed in this research.

Notably, however, systems that included panels that appeared to be of good quality did not succeed at higher rates than did those with apparently low-quality panels, as long as the panels were mono- or polycrystalline PV rather than thin-film technology. Proper maintenance of panels, including clearing shading and cleaning, did not appear to relate to success.

The statistical significance of the following observations cannot be tested due to in ability to obtain random samples or controls. However, a few technical features did appear to relate slightly to system success. The use of inexpensive automotive batteries in place of more suitable, albeit more expensive, solar or marine deep-cycle batteries was found slightly more among successful systems than among unsuccessful systems, suggesting that people's ability to replace batteries with a lower-cost alternative may be of greater benefit than the reduction in real cost over the long term that could be obtained by using the better battery. Slightly more successful systems than unsuccessful systems had functioning charge controllers, although the difference in frequency was not large. Proper allowance of airspace under the panel, as required by industry standards, did not lead to system success; greater numbers of successful systems than unsuccessful systems were mounted flush with a rooftop, which may add stability and accessibility at the expense of adequate ventilation.

Independently of system success, users were not educated about proper disposal of used components. Lead-acid batteries in particular can pose threats to human and environmental health. While some users knew that the "best" thing to do with their spent batteries was to give or sell them to a battery recycler, few knew that improper disposal could be a threat to their families or communities.

[84] U.S. and European, respectively, quality standards evaluators.

8.7. Applicability and limitations of results

This research is intended to contribute to the body of knowledge about electrification in rural development by expanding the understanding of the realities of development within the academic community, and by providing information that can contribute to greater project success among governments, donors and development organizations. However, context impacts the results of a study or evaluation (White and Bamberger, 2008), so these results reflect outcomes for stand-alone PV systems that met my selection criteria.

One limitation of this research is my inability to draw valid statistical inferences from the data gathered. Firstly, the data are from a non-random sample of PV system users. Further, the data was gathered in semi-structured interviews that focused on topics of greatest interest to individual users, rather than being gathered from a consistent survey instrument used with all respondents. Though this precludes statistical inference, it allowed for a greater depth and breadth of knowledge to be gained from the users whose perspectives were the intended subjects of this research.

Another limitation to these results is that only rural stand-alone PV systems were included. Anecdotal observation suggests that interconnected systems such as micro-hydroelectric systems may have very different outcomes. The data are further limited to rural communities in Guatemala and to a few specific development programs.

That many of the causes of success and failure observed in this research are likely to be present in other contexts is a hypothesis that merits future study, and is not a conclusion of this research.

8.8. Areas of future research

Many factors that might be expected to influence the success of stand-alone PV systems in Guatemala are not explicitly included in this study. This section includes areas for further research that were highlighted by this study. Except where otherwise noted, a methodology analogous to that used for my research could be used to explore these questions.

Comparison of these results to similar studies in other countries in the region and other regions in the world, and to studies of other rural electrification technologies in the same locations will lend insight into which factors are more universal and which are particular to Guatemala or to stand-alone PV systems. The contrasts between stand-alone PV systems and the community-interconnected micro-hydroelectric systems I observed while conducting this study were at times remarkable. A comparison of the outcomes of electrification using stand-alone systems as compared to community interconnected systems could yield information on the means of electrification that are most effective for communities and most cost-effective for donors, and what circumstances drive those decisions.

Beyond these general comparisons, topics meriting further investigation include questions of development work done under existing aid and development paradigms, direct and indirect economic impacts of systems, and the influences of culture and peoples' roles in society on system success. I discuss each of these in the following subsections.

8.8.1. Development paradigms

This research challenges the long-held ideas that user contribution to projects (in cash or in-kind) and that user ownership of systems lead to greater system success. These hypotheses were not borne out by the data in general. Because this result differs markedly from received wisdom, these results should be confirmed by further investigation in this and other populations. One of the hypothesized reasons that ownership does not lead to success is that the donor did not contribute what beneficiaries actually wanted or needed and as such beneficiaries did not value it regardless of their contribution or of ownership structure. To test this hypothesis, a comparison could be made of these factors in communities that initiated projects and requested solar home systems from a donor versus those that accepted projects when offered but did not actively pursue them before the donor presented the idea.

None of the beneficiaries in this research had the benefit of further training on the maintenance of their systems after the initial implementation was complete, although some participated in more thorough training than others. The timing of the training is significant in that it predates the need for battery replacement – usually the first major maintenance item with a stand-alone PV system – by several years. An examination of the success of systems for users who are given supplemental training after three years (the minimum length of time that a reasonably well maintained battery should last) could inform future development projects if a short refresher course at that time increased long-term success significantly.

The development community values and invests resources in non-verbal documentation for instruction and reference in populations with low literacy: if people cannot read, make the instructions pictorial or graphical. This is logical and is used in developed world instructions that are sent with products to countries that speak different languages (for example, Ikea furniture and Lego toys are sold with graphical instructions). However, anecdotes suggest that people with low or no literacy benefit less from these types of instruction manuals than might be supposed. The idea of referring to a piece of paper to learn to do something is almost self-evident to those who live in highly literate societies. However, those who do not read have little experience with expecting to find information in written or illustrated form, and may be less likely to value or preserve paper. A question pertinent to the success of rural renewable energy systems but excluded from this research is whether receiving physical documentation on system maintenance aids in system success, and whether those with low levels of literacy preserve and make use of non-verbal instruction sheets at the same rate as their more literate peers. Do those who cannot read have the means and motivation to keep any documents, including legal documents like birth certificates or land titles and "helpful" documents like PV maintenance instructions? If pictorial instructions that accompanied a donation are preserved, are they used by either literate or illiterate beneficiaries?

8.8.2. Economic implications

The only economic or vocational activities explicitly included in this work are those that users claimed were influenced by the PV system directly, and not the indirect economic effects such as improved health and education, greater knowledge (enabled by cell phone coverage) of seasonal jobs outside the community, or trickle-down impacts in which people who directly benefited from the systems would, as a result, hire more labor or buy more goods from local sources. System success may be influenced by the nature of users' economic activities: do those who must travel for wage labor see less success because they are home with their systems less?; are those with more technical careers better able to maintain their systems?; does the timing of income (seasonal versus weekly or monthly) change system success?; what financing mechanisms are available, and how do they change system success?

All respondents perceived light quality to be better with solar or other electric lighting sources than with traditional lighting sources such as candles, gas lamps and *ocote* torches. Among these, *ocote* provides the lowest quality of light and creates the most unpleasant indoor air quality effects, but it is not purchased; users cut it from nearby trees for free. To better understand the threshold between willingness to pay and ability to pay, traditional users of *ocote* who have received donated solar home systems merit further study. *Ocote* users have the most utility to gain from the use of electric light, compared to users of gas lamps or candles, but they are also generally the poorest users, who settle for *ocote* because they cannot afford better sources. Two possible hypotheses suggest themselves: either *ocote* users will be more successful with their solar home systems because they have so much to gain, or they will be less successful because they have so few resources to maintain their systems. Such an analysis would shed further light on the questions surrounding system success and failure, and would require a more ethnographic methodology, spending more time with individual beneficiaries to understand their motivations and decisions.

One important question for future study is how the success and failures of these systems differ from those of systems purchased by their end users, which were not examined in this dissertation. In addition to systems purchased in retail markets, I am interested in a phenomenon I call "secondary beneficiaries." Donated panels are often sold on the black market, but this does not end their useful lives in providing electricity to the rural poor. Many of these panels seem to be purchased by local elites – people poor by traditional definition, but wealthier than their neighbors. They become beneficiaries of donated projects since they are able to purchase systems to provide themselves with electricity when purchasing the same system from a retailer would be economically infeasible. The research questions I seek to answer are these: who are the purchasers of donated systems that are then sold; how successful are these systems compared to those that are kept by intended beneficiaries and those purchased through legitimate retail markets; and although the end users are not the intended beneficiaries, are the benefits to them consistent with donors' development goals?

The economic analyses in this research[85] suggest that most users should be able to reduce their energy expenditures by saving for PV maintenance rather than purchasing candles and kerosene as needed. These theoretical cost reductions could be achieved by simply saving cash – an amount less than or equal to a household's previous monthly expenditures on candles and gas – as long as the PV system is in operation. At the end of the useful life of the battery or other components, the savings fund would more than cover the maintenance expenses. However, this sort of cash saving is uncommon and perhaps unrealistic for a variety of reasons discussed in Chapter 5. Community-level cooperatives that help users save only for solar home system maintenance have not met with tremendous success, possibly in part because they end up restricting a large portion of a household's assets for a long period to a single purpose: PV maintenance.

A research question suggested by this phenomenon is whether the financing mechanisms available to users strongly influence system success. Would savings accounts that allow users to withdraw money for other large expenses rather than solely for solar home system maintenance lead to greater cash savings and would that in turn lead to greater system success? Would credit programs that provided maintenance loans be repaid consistently enough to make them viable? Would group-based savings or borrowing programs help? Is a portfolio of financial options necessary to increase system success? This could be investigated by studies of development interventions involving microfinance in Guatemala. As few of these are in place, new microfinance interventions should be implemented with careful assessment mechanisms included in all stages of planning, implementation and follow-up.

8.8.3. Cultural influences

Although many aspects of culture were included in this research, many more remain uninvestigated. Gender and religion have been suggested to play significant roles in the outcomes of development interventions, though they were not studied in depth in this research.

[85] See Chapter 5 for details.

This research did not differentiate female-headed households from those headed by men. Women typically spend more time working inside the home and therefore derive greater benefit from donations that make work inside the home less burdensome. A question left unanswered by these analyses is whether systems donated to female-headed households succeed at a greater rate because women use or value them more, if women's traditionally lower incomes make them less likely to be able to maintain their systems, or whether the gender of the head of household influences or fails to influence system success for other reasons.

Religion is suggested to be a driver of or proxy for modernizing ideas: do the systems of Protestant or Evangelical Christian families succeed at greater rates because of their supposed greater adaptability than traditional Catholics; does the impact of religion depend on local religious leadership rather than on broad expectations of religious beliefs; or is religious identification irrelevant to system success?[86] Future research on stand-alone PV systems in rural Guatemala will also narrow the focus of this study: what are the factors that will lead to greatest system success in very poor, indigenous communities, and what prior interventions are prerequisite in the poorest of these communities for system success?

8.9. Summary

This research has provided answers to many questions about the success of electrification for the rural poor. Some were predictable: modern energy sources allow modern means of communication such as cell phones and television; cost is a barrier to system maintenance; and weak national institutions impede the process of electrification. Others were more surprising and, at times, uncomfortable for sponsors of rural energy development programs: user ownership does not lead to system success; wholly donated systems can be a cost burden for beneficiaries; excluding already marginalized people from donation programs could lead to a higher percentage of successful systems.

In aggregate, this study has led to more questions than answers. Many questions will not be answered definitively by any study, but can only be answered by the specific population that is gaining access to

[86] Anecdotal

electricity for the first time. That, perhaps, is the most useful conclusion this work provides to those who are interested in development through electrification: know the individuals involved before you begin, and invest in maintaining that relationship to enable them to invest in maintaining their energy systems.

Appendix A: Survey Instrument

"N/A" indicates a question was not used.

CUESTIONARIO COMUNIDADES

1. INFORMACIÒN GENERAL

País: ______________________ Boleta No. ______________

Departamento: ______________________ Tiempo en operación: __________

Municipalidad: ______________________ Tipo de ER: ______________________

Comunidad: ______________________

Fecha de entrevista: __________________

Vivienda No. ________________

Persona entrevistada (ALIAS): ____________________________

Miembro de comité: __________________ Puesto: _____________________

2. INFORMACIÒN DEMOGRÀFICA

No.	Edad ADULT OR CHILD	N/A	Sexo	N/A	Idiomas que habla				N/A	N/A
							Castellano	Otro		

a) Usted usa el sistema de ER? 0a

- ☐ No
- ☐ Sí

Todas las preguntas que le voy a hacer se refieren a su sistema de energía renovable.

3. ANTECEDENTE DEL PROYECTO Y SOCIALIZACIÒN

a) Cómo se originó el proyecto? 21a1

____

____

____

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b) En que año se instaló el proyecto? ____.

c) Cómo se financió el proyecto? 2-16

---

d) La comunidad tuvo que hacer alguna contribución (mano de obra, material, efectivo, etc.) para la implementación del proyecto? 5a

- ☐ No
- ☐ Sí
- ☐ No sé

e) Cuál fue la contribución? 5b

---

f) El proyecto que tienen ahora es el que planearon originalmente? 21a2

- ☐ No
- ☐ Sí

IF NO, CONTINUE, IF YES, GO TO E)

g) Cuáles fueron sus expectativas originales? 21a8

---

h) Me puede platicar qué cambios hicieron? 21a3

---

i) Porqué se hicieron esos cambios? 21a4

---

j) Estuvieron de acuerdo con el cambio? 21a5

- ☐ No
- ☐ Sí

k) Cómo cambiaron sus expectativas del proyecto con el cambio? 21a9

---

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l) La comunidad fue consultada e informada durante todo el proceso de planeación? 21a6

- ☐ No, para nada
- ☐ No mucho
- ☐ Más o menos
- ☐ Sí
- ☐ Completamente

m) IF YES, cómo? *Ask specifically about reuniones de socialización and if they were enough. 21a6a

n) La comunidad pudo participar durante el proceso de implementación? 21a7

- ☐ No, para nada
- ☐ No mucho
- ☐ Más o menos
- ☐ Sí
- ☐ Completamente

o) IF YES, cómo? 21a7a

p) Usted ha participado de forma activa? 21f

- ☐ No, para nada
- ☐ No mucho
- ☐ Más o menos
- ☐ Sí
- ☐ Completamente

q) IF YES, de qué forma? 21g

r) Normalmente la comunidad participa de forma activa? 21h

- ☐ No, para nada
- ☐ No mucho
- ☐ Más o menos
- ☐ Sí
- ☐ Completamente

s) Cómo se llevan con el desarrollador del proyecto? 21h4

t) Cuáles son las partes buenas de esta relación? 21h5

u) Cuáles son las partes difíciles de esta relación? 21h6

v) Hay participación activa por parte de la municipalidad? 21i
- ☐ No
- ☐ Sí

w) Si no, porqué? 21j

x) Si sí, cómo? 21k

y) Hay participación activa por parte del departamento? 21i1
- ☐ No
- ☐ Sí

z) Si no, porqué? 21j1

aa) Si sí, cómo? 21k1

bb) Todavía mantienen contacto con el desarrollador/donante? 21l
- ☐ No
- ☐ Sí

IF no, go to next section.

cc) Si sí, de qué forma? 21m

dd) Están planeando más proyectos para la comunidad con este desarrollador/donante? 21n

- ☐ No
- ☐ Sí

ee) Si sí, cuáles? 21o

ff) Están planeando más proyectos para la comunidad con otro desarrollador/donante?

- ☐ No
- ☐ Sí

gg) Si sí, cuáles?

hh) Cuáles son otros proyectos recientes?

4. USOS

a) Para qué lo usa? 0b

- ☐ Usos productivos — IF yes, go to section 4.1
- ☐ Uso doméstico — IF yes, go to section 4.2
- ☐ Uso comunitario — IF yes, go to section 4.3

4.1. USO DOMÉSTICO

Me gustaría platicar con usted sobre el consumo de energía en su hogar y el impacto que ha tenido el sistema de ER a nivel doméstico.

Note: Leña will not include that for cooking or heating since the system will not impact that.

a) Cómo usa la energía en su vivienda? Por ejemplo, para iluminar, para cocinar, para trabajar (costura, carpintería), para agua para su vivienda 2g

b) Está a gusto con la energía? 2h

- ☐ No
- ☐ Sí

c) Si no, porqué? 2i

---

d) Hay algo más que le gustaría hacer con esa energía? 2j

Additional questions based on energy consumption chart.

e) Porqué tiene que complementar su consumo de energía con otras fuentes? 2k

---

Antes del proyecto
1 – 1h

LENA					CANDELAS				GAS O KEROSENE				OCOTE				BATERIAS			
Compra o recoge	Precio unidad	duración	Consumo		Precio	duración	Consumo		Precio	duración	Consumo		Precio	duración	Consumo		Precio	duración	Consumo	
			Día	Mes			Día	Mes			Día	Mes			Día	Mes			Día	Mes

PROPANO					DIESEL				OTRO				OTRO				OTRO			
Compra o recoge	Precio unidad	duración	Consumo		Precio	duración	Consumo		Precio	duración	Consumo		Precio	duración	Consumo		Precio	duración	Consumo	
			Día	Mes			Día	Mes			Día	Mes			Día	Mes			Día	Mes

Después del proyecto

LENA					CANDELAS				GAS O KEROSENE				OCOTE				BATERIAS			
Compra o recoge	Precio unidad	duración	Consumo		Precio	duración	Consumo		Precio	duración	Consumo		Precio	duración	Consumo		Precio	duración	Consumo	
			Día	Mes			Día	Mes			Día	Mes			Día	Mes			Día	Mes

PROPANO					DIESEL				OTRO				OTRO				OTRO			
Compra o recoge	Precio unidad	duración	Consumo		Precio	duración	Consumo		Precio	duración	Consumo		Precio	duración	Consumo		Precio	duración	Consumo	
			Día	Mes			Día	Mes			Día	Mes			Día	Mes			Día	Mes

4.2. USOS PRODUCTIVOS E INGRESOS MENSUALES (ANTES Y DESPUÉS)

3 - 4

N/A														

Otro:

a) El sistema de ER le ha permitido tener mayores ingresos? 4g5
- ☐ No
- ☐ Sí

b) Cómo? *Ask specifically about additional productive use applications powered by the RE system 4g6

---

c) Usted sabe si el sistema de ER ha permitido a otros miembros de la comunidad tener mayores ingresos? 4g7
- ☐ No
- ☐ Sí

d) Cómo? 4g8

---

e) Usted sabe si el sistema de ER ha causado a otros miembros de la comunidad perder ingresos? Por ejemplo, hay alguien que antes vendió candelas pero ahora no?
- ☐ No
- ☐ Sí

f) Cómo?

g)	Hay algo más que a usted le gustaría que el sistema de ER hiciera para que pudiera generar más ingresos?	4g9

4.3. SERVICIOS ENERGÉTICOS

a) Me gustaría que me platique ahora sobre los servicios con los que cuenta la comunidad, si éstos tenían energía antes del proyecto, si tienen energía después del proyecto y si ha notado diferencias en la calidad de energía.

11a, 11b, 12, 13

SERVICIO	ENERGIA ANTES	ENERGIA DESPUES
Iglesia		
Escuela		
Centro de salud		
Centro comunitario		
Alcaldia		
Otro		
Otro		

*In case there were energy services before:

b) Usted nota algún cambio en la calidad de la energía antes y después del sistema de ER? 14

- ☐ No
- ☐ Sí

c) Le ha beneficiado que haya luz en estos lugares? 15

- ☐ No
- ☐ Sí

d) IF no, porqué? 15a

____

____

____

e) IF yes, cómo? 15b

____

____

____

5. GOBERNABILIDAD

Las siguientes preguntas se refieren a la estructura de organización que tienen para el sistema de ER.

a) Tienen algún comité u otra estructura de organización para el sistema de ER? 20a

- ☐ No
- ☐ Sí
- ☐ No sé

b) IF NO: Quien tiene responsabilidad por el sistema?

____

____

c) IF YES: Qué tipo de estructura es? 20c

- ☐ Comité
- ☐ Asociación
- ☐ Cooperativa
- ☐ Sociedad
- ☐ Otro

d) Qué objetivo específico tiene este [ESTRUCTURA]? 20x2

e) Usted participa en este [ESTRUCTURA]? 20h

- ☐ No
- ☐ Sí

f) IF no, porqué? MAYBE ASK HERE WHETHER THEY'RE ELIGIBLE TO PARTICIPATE? 20i

g) IF yes, cómo? 20j

h) Normalmente hay participación activa por parte de los miembros del comité y usuarios? 20y

- ☐ No
- ☐ Sí

i) Hay participación activa de las mujeres? 20g

- ☐ No
- ☐ Sí — If asking a woman: Cómo le gustaría participar? 20g3

j) Si no, porqué? 20g1

k) Si sí, cómo? 20g2

l) La [ESTRUCTURA] está legalmente establecida? 20b

- ☐ No
- ☐ Sí
- ☐ No sé

m) Cómo está formada? 20d

n) Ustedes eligen a las personas para ocupar puestos? 20k

- ☐ No

- ☐ Sí
- ☐ No sé

o) Me puede explicar el proceso bajo el cual los eligen? OR CHOOSE, IN THE EVENT THAT THEY AREN'T ELECTED 20l

____

____

____

p) Existe algún reglamento interno o algo similar? 20e

- ☐ No
- ☐ Sí If yes, puedo verlo?
- ☐ No sé

q) Cómo se toman las decisiones? 20f

____

____

____

r) Tienen reglas claras sobre el manejo del sistema? 20m

- ☐ No
- ☐ Sí
- ☐ No sé

s) Me puede platicar estas reglas? 20n

____

____

____

t) Tienen algún sistema para implementar reglas, por ejemplo, sanciones a quien no cumpla las reglas? 20o

- ☐ No
- ☐ Sí
- ☐ No sé

u) Me puede platicar este sistema? 20o1

____

____

____

v) Tienen diferentes sanciones dependiendo de la falta cometida? 20p

- ☐ No
- ☐ Sí
- ☐ No sé

w) Tienen algún método para definir si los miembros del [NAME] han cumplido con sus funciones, por ejemplo, reuniones con la comunidad donde expliquen lo que han hecho? 20q

- ☐ No
- ☐ Sí
- ☐ No sé

IF no,

x) Cree que sea necesario? 20r

- ☐ No
- ☐ Sí

IF yes,

y) Cree que sea útil y suficiente? 20s

- ☐ No
- ☐ Sí

z) El COCODE, la municipalidad, o alguna otra entidad del gobierno ejercen influencia sobre el [ESTRUCTURA]? 20t

- ☐ No
- ☐ Sí
- ☐ No sé

aa) Si sí, de qué forma? 20u

---

bb) Cree que ha sido útil esta influencia o participación? 20v

- ☐ No
- ☐ Sí

cc) Si sí, porqué? 20w

---

dd) Cree que el [ESTRUCTURA] esté cumpliendo con su objetivo? 20x

- ☐ No
- ☐ Sí

ee) Porqué? 20x1

---

ff) Cuáles cree que sean las contribuciones más grandes que ha tenido el [ESTRUCTURA]? 20z

---

---

gg) Hay algún otro comentario que le gustaría hacer sobre el [ESTRUCTURA]? 20aa

---

---

6. ESTRUCTURA TARIFARIA

Las siguientes preguntas se refieren a la tarifa que pagan para el uso del sistema de energía renovable.

a) Ustedes pagan alguna tarifa para usar el sistema de ER? 5c
- ☐ No
- ☐ Sí
- ☐ No sé

b) Cuál es la tarifa? ________________________________ 6h/6i

c) Usted está en posibilidad de pagar esta tarifa? 6l
- ☐ No
- ☐ Sí

d) IF NO, es más de lo que pagaba anteriormente? 6l1
- ☐ No
- ☐ Sí

e) Usted sabe como se decidió esta tarifa? 6a
- ☐ No
- ☐ Sí

f) El [ESTRUCTURA] se encarga de los cobros? 6b
- ☐ No If No, ask i)
- ☐ Sí
- ☐ No sé

g) Cómo está estructurada esta entidad? ____ 6c

____

____

____

h) Ustedes reciben estados de ingresos y egresos? 6e
- ☐ No
- ☐ Sí
- ☐ No sé

i) Con qué frecuencia? ____________________________________ 6f

j) Sabe para qué usan el dinero? 6e1
- ☐ No
- ☐ Sí
- ☐ No sé

k) Para qué? 6f1

____

____

l) Sabe si la tarifa cubre todos los gastos de O&M del sistema? 6j
- ☐ No
- ☐ Sí
- ☐ No sé

m) Si no, porqué? *Ask committee members how difference is covered. 6k

n) Usted sabe qué hacer si tiene alguna pregunta, queja o comentario sobre el sistema o la tarifa? 6g

- ☐ No
- ☐ Sí

7. CAPACITACIÓN

a) Han tenido sesiones de capacitación? 21p

- ☐ No
- ☐ Sí
- ☐ No sé

b) Cuántas capacitaciones han tenido? ______________________________ 21p1

c) Usted participó en las capacitaciones? 21p4

- ☐ No
- ☐ Sí En cuáles? ____________________________________ 21p5

d) Cuánta gente ha participado en las capacitaciones? 21p3

e) Qué temas se cubrieron? *If O&M, admin., and disposal of components not mentioned, ask specifically 21p2

f) Cree que fueron útiles las capacitaciones? 21p6

- ☐ No
- ☐ Sí

g) Si no, porqué? Qué faltó? 21p7

For técnicos and financial/admin. staff:

h) Considera que le dieron suficiente capacitación? 21p8

- ☐ No
- ☐ Sí

i) Si no, porqué? 21p9

j) Está planeando tomar sesiones de re-capacitación? 21p10
- ☐ No
- ☐ Sí

k) Considera necesario realizar sesiones de recapacitación? 21p11
- ☐ No
- ☐ Sí

l) Hay alguna otra capacitación que le gustaría tomar para mejorar sus funciones? 21p12

8. RESOLUCIÓN DE PROBLEMAS

a) Han tenido problemas con el sistema desde que se instaló? 21p16
- ☐ No
- ☐ Sí

b) Qué tipos de problemas? 21p17
- ☐ Técnicos
- ☐ Cobros
- ☐ Otro

c) Me puede dar más detalles? 21p17a

d) Lo pudieron resolver? 21p18
- ☐ No
- ☐ Sí

e) Me puede explicar cómo lo resolvieron? 21p19

f) Quien se encarga de la operación y mantenimiento del sistema? 21p13
- ☐ Técnico de la comunidad
- ☐ Técnico de la municipalidad
- ☐ Vendedor del sistema
- ☐ Desarrollador
- ☐ Otro
- ☐ Yo

g) IF Yo: Tiene un programa de mantenimiento preventivo, o hace usted mantenimiento solo cuando hay problema con el sistema?
- ☐ Mantenimiento preventivo
- ☐ Cuando hay problema

h) IF PREVENTIVO: Me puede platicar qué mantenimiento hace?

i) Usted sabe a quien contactar cuando tiene un problema con el sistema? 21p14
- ☐ No
- ☐ Sí

j) A quién? 21p15

k) Usted sabe a donde se puede ir para conseguir partes (como baterías) para el sistema?
- ☐ No
- ☐ Sí

l) A donde?

m) Cuanto tiempo necesita para ir desde aquí hasta allá?

9. PERCEPCIÓN

a) Sabe si hay alguien en la comunidad que piense que el sistema está en conflicto con su religión? 16a
- ☐ No
- ☐ Sí
- ☐ No sé

b) Qué conflicto? 16b

c) Sabe si hay alguien en la comunidad que piense que el sistema está en conflicto con alguna otra cuestión social o cultural? 17a
- ☐ No
- ☐ Sí
- ☐ No sé

d) Qué conflicto? 17b

e) Cree que se puedan resolver los conflictos? 17c

- ☐ No
- ☐ Sí
- ☐ No sé

f) Cómo? 17d

---

g) Ha tenido este proyecto consecuencias negativas ambientales?
- ☐ No
- ☐ Sí
- ☐ No sé

h) Qué tipo?

---

i) Tienen todos en la comunidad acceso al energía de este proyecto?
- ☐ No
- ☐ Sí
- ☐ Sí, pero no todos iguales
- ☐ No sé

j) IF No OR No Iguales: Por que?

---

k) Sabe si hay cualquier otro tipo de conflicto relacionado de este proyecto? Por ejemplo, hay problemas entre los que tienen acceso al energía y los que no tienen?
- ☐ No
- ☐ Sí
- ☐ No sé

l) Que conflicto?

---

m) Cree que se puedan resolver los conflictos?
- ☐ No
- ☐ Sí
- ☐ No sé

n) Cómo?

---

10. N/A

11. DESECHO DE COMPONENTES VIEJOS

a) Ustedes saben qué hacer con las partes del sistema que ya no sirven? MAYBE OFFER EXAMPLE OF DEAD BATTERIES 22d

- ☐ No
- ☐ Sí

12. ZONAS DE RIESGO DE DESASTRES NATURALES

a) Considera que el proyecto ha creado zonas de peligro de desastres naturales? 26

- ☐ No
- ☐ Sí
- ☐ No sé

b) Si sí, cómo y cuáles? 26a1

____

____

____

c) Considera que el proyecto ha incrementado zonas de peligro de desastres naturales? 27

- ☐ No
- ☐ Sí
- ☐ No sé

d) Si sí, cómo y cuáles? 27a1

____

____

____

13. CAPACIDAD DE ADAPTACIÓN A DESASTRES NATURALES

INTRO ABOUT NATURAL DISASTERS RELATED TO CC AND EXAMPLES OF ADAPTATION.

a) Considera que tener un sistema de ER les ayuda a recuperarse más rápido de huracanes, tormentas, deslaves, etc? 28c

- ☐ No
- ☐ Sí

b) Si sí, cómo les ayuda? 28d

____

____

____

c) Usted piensa que el sistema de ER es mejor para resistir los efectos de los huracanes, tormentas, deslaves, etc que su sistema anterior? 28e

- ☐ No
- ☐ Sí

d) Si sí, cómo? 28f

e) Cómo ha respondido la tecnología a los últimos huracanes, tormentas, deslaves, etc? 28i

f) Cómo podría responder mejor la tecnología a huracanes, tormentas, deslaves, etc? 28i1

g) Si el sistema se perdiera o se dañara de alguna forma, usted reemplazaría el sistema, regresaría a usar la fuente de energía que usaba anteriormente o adquiriría una nueva fuente de energía?

h) Considera que el sistema de ER les ha ayudado a crear redes sociales? 28j

- ☐ No
- ☐ Sí

i) Cómo han ayudado estas redes sociales a que ustedes se adapten a los efectos de huracanes, tormentas, deslaves, etc?28k

j) Considera que el sistema de ER les ha ayudado a crear conocimiento sobre tecnologías que los ayuden a adaptarse más fácilmente a los desastres naturales? Ejemplos: otras fuentes de ingreso, energía para hospitales, centros de atención a desastres, etc. . 28l

- ☐ No
- ☐ Sí

k) Si sí, cómo? 28m

14. EXPECTATIVA

a) El proyecto cumplió con sus expectativas? 19

- ☐ No
- ☐ Sí
- ☐ Más o menos

b) Si no, porqué? 19a

c) El proyecto ha sido importante para sus actividades diarias? 29b

- ☐ No
- ☐ Sí
- ☐ Más o menos

d) Porqué y cómo? 19c/19c1

e) El proyecto ha tenido algún impacto negativo para sus actividades diarias?

- ☐ No
- ☐ Sí

f) Porqué y cómo?

g) Usted cree que el proyecto es generalmente exitoso?

- ☐ No
- ☐ Sí
- ☐ Más o menos

h) Porqué? Que significa éxito para un proyecto como este?

i) Hay partes del proyecto que no son exitosos? Cuales?

j) Hay algún oto comentario que le gustaría hacer? 19d

Appendix B: Inspection Protocol

Southwest Technology Development Institute
New Mexico State University

SWTDI

INSPECTION FORMS FOR PHOTOVOLTIAC LIGHTING SYSTEMS

GENERAL INFORMATION

Locality: ______________________________

Municipality: ______________________________ State: __________

Location: Latitud: __________ Longitud: __________ Zone: __________

Aplication:

Residencial ( ) School ( ) Clinic ( ) Community Center ( ) Chruch ( )

Other: ______________________________

Date of Installation: __________ Installed by: ______________________________

Name of Inspector: ______________________________

Date: ______________________________ Time: ______________________________

System's Status and History

Is System operating correctly? Yes( ) No ( )

If not operating, why? ______________________________

WERE THERE ANY PREVIOUS VISITS/Technical Inspection? Yes( ) No ( )

Number of visits ? __________

Who conducted the visits? (indicate the number of visits by each institution)

( ) Regional agent Firco ( ) ( ) Sunwize

( ) other: ______________________________

Were there any formal complaints reported? Yes( ) No ( )

How many ? __________

To whom were the formal complaints reported to ? ______________________________

Who took action in solving the problems?

( ) Regional Agent Firco ( ) ( ) Sunwize

( ) others: ______________________________

Equipment Replaced

ITEM	Quantity	Responsible person	Date
Modules			
Controller			
Inverter			
Batteries			
Lamps			

PHOTOVOITIAC ARRAY

Manufacturer: Kyocera ( ) Siemens ( ) Solarex ASE ( ) Other ( ) ____________________

Model (s): ________________________ Watts: ______________

Total Array (Watts) _______ Number of modules in Series: _______ Number of Modules in Parallel:_______

Mount structure: ______________ Array orientacion: _________ Array inclination: ________

Number of damaged modules: __________

Cleanliness of modules: clean ( ) dirty ( ) very dirty ( )

Array installed in proper location (shadding , distance, etc.):

Yes ( ) No ( ): Why? ____

Status of cable on modules:

Electrical connections (tension, proper terminals) Good ( ) Bad ( ): Type and size __________

Cable in conduit ( ) Cable exposed ( )

Other components:

Grounding system Good ( ) Bad ( )

Lighting and surge Protection Yes ( ) No ( )

Status of Junction box

ITEM	Yes/No
Loose connections	
Corrosion	
Excessive temperature	
Water Resistant (sealed)	

BATTERY BANK

Battery manufacturer: _________________Model: ____________________

Number of batteries in series: _____ Number of batteries in Parallel:_____ Amp Hour Capacity (AH)_______

Are the batteries protected in an enclosure box to prevent access from people? Yes ( ) No ( )

IF yes, is the battery enclosure box adequetly ventilated Yes ( ) No ( )

Are the proper battery connectors used? Yes ( ) No ( )

Number of batteries with low electrolyte: ________

Battery Terminals

ITEM	Yes/No
Corrosion	
Loose connection	
Overheated	

Electrolyte Level

LEVEL	Cell No.
Normal	
Low	
High	

Status Indicator

INDICATION	Yes / No
Green	
Black	
Red	

CONTROL BOX – CHARGE CONTROLLER AND INVERTER

Number of control boxes: ________

Electrical connections in good status? Yes ( ) No ( )

Type of charge controller: ______________________________

Model: ______________________________

Serial No. ______________________________

LED indicator on charge controller

Indication	Yes/No
ON – constantly	
Blinking slowly	
Blinking fast	
OFF – constantly	

Type of inverter: ___________________________ :

Model:______________________________

Serie Number : _________________________

LEDs indicators on inverter

Indication	Yes/no
OFF	
GREEN	
RED	

Lights and other loads

Number of lights : _______ Power (Watts) _________ Type: _____________ Functioning? ____________

Other lights:

Number of lights: ______ Power (Watts) ________ Type: ______________ Functioning? _______________

Lighting area

Location/room	Number of light fixtures/ Watts	Estimated area

Other existing loads

Appliance	Manufacturer/model	Voltage (V)	Power (W)	Use (hrs.)

Is there any intereference (noise, static etc) observed on the loads installed. Yes ( ) No ( )

IF yes what kind of interference?

( ) Static ( ) Noise ( ) Other interference: ___________________________________

Appendix C: Data Summary

Locations

Community Name	Municipality	Department
Agua Caliente	Cahabón	Alta Verapaz
Chaslau	Cahabón	Alta Verapaz
Chiis	Cahabón	Alta Verapaz
Col. Agrícola San Juan	Cahabón	Alta Verapaz
El Carmen	Cahabón	Alta Verapaz
Gualibaj	Cahabón	Alta Verapaz
Seazir	Cahabón	Alta Verapaz
Bombil Pek	Chisec	Alta Verapaz
Baldío Xalaché	Cobán	Alta Verapaz
Salacuín	Cobán	Alta Verapaz
Tortugas	Cobán	Alta Verapaz
Naranjito El Zanjo	Fray Bartolomé de las Casas	Alta Verapaz
Sepur Limite	Panzós	Alta Verapaz
La Unión	Raxrujá	Alta Verapaz
Mucbil'ha	Raxrujá	Alta Verapaz
Chuaberená	Cubulco	Baja Verapaz
Salval Pop	Patzún	Chimaltenango
San Rafael Sumatán	San Pedro Yepocapa	Chimaltenango
Los Horcones	Esquipulas	Chiquimula
Timushan	Esquipulas	Chiquimula
Parcelamiento El Socorro	Santa Lucía Cotzumalhuapa	Escuintla
Cassiero Bara del Coyolate	Nueva Concepcion	Esquintla
Sta Ana Mixtan	Nueva Concepcion	Esquintla
Sta Marta el Mar	Nueva Concepcion	Esquintla
Sto Domingo Los Cocos	Nueva Concepcion	Esquintla
Microparcelamiento el Naranjo	Sta Lucia Cotzumalhuapa	Esquintla
Bocancha	El Estor	Izabal
Chapín Abajo	El Estor	Izabal
Chapín Arriba	El Estor	Izabal
Chichipate	El Estor	Izabal
Chinebal	El Estor	Izabal
Guaritas	El Estor	Izabal
Playa Pataxte	El Estor	Izabal
Selempín	El Estor	Izabal
Sepóm	El Estor	Izabal
El Calvario	Livingston	Izabal
Santa María del Mar	Puerto Barrios	Izabal

Caserío El Zapote	Sayaxché	Petén
Sta. Isabel	Sayaxché	Petén
Zona arqueológica Cancuén	Sayaxché	Petén
Nueva Alianza	El Palmar	Quetzaltenango
Amajchel	Chajul	Quiché
Encuentros Amajchel	Chajul	Quiché
Ilom	Chajul	Quiché
Juá	Chajul	Quiché
Nueva Amajchel	Chajul	Quiché
Sta. Clara	Chajul	Quiché
Visiquichun	Chajul	Quiché
Ixtahuacán Viejo	Ixtahuacán Viejo	Sololá
El Jasmin	Gualán	Zacapa
El Zapotal	Gualán	Zacapa
Finca las Nubes	Gualán	Zacapa
La Bolsa	Gualán	Zacapa
Sta. Cecilia	Gualán	Zacapa
Vista Hermosa	Gualán	Zacapa

Select results from system physical inspections

Count of observations. Numbers may differ because individual inspection protocols did not necessarily include all data.

Application		**Panel Manufacturer**		**Array Watts**		**Array Orientation**	
Public (non-commercial) building	25	Shell	13	> 50 W	4	N, NE, NW	2
Income generating	6	Seimens	17	50- 199 W	17	E, ENE, ESE	3
Emergency/early warning systems	2	Unisolar	4	100 - 249 W	5	S, SSW, SSE	33
Domestic	41	Other	9	> 249 W	9	SE, ESE	7
						W, SW, WSW	4
						Flat	3

Array Inclination		**Module Cleanliness**		**Battery Type**		**Number of lights**		**Other Loads**	
0^o	3	Very dirty	21	Car Battery	25	1	6	Cell Phone Charging	10
5^o-14^o	5	Dirty/dusty	17	Deep-Cycle Battery	32	2	8	Radio/sound system	8
15^o	29	Clean	5			3	11	TV	8
16^o-30^o	12					>3	5		
>30^o	2								

Select results related to economics

Count of observations. Numbers may differ because individual survey respondents did not necessarily respond to all questions.

5c Is there a tariff for use/ownership?		**6h Tariff, Q/Month**		**6l Is the tariff affordable to you?**		**4g7 Did the project result in an increase in income for anyone in the community?**		**4g8a Did the project result in a decrease in income for anyone in the community?**	
Yes	29	< 6Q	2	Yes	8	Yes	8	Yes	6
No	53	6-10Q	2	No	5	No	73	No	31
Unsure	0	11-15Q	1	Unsure	0	Don't Know	4	Don't Know	3
		16-20Q	21						
		21-25Q	2						
		>25Q	1						

Select results related to social implications

Count of observations. Numbers may differ because individual survey respondents did not necessarily respond to all questions.

16a Has the project caused religious or cultural conflict		**17e Are there negative environmental consequences?**		**17g Did everyone in the community have equal access to the project?**		**28j Has the project helped create or reinforce social networks?**		**28l Has the project resulted in an increase in your technical knowledge?**	
Yes	0	Yes	2	Yes	52	Yes	25	Yes	15
No	65	No	60	No	15	No	5	No	3
Unsure	5	Unsure	7	Unsure	2				

Select results related to project success

Count of observations. Numbers may differ because individual survey respondents did not necessarily respond to all questions.

19 Does the project meet your expectations?		19b Is the project important in your regular activities?		19e Has the project had any negative impact on you?		19f Do you consider the project successful?		28i2 If your system were lost or dammaged, what would you like to do?	
Yes	75	Yes	78	Yes	0	Yes	76	Replace with same	33
No	2	No	0	No	54	No	1	Grid	4
More or less	3	More or less	1			More or less	4	Traditional sources	15
								Generator	3

Select results related to project origins and implementation

Count of observations. Numbers may differ because individual survey respondents did not necessarily respond to all questions.

21a2 Is the project in place the original project planned?	21a6 Were you consulted in planning?	21a7 Were you consulted in implementation?	21h Did the community participate in implementation?	5a Did the community contribute to the project?	t21p Were training sessions offered?	21p4 Did You Attend?	21p6 Was the training useful?	21p8 Was the training sufficient?
Yes 9	Yes 66	Yes 52	Yes 19	Yes 65	Yes 44	Yes 27	Yes 30	Yes 12
No 2	No 8	No 12	No 0	No 13	No 37	No 10	No 1	No 18
Don't Know 1	Don't Know 1	Don't Know 4	Don't Know 1	Unsure 4	Don't Know 2			Don't Know 1

Select results related to current system operation

Count of observations. Numbers may differ because individual survey respondents did not necessarily respond to all questions.

Economically Productive Uses	Domestic Uses	Community Uses	21p16 Have you had problems with your system?	21p18 Were you able to resolve them?	21p15a Do you know where to go to get replacement parts?	22d What do you do with failed components?	21l Do you know how to contact the developer now?	20a Is there a governance structure for the project?	20g Do women participate in project governance?
Yes 25	Yes 51	Yes 44	Yes 53	Yes 17	Yes 42	Sell or recycle 14	Yes 22	Yes 40	Yes 15
No 90	No 64	No 71	No 35	No 23	No 23	Don.t know, dump, leave in place, other inappropriate 62	No 39	No 32	No 18
			Don't Know 1					Don't Know 4	Don't Know 1

Appendix D: Institutional Review Board Documentation

IRB Authorization

JOHNS HOPKINS
UNIVERSITY

Homewood Institutional Review Board
151 Krieger Hall / 3400 N. Charles Street
Baltimore MD 21218-2685
410-516-6580 http://web.jhu.edu/Homewood-IRB/

Michael McCloskey
Chair

June 2, 2008

Erica Schoenberger PhD
Hope Corsair, student investigator
Dept of Geography & Environmental Engineering
Ames 313

Re: HIRB No. 2008064 *"Causes of Success and Failure of Rural Renewable Energy Systems in Guatemala"*

The research identified above qualifies as exempt from IRB review for the protection of human research subjects, in accordance with 45CFR46.101(b), exempt category no. 2.

No further communications with the IRB are necessary **unless the procedures in your project are changed in such a manner as to void the basis of the exemption**, in which case IRB-approval must be obtained prior to implementation of the change.

Homewood IRB

cc: Ms. Cheryl Howard, Research Projects Admin.

Funded by: (no funding anticipated)

APPROVAL IS GRANTED UNDER THE TERMS OF **FWA00005834** FEDERAL-WIDE ASSURANCE OF COMPLIANCE WITH DHHS REGULATIONS FOR PROTECTION OF HUMAN RESEARCH SUBJECTS

Johns Hopkins University

Homewood Institutional Review Board (HIRB)

Application for Exemption

Limited types of human participant research are exempt from Federal regulations for the protection of human research participants [45 CFR (Code of Federal Regulations) 46]. Studies in which the **ONLY** involvement of human participants is in one or more of the six exempt categories of research listed in the Federal Regulations and in this form **MAY** qualify for exemption. HIRB is ultimately responsible for verifying whether studies meet the required criteria for exemption. Studies that qualify for exempt status may not be undertaken until HIRB verifies the exemption.

Exemption from federal regulations does not absolve investigators from their ethical obligation to protect the welfare and rights of human participants and, when appropriate, to obtain informed consent.

To determine whether your study qualifies for exempt status and under which categories, please complete the Exemption Checklist in this document. If all of the research activities in your study fall into one or more of the exemption categories, you may submit an Application for Exemption, which is below. If all the research activities in your study do not fall into one or more of the exemption categories, you must complete and submit anApplication for Expedited/Full Board Review.

Please ensure that you have fully completed the application, including providing the required signatures and, when applicable, additional documentation. Complete applications may be mailed, delivered, or e-mailed to HIRB. Only signature pages may be faxed. Faxing complete applications should be avoided except in unusual circumstances. If you have any questions, please contact us.

Homewood Institutional Review Board (HIRB)
151 Krieger Hall
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Phone: 410-516-6580
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Johns Hopkins University

Homewood Institutional Review Board (HIRB)

Checklist for Exempt Status

Below are six categories of research that may be exempt from Federal regulations for the protection of human research participants. Please review each of the categories below (including any additional tests where indicated) and check any that apply to your proposed study. If the activities in your study do **not** fit entirely into the exemption categories, please complete an Application for Expedited/Full Board Review.

Please note that the exemption categories **DO NOT** apply when research activities involve any of the following:

- Clinical studies of medical devices, procedures, treatments, or drugs.
- Pregnant women, fetuses, neonates, or human in vitro fertilization.
- Prisoners.
- Surveys or interviews that include minors (i.e., children) as participants.
- Collection or study of existing data if the information is recorded in such a way that participants can be identified, either directly or through identifiers linked to the participants and disclosure of the participants' responses outside the research could reasonably place them at risk of criminal or civil liability or be damaging to their financial standing, employability, or reputation.
- Research techniques or activities that expose participants to discomfort or risk beyond that encountered in daily life.
- Deception of research participants.

Studies involving any of these elements **DO NOT** qualify for exemption, and investigators should submit an Application for Expedited/Full Board Review.

EXEMPTION CATEGORIES

CATEGORY 1
Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as (a) research on regular and special education instructional strategies and (b) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
☐ Check if any part of your project falls within Category 1.

CATEGORY 2

Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior.

To be eligible for exemption under this category, the research must pass **TWO** additional tests.

Test I: Children

Children are persons who have not attained the legal age for consent to treatments or procedures involved in the research, under the applicable law of the jurisdiction in which the research will be conducted.

Does any part of your project involve research in which children are studied through (a) survey procedures, (b) interview procedures, or (c) observations of public behavior in which the investigators participate in the activities being observed?

☒ No ↳ Your project passes Test I.

☐ Yes ↳ Your project fails Test I, and does **NOT** qualify for exemption from review.

Test II: Identifiability & Risks

a. Will the information obtained in the research be recorded in such a manner that the human participants can be identified, directly or through identifiers linked to the participants?
☒ Yes ☐ No

b. Could any disclosure of the human participants' responses outside the research reasonably place the participants at risk of criminal or civil liability or be damaging to the participants' financial standing, employability, or reputation? ☐ Yes ☒ No

**** IMPORTANT ****

For (a), what matters is NOT whether participants will be identified when the results of the research are reported. What matters is whether the data are recorded in such a way that the information obtained from a participant can be linked to the identity of that participant.

Example: Data for each participant are recorded on a page that identifies the participant only by a code number. The researcher keeps a key that associates a name with each code number. Even if no names or code numbers are listed in publications or other reports, the data are recorded in such a way that participants can be identified, and the answer to (b) is YES.

If you answered:

No to (a) **OR** No to (b) ↳ ☒ Your project passes Test II.

Yes to (a) **AND** Yes to (b) ↳ ☐ Your project fails Test II, and is **NOT** exempt.

☒ Check if any part of your project falls within Category 2 and passes **BOTH** additional tests.

CATEGORY 3
Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under Category 2, if (a) the human participants are elected or appointed public officials or candidates for public office or (b) Federal statute(s) require(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.
☐ Check if any part of your project falls within Category 3.

CATEGORY 4

Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens. **Existing** means collected (i.e., on the shelf) prior to the study for a purpose other than the proposed study. It includes data and specimens collected in research and nonresearch activities.

To be eligible for exemption under this category, the research must pass an additional test.

Test III: Information Sources & Identifiability

a. Are the sources of the information publicly available? ☐ Yes ☐ No

b. Will the information obtained in the research be recorded in such a manner that the human participants can be identified, directly or through identifiers linked to the participants? ☐ Yes ☐ No

**** IMPORTANT ****

For (b), what matters is NOT whether participants will be identified when the results of the research are reported. What matters is whether the data are recorded in such a way that the information obtained from a participant can be linked to the identity of that participant.

Example: Data for each participant are recorded on a page that identifies the participant only by a code number. The researcher keeps a key that associates a name with each code number. Even if no names or code numbers are listed in publications or other reports, the data are recorded in such a way that participants can be identified, and the answer to (b) is Yes.

If you answered:

Yes to (a) **OR** No to (b) → ☐ Your project passes Test III.

No to (a) **AND** Yes to (b) → ☐ Your project fails Test III, and is **NOT** exempt.

☐ Check if any part of your project falls within Category 4 and passes the additional test.

CATEGORY 5
Research and demonstration projects that are conducted by or subject to the approval of Department or Agency heads, and which are designed to study, evaluate, or otherwise examine: (a) public benefit or service programs; (b) procedures for obtaining benefits or services under those programs; (c) possible changes in or alternatives to those programs or procedures; or (d) possible changes in methods or levels of payment for benefits or services under those programs. **** IMPORTANT **** **This exemption will not usually apply to research conducted by non-governmental institutions.** The exemption is for projects conducted by or subject to approval of Federal agencies and is most appropriately invoked with authorization by or concurrence of the funding agency. Please contact HIRB for additional guidance.
☐ Check if any part of your project falls within Category 5.

CATEGORY 6
Taste and food quality evaluation and consumer acceptance studies, (a) if wholesome foods without additives are consumed or (b) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration or approved by the Environmental Protection Agency or the Food Safety and Inspection Service of the U.S. Department of Agriculture.
☐ Check if any part of your project falls within Category 6.

QUALIFICATION FOR EXEMPTION

Do **ALL** of the human participant research activities in your study fall into one or more of the above exemption categories and pass **ALL** additional required tests?

☒ YES	Specify the category number(s) in which the research falls: 2 Your study may qualify for exemption. Continue to the Application for Exemption below and submit the complete application (including this checklist) to HIRB.
☐ NO	Your study does not qualify for exemption. Please complete and submit the Application for Expedited/Full Board Review.

Johns Hopkins University

Homewood Institutional Review Board (HIRB)

Application for Exemption

PRINCIPAL INVESTIGATOR

Name:	Dr. Erica Schoenberger	Title:	Professor
Position:	JHU Faculty If Other, Please Specify:		
Department:	Geography and Environmental Engineering	Mailing Address:	313 Ames Hall 3400 North Charles Street Baltimore, MD 21218
Phone:	(410) 516-6158		
Fax:	(410) 516-8996		
E-mail:	ericas@jhu.edu		
Signature:		**Date:**	

STUDENT INVESTIGATOR/CO-INVESTIGATORS (IF APPLICABLE)

Student Investigators must have a faculty member serve as Principal Investigator for all research projects with human participants. For any additional investigators on this study (e.g., students, consultants) please complete a Research Team Members Form.

Name:	H. J. Corsair	Title:	
Position:	Graduate Student		
Department:	Geography and Environmental Engineering	Mailing Address:	313 Ames Hall 3400 North Charles Street Baltimore, MD 21218
Phone:	(310) 228-8696		
Fax:	(410) 516-8996		
E-mail:	hjcorsair@yahoo.com		
Signature:		**Date:**	

ADDITIONAL RESEARCH TEAM MEMBERS

For all additional research team members on this study, please complete a Research Team Members Form. Research team members include anyone — whether affiliated with the Johns Hopkins University or not — who (a) interacts with research participants (e.g., in recruiting, obtaining informed consent, collecting data, or debriefing); (b) prepares materials for use with participants (e.g., letters to potential participants, interview protocols); or (c) has access to data collected from participants.

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RESEARCH PROTOCOL

STUDY TITLE

Causes of Failure of Rural Renewable Energy Systems in Guatemala

STUDY SITE(S)

Where will the study be conducted? Check all locations that apply.

- ☐ Applied Physics Laboratory (APL)
- ☐ Krieger School of Arts and Sciences
- ☐ Kennedy-Krieger Institute (KKI)
- ☐ Peabody Institute
- ☐ School of Advanced International Studies (SAIS)
- ☐ School for Professional Studies in Business and Education
- ☒ Whiting School of Engineering
- ☐ Other U.S. Site(s). Specify:
- ☒ International Site(s). Specify: Guatemala, in various rural communities

FUNDING STATUS

Indicate the project's funding status below.

- ☐ Project is currently funded. *Submit the complete grant proposal and application.*
  - Funding Agency (e.g., NSF):
  - Grant/Contract Number:
- ☐ Project has been submitted for funding.
  - Funding Agency (e.g., NSF):
- ☒ No Funding Obtained or Applied For.

PURPOSE OF THE STUDY

Describe the goals of the study clearly below.

The goal of this study is to determine the causes of failure of rural renewable energy systems (such as are often used in international development work). This research will consider possible technical, social and economic causes of failure in agrarian communities in Guatemala.

DESIGN & METHODOLOGY

Describe the design and methodology of the study clearly below.

The student investigator will travel to Guatemala and visit rural communities that have working

and non-working solar-electric and small hydro-electric energy systems. These communities are identified by the investigators' contacts development and trade groups in Guatemala. These contacts will provide introductions between the student investigator and one or more community members. The student investigator will examine the physical renewable energy system to determine its operability and technical specifications. The investigator will also survey four or more members of each community visited to assess the community's use, understanding and perceptions of the system. The resulting survey and numerical data will be analyzed statistically and the non-quantifiable data will be analyzed qualitatively.

PROCEDURES & ACTIVITIES

Describe the study's procedures and activities that participants will be asked to perform. *Attach all surveys, interview questions and guidelines, and other relevant materials you will use in this study.*
Participants will be asked to answer the questions included in the attached survey. They will be encouraged to expand upon their answers rather than limiting them to the specifics of the question. Participants who identify themselves as operators of the renewable energy systems will also be asked to provide or allow the investigator to access the system.

PARTICIPANTS

Describe the participant population(s) and the total number of participants to be enrolled.
The participants in this study will be members of rural communities in Guatemala. These community members may range from large plantation owners to subsistence-level farmers. Only adults will be included. Equal numbers of male and female participants will be sought. Approximately 120 total participants will be surveyed.

SPECIAL CATEGORIES OF PARTICIPANTS

Check all categories that apply to this study. Additional regulations and review requirements apply to some participant categories.	
☐	JHU Students
☐	JHU Employees
☐	Children (< 18 years old) If checked, give age range:
☐	Cognitively-Impaired Individuals
☒	Individuals with Limited or No Reading Skills
☒	Non-English Speakers
☐	Pregnant Women/Fetuses

☐	Prisoners

PARTICIPANT RECRUITMENT

In the area below, describe how you will identify and recruit participants. *Please attach copies of all recruitment materials (e.g., ads, bulletin board notices, e-mails, phone scripts).*
Participants will be recruited through word-of-mouth. The investigators' in-country contacts include members of development organizations who are willing to take an investigator to communities with renewable energy projects of their desing, and to introduce the investigator to community members. Other in-country contacts include staff members of a plantation owners' cooperative. These staff members have indicated an interest in bringing the investigator to a number of plantations to assess the success of renewable energy systems on the plantations. Contacts within the Peace Corps are willing to put an investigator in touch with Peace Corps volunteers who are currently in communities with renewable energy systems. These Peace Corps volunteers will introduce the investigator to community members who may participate in the study.

RISKS

Please consider the risks your study may pose to participants, including physical, psychological, social, economic, and other risks or harms. In the area below, explain any risks posed by your study or state that your study poses no risks to participants.
Inquiries by a foreigner about renewable energy systems within a community may create the expectation that development aid for improved electric systems will follow. There is a risk that community members may make decisions based on this false expectation.

MINIMIZATION OF RISKS

Explain the procedures for minimizing any risks to participants, including procedures for protecting the anonymity of participants and confidentiality of data.
The investigator will make clear that the survey is about existing systems, and that no aid or assistance is likely to result from the inquiry. Survey participants' anonymity will be preserved by deliberately not collecting sufficient data to identify participants individually (no name, address or other specific, identifying information will be collected). To further protect the anonymity participants, communities will identified by code rather than name (to allow the student investigator to return to the community for further information, if needed), and the key will be kept apart from the data during the study and destroyed at the completion of the study.

BENEFITS

Describe any potential benefits to participants and/or society. Be realistic in your assessment of potential benefits.
The overall benefit of the research will be to enable development professionals to make decisions that will result in higher success rates among renewable energy development projects. The benefits to the participants will be limited to any small assistance the invesitgator can give in improving the functioning of the system while visiting the community.

CONSENT

Exemption from Federal regulations does not negate the ethical obligation to inform participants about their involvement in a study, **when appropriate**. Please indicate whether consent will be obtained for this study by checking one of the boxes below.

☒ Yes. Describe the consent process and attach any disclosures, consent forms, and oral consent scripts.

Oral consent will be obtained from study participants. See attached script.

☐ No. Explain why consent is not required or is not appropriate for the proposed study.

CONFLICTS OF INTEREST

Please indicate whether the principal investigator or any other key research personnel for this study have any potential conflicts of interest. Potential conflicts of interest arise when, for example, investigators have an interest in or serve as an officer for an outside entity whose financial interests may be affected by the research.

☒ No

☐ Yes. Please describe the nature of the potential conflict.

INVESTIGATOR TRAINING

University policy requires that **ALL** individuals engaged in human participant research complete training in human research protections. *If proof of training is not already on file with HIRB, please submit a copy of training certificates for study team members with this application.* HIRB's training policy can be found on the HIRB website.

APPLICATION CHECKLIST

To ensure that your application is complete, please review the checklist below. All items may not apply to your study. All signatures must be obtained and applicable additional forms and documentation must be fully completed before the review process begins.

- ☐ Signature of Principal Investigator
- ☐ Signature of Student Investigator/Co-Investigator
- ☐ Research Team Members Forms
- ☐ Certificates of Training in Human Participant Research
- ☐ Grant Proposal and Application
- ☐ Surveys, Questionnaires, Interview Guides, and Other Relevant Measures Used in the Study
- ☐ Recruitment Materials (e.g., Ads, Invitations)
- ☐ Consent Forms/Scripts
- ☐ Exemption Checklist

Consent Script

"Hola ¿cómo está? Mi nombre es Esperanza Hope Corsair. Soy una estudiante en la Universidad Johns Hopkins en los Estados Unidos y me encuentro desarrollando un estudio sobre sistemas de energía solar como el que tiene usted. No estoy aquí para arreglar problemas que el sistema tenga o para hablar sobre futuros proyectos de energía solar. Deseo que mis estudios sirvan para que estos sistemas sean mejores en el futuro. Mi estudio requiere el análisis de los (partes del sistema, que pueden variar por ubicación), y conversar con personas como Usted acerca de sus experiencias en el uso de los equipos.

Quisiera preguntarle si Usted tiene tiempo para platicar conmigo durante aproximadamente media hora (personas dedicadas a mantenimiento, una hora) acerca de este sistema. Las respuestas que usted me dé solo las voy a usar yo. No voy a anotar su nombre ni comentar con nadie acerca de sus opiniones (para personas de mantenimiento: en general otras personas podrían identificarlo(a) por las opiniones técnicas sobre el sistema que Usted conoce).

No hay problema si Usted no quiere responder a alguna o todas las preguntas. Tampoco será ningún problema si Usted debe irse antes de que acabe la entrevista. Estaré muy agradecida por cualquier información que Usted decida compartir conmigo acerca de su sistema solar. Muchas Gracias por su atención."

Documentation of Human Research Training

CITI Course in The Protection of Human Research Subjects

Human Research Curriculum Completion Report
Printed on Tuesday, January 16, 2007

Learner: H.J. Corsair (username: hjcorsair)
Institution: Johns Hopkins Bloomberg School of Public Health
Contact Information: Department: Geography and Environmental Engineering
Phone: 310 228 8696
Email: hjcorsair@yahoo.com
Biomedical Research Investigators: This Learner group is mandatory for all Principal Investigators, Co-investigators, Student Investigators and Study Staff

Stage 1. Basic Course Passed on 01/16/07 (Ref # 806897)

Required Modules	**Date completed**
Belmont Report and CITI Course Introduction	01/16/07
History and Ethical Principles	01/16/07
Basic Institutional Review Board (IRB) Regulations and Review Process	01/16/07
Informed Consent	01/16/07
Research With Protected Populations - Vulnerable Subjects: An Overview	01/16/07
Johns Hopkins Bloomberg School of Public Health	01/16/07

For this Completion Report to be valid, the learner listed above must be affiliated with a CITI participating institution. Falsified information and unauthorized use of the CITI course site is unethical, and may be considered scientific misconduct by your institution.

Paul Braunschweiger Ph.D.
Professor, University of Miami
Director Office of Research Education
CITI Course Coordinator

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Curriculum Vita

Hope Jennifer Corsair was born in Newport, Rhode Island in 1972. Her family moved to the San Francisco Bay Area, where she spent much of her childhood. She attended Lehigh University in Bethlehem, Pennsylvania, to study engineering as an undergraduate student, earning a multidisciplinary degree in Fundamental Sciences from Lehigh's College of Engineering in 1995. She had a long-standing interest in energy and worked as a resource planning engineer and later as a consultant in economic modeling in the electric utility industry. She left industry to pursue a master's degree in Civil and Environmental Engineering from the University of Colorado in Boulder. She completed her thesis on the cost-effectiveness of PV systems while engaged as a research assistant at the National Renewable Energy Laboratory in Golden, Colorado. She was awarded her MS degree in 2005. Hope furthered her graduate studies at The Johns Hopkins University in the Department of Geography and Environmental Engineering, earning her Master of Science degree in 2010. She was twice the recipient of an NSF GK12 fellowship. In 2011 she accepted a position as an assistant professor in the Renewable Energy Engineering program at the Oregon Institute of Technology. In 2012 she was named program director of the Master of Science in Renewable Energy Engineering program in its inaugural year.