Sustainable Development, Climate Change, and Renewable Energy in Rural Central America

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Abstract

Can rural renewable energy projects simultaneously meet the multiple goals of sustainable development, climate change mitigation and climate change adaptation? If so, under what conditions? Rural communities throughout Latin America have increasingly suffered the impacts of climate change and few policies exist to help them adapt to these impacts. The basic infrastructure and services that they frequently lack can be provided by low carbon technologies, potentially funded by international carbon finance flows that could enable the Millennium Development Goals of economic growth and poverty alleviation to be met while minimizing carbon emissions. This research will focus on this interrelationship among development, climate change mitigation and climate change adaptation policies and practices using political ecology to analyse community renewable energy projects in rural Central America.

I assess fifteen community-owned renewable energy projects in Guatemala and Nicaragua to analyse whether current renewable energy projects are achieving these goals in an integrated way. The projects were established primarily as development, emissions reductions, climate change adaptation and disaster relief. The projects are evaluated on economic, development and climate change indicators that include sustainable development, poverty alleviation, emissions reductions, and climate vulnerability. I examine how the type of common property governance, local historical and environmental background and project implementation process influence the project success in meeting multiple objectives of climate adaptation,

mitigation and development. Research methods include participatory poverty assessment techniques, semi-structured interviews, stakeholder analysis, and a combination of rapid and participatory methods. The analysis of sustainable development and vulnerability used the Sustainable Livelihoods Approach methodologies and emissions reductions were calculated using standard carbon reduction methodologies.

The results show that, under certain conditions, renewable energy projects can simultaneously meet these three objectives, and thus that responses to climate change can be integrated with poverty alleviation and sustainable development. Small scale hydroelectric and solar systems can reduce emissions, enable adaptation and help local livelihoods although there are numerous problems that limit the success of projects including poor design, inequitable distribution of benefits, and poorly designed governance and maintenance structures.

CHAPTER 1: INTRODUCTION

This dissertation analyzes the linkages between objectives of sustainable development, climate change adaptation and climate change mitigation in rural Central American communities by focusing on the role of renewable energy systems as a means to achieve triple goals of mitigation, adaptation and poverty alleviation. I use a political ecology approach to assess the importance of and relationships between political economy, social and community structures, local historical backgrounds and the use of natural resources. The renewable energy systems I considered are solar photovoltaics, small-scale hydroelectrics and biodiesel. I also use common property resources theory to establish criteria for evaluating the success of community-owned renewable energy systems. I want to assess whether community-owned renewable energy systems are a factor in achieving the triple objective.

Rural communities can benefit from having 1) access to modern energy sources, 2) decentralized energy systems, independently of the source, and 3) renewable energy systems. Access to modern energy services (i.e. not traditional biomass) enables populations to have a better quality of life by being able to power schools, health centers and communication systems, among others, and to create additional sources of income by powering productive use applications. Additionally, having a

decentralized system enables community ownership of the energy system. Un-electrified populations are usually unable to get grid electricity because of their distance from the grid and the difficult terrain to get there.

Diesel generators have the advantage of having cheap capital costs and well developed supply chains, making them a common solution for decentralized energy schemes in isolated communities (Casillas, Kammen 2011). Decentralized energy systems have the additional advantage of being able to provide electric service to populations who would otherwise not have it, besides creating demand and a growing customer base (Ahlborg, Hammar 2012). When using a decentralized scheme, production and consumption are usually tightly coupled, making them especially attractive (Bouffard, Kirschen 2008) and the systems are not as sensitive to availability uncertainty and transportation problems (Bouffard, Kirschen 2008). For rural electrification purposes, grid extension is sometimes unfeasible because of low load factors, long distribution lines with low load densities and losses in the transmission and distribution lines (Sinha, Kandpal 1991). In other cases, the electric grid does serve rural populations, but it tends to be vulnerable to extreme climate events, proving an unreliable energy source when needed (de Gouvello, Leterme 1999). Existing studies that model 'the ideal decentralized system generators' agree that hybrid systems are the most reliable, whether they combine different renewable energy sources, or a fossil-based with a renewable energy source (Casillas, Kammen 2011, Mondal, Denich 2010, Monroy, Hernández 2008, Contreras 2008). Although the technologies are considered mature, there are millions of decentralized energy systems installed that can be considered a total or partial failure either because the technologies are not ideal for the geography in

which they are implemented or because there is inappropriate technology transfer to the user (Schäfer, Kebir & Neumann 2011). Independently of the energy source of these decentralized systems, new approaches need to be taken, such as integrating the user in strategy development and implementation of systems and including a 'service package' and productive uses, which do not always exist albeit their reported benefit (Schäfer, Kebir & Neumann 2011).

Most studies, however, focus their attention on distributed renewable energy systems (DRE) as they are located in areas in which natural resources, such as solar, wind, or hydroelectric, can be taken advantage of (Ahlborg, Hammar 2012, Contreras 2008, Mahapatra, Dasappa 2012, Silva Herran, Nakata 2012). The use of these renewable energy resources can also reduce the financial burden of the populations, although they are still faced by a number of challenges which can vary by country and context. In many countries, distorted markets with dominant monopolies or oligopolies do not leave room for an equitable playing field for renewable energy and incentives such as feed-in-tariffs, would promote greater RE use (Hinrichs-Rahlwes 2013). In Bhutan, the main challenges considered are governance, legal frameworks and human capacity, together with the high vulnerability of their natural resources to extreme climate events (Uddin, Taplin & Yu 2007). A case study of rural communities in Senegal points out that the main barrier is the high investment and/or operation expenditure, highlighting that projects are not profitable without subsidies (Contreras 2008) even though PV is proven to be the least cost solution. Contreras recommends emphasis on three main elements for future projects: willingness to pay, reduction of levels of supply service and support of communal management (Contreras 2008). Other countries have made progress

in the field of policy. In some cases, government policies did not recognize the usefulness of DRE's and did not envision them as a preferred mode for rural electrification. Countries like India have since benefitted much from PV systems and other renewable energy sources (Sharma 2007).

In many isolated off-grid populations, a decentralized and renewable system is the only available option. Finally, the use of renewable energy sources reduces greenhouse gas emissions and reduces fuel costs. This last consideration is important in Central America, a net importer of fossil fuels, and especially important for rural populations who spend a higher percentage of their income on energy than urban populations. In reducing greenhouse gas emissions, renewable energy may also generate carbon finance for communities and their projects. Decentralized renewable energy systems offer all of the benefits mentioned above.

Literature suggests that decentralized renewable energy (DRE) projects have the potential to contribute to climate change mitigation, climate change adaptation, and sustainable development objectives. With regards to mitigation, decentralized renewable energy reduces greenhouse gas (GHG) emissions by displacing fossil fuel generation (Drennen, Erickson & Chapman 1996, Johansson 1994, CEPAL 2007b, Acker, Kammen 1996, Islam, Ruhul Amln & Sadrul Islam 2006). In rural populations, DRE not only provides a change from traditional energy sources, which mainly consist of fuel wood and other forms of biomass, to modern ones, but also avoids the introduction of greenhouse gas producing diesel or natural gas generators. In terms of adaptation, DRE provides electricity that can be used both to prepare for and recover from disasters and to provide additional income and

livelihood opportunities, thus reducing dependency on natural resources and poverty that exacerbates vulnerability. For example, DRE can power early warning systems, telecommunication systems, health clinics and potable water systems. It can also provide power for irrigation for drought-vulnerable crops and electricity for other income-generation activities. It is also important to add that besides being able to meet climate change adaptation objectives, the multiple benefits of DRE's, described above, can also increase the adaptive capacity of the populations to extreme weather events. DRE has been primarily focused on sustainable development and poverty alleviation by providing access to cheap modern energy sources for applications that range from productive use applications to energy services aimed at improving quality of life.

Literature has portrayed DRE as being able to meet a double objective, for example, by meeting poverty alleviation and climate change mitigation (Silva, Nakata 2009). As shown in Chapter 2, literature has also shown linkages between climate change mitigation and climate change adaptation and between climate change adaptation and poverty alleviation and sustainable development. Therefore, this dissertation suggests that DRE systems can simultaneously meet the triple objective.

"Sustainable development" implies the use of appropriate technology for the preservation of environmental resources when meeting development needs (Elliott 1994). Rural sustainable development includes putting people first, building on their capabilities rather than their needs, and involving them in the decision-making process (Chambers 1988, Scoones 1998). Thus, in order to study whether DRE contributes to sustainable development, it is important to study the social and

economic benefits or costs in the community. I use the sustainable livelihoods framework to analyze community development benefits (Elliott 1994, Chambers 1988, Scoones 1998, Chambers 1987, Chambers, Conway 1992) since it provides a useful means of thinking about development and has been widely used by development professionals.

A number of definitions are somewhat contested. Table 1 provides the definitions I use. A more extense list of definitions can be found in Appendix 2.

Table 1. Definition of key concepts

Adaptive Capacity	Potential or ability to adapt to the effects or impacts of climate change. The enhancement of adaptive capacity is a way of reducing vulnerabilities and promoting sustainable development (IPCC 2001).
Adaptation	Adjustment in ecological, social, or economic systems in response to actual or expected climatic stimnuli and their effects or impacts (IPCC 2001).
Vulnerability	Exposure*sensitivity/Adaptive Capacity (Swart, Raes 2007).

The case studies for this dissertation are located in Guatemala and Nicaragua[1], countries that have a generally low Human Development Index and are not on track to meet the Millennium Development Goals (MDG's) in the rural areas (CEPAL 2005, Guatemala 2006, Guatemala 2002, Nicaragua 2003). In Guatemala and Nicaragua,

[1] Costa Rica was not included because there was not a good sample of projects that met the project selection criteria. Additionally, governance issues and levels of development in the country very different than in Guatemala and Nicaragua and a better comparison and analysis was possible by just working in these two countries. Instead, a greater number of projects were visited in Guatemala and Nicaragua, as described in Section 5.

which have electrification rates of 83% and 55% respectively, much of the urban population has access to electricity, but a large rural population does not have access to the national grid (CEPAL 2007c). Rural poverty, land degradation and over-use of natural resources are common in both countries. These countries are also affected annually by hurricanes and tropical storms, which exacerbates poverty and causes setbacks to economic and social development (Navarrete, Gómez & Gallopín 2007, Holt-Giménez 2001, Roberts 2007). Rural renewable energy systems have been implemented in the region over at least 10 years and lessons learned from renewable energy development in these countries have been applied elsewhere (Hanley et al. 2002, Ley et al. 2006a, Ley et al. 2006b). The prospects for the expanded use of rural renewable energy for sustainable development are considerable, and there is a growing interest in climate change adaptation and the potential for increased climate change mitigation efforts, mainly because of the countries' high vulnerability to extreme climate events and the increasing use of coal and fossil fuels in the energy matrix.

Although some studies have looked at the role of decentralized renewable energy systems in development programs and emissions reductions for climate change mitigation there is little or no literature that examines the additional contributions of DRE towards climate change adaptation. In fact, the important role of energy for the achievement of the MDG's has only recently been highlighted (UNDP/ESMAP/World Bank 2005) and energy for climate change and sustainable development is generally an understudied area of academic research. At the Rio+20 conference in 2012, energy was a focus of discussion with the Energy for All initiative.

Venema makes an argument in favor of DRE's meeting the triple objectives:

> *'Well-designed decentralized renewable energy projects are in fact a mitigative and an adaptive response to climate change. DRE's address core sustainable development priorities and build adaptive capacity to climate change, without increasing GHG emissions.'* (Venema, Rehman 2007)

My research asks if and under what conditions rural renewable energy systems can meet this triple objective of mitigation, adaptation and poverty alleviation.

The main **research question** for my dissertation asks:

Can rural renewable energy projects simultaneously meet the goals of sustainable development, climate change mitigation, and climate change adaptation? If so, under what conditions?

I have attempted to answer this question using case studies of renewable energy projects in Central America. The research sub-questions, all related to rural renewable energy systems, follow:

1. How well are projects meeting their goals of sustainable development, climate change mitigation and climate change adaptation?

2. What are the relative roles of local historical background and physical characteristics, type of community governance, and funding source and project implementation process in the success of projects in meeting adaptation, mitigation and development goals?

3. What are the challenges in integrating development and climate change adaptation policies in rural Central America? How might the evolving international climate regime contribute to this integration?

CHAPTER 2: THEORETICAL APPROACH, RESEARCH DESIGN AND METHODOLOGIES

2.1 Literature Review and Theoretical Background

The literature relevant to this dissertation includes studies on climate change adaptation, climate change mitigation, decentralized renewable energy for poverty alleviation, and mainstreaming of climate change with sustainable development. This literature review also includes a section on political ecology and common property resources, the theoretical bases for this research.

2.1.1 Climate Change Adaptation

Despite greenhouse gas emission reduction efforts and policies, current literature points to the need for climate change adaptation due to adverse impacts of increasingly frequent extreme weather events and the likelihood of continued climate change (Venema, Rehman 2007, Adger 2001, Adger 2003, Adger, Arnell & Tompkins 2005, Adger 2006, Adger, Arnell & Tompkins 2005, Adger et al. 2003, Burton et al. 2007, Burton et al. 2002, Eriksen, O'Brien 2007, Leary, Kulkarni & Seipt 2007, Smit, Pilifosova, Smith 1997, Thomas, Twyman 2005, Tompkins, Neil Adger 2005, Tompkins 2005, Yohe, Tol 2002). Sperling (2003) defines adaptation as 'enabling people to manage climate-related risks without suffering reversals in human development' (Sperling 2003). Researchers have emphasized that adaptation is not an alternative to mitigation (Adger, Arnell & Tompkins 2005) and

that both actions must be undertaken since efforts to control GHG emissions will not eliminate the risks of climate change.

The poorest and most vulnerable populations within developing countries suffer the worst effects of extreme weather events, especially populations in which natural resource bases are fundamental for their livelihoods (Adger et al. 2003, Thomas, Twyman 2005). Wealth, access to technology, stable and effective institutions, displacement due to wars or civil unrest, systems for the dissemination of information, equitable distribution of power, and well-functioning social systems determine the adaptive capacities of communities (Smith, Klein & Huq 2003). The United Nations Development Programme (UNDP) 2007/2008 Human Development Report (HDR) emphasizes the importance of adaptation integrated with development since 'adaptation is about investment in everything that will make societies … more resilient. Adaptation is about development for all' (UNDP 2007). Therefore, failure to address adaptation will deter developing countries from growing economically and alleviating poverty (UNDP 2007).

In the policy community, the Third Assessment Report of the IPCC (IPCC TAR) was the first assessment report that brought to light the linkage of adaptation and sustainable development (IPCC 2001). Two efforts towards the integration of these fields are particularly important. The first is the report on 'Assessments of Impacts and Adaptations to Climate Change' that was developed shortly after and because of the IPCC TAR (Leary, Kulkarni & Seipt 2007). It is a compilation of regional and local case studies in developing countries that illustrates the significance of climate change within sustainable development. The second is the 'Adaptation Policy

Framework' created by the UNDP to assist developing countries to create adaptation strategies considering sustainable development challenges (Wilbanks 2003). More recently, the National Adaptation Plans of Action (NAPA's) are being developed for LDC's (UNDP 2007) and some lessons learned can be applied for future NAPA's. Adaptation and poverty alleviation planning should be linked, but are still being done separately (UNDP 2007). More recently, other institutions have created policy and guidance documents, such as the OECD with its 'Integrating Climate Change Adaptation into Development Cooperation' policy guidance document (OECD 2009) and the World Bank through it's booklet "Development and Climate Change: The World Bank Group at Work" (The World Bank 2008a).

Adaptation literature has focused on specific options that include crop diversification (Bradshaw, Dolan & Smit 2004, Naylor et al. 2007), insurance (Crichton 2007, Linnerooth-Bayer, Mechler 2006, Mills 2007, Moser et al. 2007, Romilly 2007, Johnson, Penning-Rowsell & Parker 2007), and flood risk management (Johnson, Penning-Rowsell & Parker 2007, Tol et al. 2003). However, there is little literature on the use of renewable energy to increase adaptive capacity. Eriksen and O'Brien (2007) and Venema and Rehman (2007) hypothesize DRE may be one strategy to meet the triple objective, although they do not provide in-depth details on how this will happen (Eriksen, O'Brien 2007)(Venema, Rehman 2007).

In the past years, community based adaptation (CBA) has been suggested by scholars and exemplified in a number of case studies. Adhikari and Taylor (2011) indicate that successful adaptation at the local level is influenced by key factors, including 'importance of culture, the role of institutions, and the significance of

mainstreaming and good governance' (Adhikari, Taylor 2012). These results were obtained after field visits to four different countries and the main conclusion reached is that community adaptation can strongly influence policy. Boyd et.al. (2008) suggest that a 'resilience lens' may help achieve the goal of successful livelihoods within the development policy sphere, as it will also consider climate change impacts (Boyd et al. 2008).

Case studies have evaluated the role of CBA in different sectors. For example, a study reviewed CBA activities to reintroduce traditional rice varieties and improve yields (Ensor, Weragoda 2009), while another highlighted insights from a farming community in Sri Lanka, observing that local experience and social networks 'significantly influence adaptation' (Esham, Garforth 2012). The analysis of adaptation within Canada's indigenous populations highlighted the importance of community participation for the protection of these communities (Andrachuk, Smit 2012) and for the better understanding of health related effects of climate change (McClymont Peace, Myers 2012). Lack of access to information, services and infrastructure is claimed to be one of the main barriers to CBA (Mapfumo et al. 2012, Gentle, Maraseni 2012); however, the value of local knowledge is also acknowledged as a valuable asset for increasing adaptive capacity (McNamara, Westoby 2011, Picketts et al. 2012) and for internalizing the adaptation process (Shajahan, Reja 2011).

The role of institutions within CBA has also been noted, including how institutions can support local adaptation (Moser, Stein 2011). It is also observed; however, that

institutions can create conflicts, for example, with land tenure problems when local institutions are not strengthened (Mapfumo et al. 2012).

CBA is important within this dissertation as I analyse the role that DRE systems have played in enabling adaptation at the local, communal levels by considering the roles of culture, institutions and governance.

Theoretical approaches to climate change adaptation include approaches based on cultural ecology that examine the role of technology and social organization in adapting to environmental extremes (Berkes, Jolly 2002, Leduc 2006, Moss et al. 2010, Nunn 2009, Turral, Svendsen & Faures 2010), and economic studies of adaptation that assume the main barriers are financial (Bryan et al. 2009, Burch, Deressa et al. 2009, La Rovere, Avzaradel & Monteiro 2009, Mukheibir 2008, Stanton, Ackerman 2009). Many recent studies focus on the role of the institutions in facilitating or preventing adaptation (Burch, Engle, Lemos 2010, Glavovic, Saunders & Becker 2010, Marshall 2010, Pahl-Wostl 2009, Plumeau, Lawe 2009) from theoretical perspectives that range from rational choice (Paavola 2008) to political economy (Keskitalo 2009, McLaughlin, Dietz 2008, Stahel 2008).

Among the gaps in the current literature is the failure to look at renewable energy as a means of adaptation.

2.1.2 Climate Change Mitigation

Climate change mitigation strategies include the use of energy efficiency, low carbon and renewable energy technologies, encouraged by regulations, incentives, market-based policy instruments, and regulated and unregulated carbon markets. The emissions reductions achieved by displacing fossil fuel generation with renewable energy technologies (RET's) are well documented, making renewable energy an option for climate change mitigation (Drennen, Erickson & Chapman 1996, Johansson 1994, CEPAL 2007b, Acker, Kammen 1996, Acker, Kammen 1996, Islam, Ruhul Amln & Sadrul Islam 2006, Islam, Ruhul Amln & Sadrul Islam 2006, Del Río 2007, Olsen 2007, Patel, Ragavan 2000, Purohit, Michaelowa 2008, Sirohi 2007, Wohlgemuth, Missfeldt 2000, Uddin, Taplin & Yu 2007, Walker, Devine-Wright 2008). The UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol set out targets for greenhouse gas emission reductions that included options for developed countries to obtain carbon credits to meet their obligations by investing in carbon reduction projects in the developing world, including those that provided renewable energy instead of fossil fuels. North south transfers of funding for renewable energy emerged as a result of the Kyoto protocol in which developed countries took on emission reduction commitments (United Nations 1998).

The Clean Development Mechanism (CDM), a regulated carbon market, is one of the flexible development mechanisms of the UNFCCC's Kyoto Protocol that was designed to assist developed countries comply with their quantifiable emissions reductions commitments while contributing to sustainable development goals in

developing countries (United Nations 1998). Renewable energy projects can be developed under the CDM (Wohlgemuth, Missfeldt 2000, Uddin, Taplin & Yu 2007) and the latest data from the UNFCCC report more than 3526 projects and 297,772 millions of certificates of emissions reduction through renewable projects that include hydro, landfill gas, wind, biomass, geothermal and solar energy. Table 2 details the distribution:

Table 2. CDM Projects: RE vs. non-RE[2]

	CDM							
Type	number		CERs/yr (000)		2012 CERs (000)		CERs Issued (000)	
Wind	2597	29%	239193	19%	307740	12%	79442	8%
Hydro	2317	26%	327655	26%	407007	16%	102864	10%
Biomass energy	906	10%	60855	5%	153587	6%	26474	3%
Methane avoidance	776	9%	35011	3%	94781	4%	12084	1%
EE own generation	476	5%	62302	5%	178514	7%	46025	5%
Landfill gas	430	5%	83594	7%	187813	7%	27731	3%
Solar	372	4.1%	12260	1.0%	5845	0.2%	166	0.02%
EE Industry	164	1.8%	7961	1%	15766	1%	2074	0.2%
Fossil fuel switch	149	1.7%	71340	6%	162389	6%	35505	4%
Coal bed/mine methane	112	1.2%	72089	6%	102943	4%	16177	1.6%
EE Supply side (power plants)	119	1.3%	64399	5%	42301	2%	1811	0.2%
EE Households	117	1.3%	4348	0.3%	4768	0.2%	135	0%
N2O	109	1.2%	58480	5%	251382	10%	214397	21%
Afforestation & Reforestation	71	0.8%	3649	0.3%	21233	0.8%	4072	0%
Fugitive	65	0.7%	48838	4%	82742	3%	10460	1.0%
Cement	43	0.5%	6559	1%	25298	1%	2154	0.2%
Transport	43	0.5%	5568	0.4%	6774	0.3%	486	0.0%
EE Service	38	0.4%	1724	0.14%	1003	0.04%	6	0%
Geothermal	35	0.4%	12196	1.0%	13242	1%	4262	0.4%
Energy distrib.	27	0.3%	10165	1%	8596	0%	316	0%
HFCs	23	0.3%	81334	6%	473654	18%	420608	42%
PFCs and SF6	18	0.2%	5540	0%	11581	0.5%	2211	0.2%
Mixed renewables	7	0.08%	417	0.0%	129	0.01%		
CO2 usage	4	0.0%	85	0.0%	240	0.01%	10	0.001%
Tidal	1	0.01%	315	0.0%	1104	0.04%		
Agriculture	2	0.02%	58	0.0%	25	0%		
Total	9021	100%	1275934	100%	2560460	100%	1009473	100%
HFCs, PFCs, SF& & N2O reduction	150	1.7%	145353	11%	736617	29%	637217	63%
Renewables	6235	69%	652892	51%	888655	35%	213208	21%
CH4 reduction & Cement & Coal mine/bed	1432	16%	246234	19%	493843	19%	68617	6.8%
Supply-side EE	622	7%	136865	11%	229412	9%	48153	4.8%
Fuel switch	149	1.7%	71340	5.6%	162389	6.3%	35505	3.5%
Demand-side EE	319	3.5%	14033	1.1%	21538	0.8%	2215	0.2%
Afforestation & Reforestation	71	0.8%	3649	0.3%	21233	0.8%	4072	0%
Transport	43	0.5%	5568	0.4%	6774	0.3%	486	0.05%

Some authors suggest that CDM projects have not contributed significantly to sustainable development especially those that focus on industrial gas capture (Del Río 2007, Olsen 2007, Patel, Ragavan 2000, Purohit, Michaelowa 2008, Sirohi 2007,

[2] http://cdmpipeline.org/cdm-projects-type.htm#2, accessed August 12th, 2012

Wohlgemuth, Missfeldt 2000, Boyd et al. 2007, Brown et al. 2004, Michaelowa, Michaelowa 2007, Sathaye, Shukla & Ravindranath 2006, Wara 2006, Wara 2007). Local, small-scale renewable energy projects, which have a larger sustainable development potential, have not been strongly represented as yet within CDM project portfolios. One of the reasons sustainable development has been overlooked is due to trade-offs between economic costs, maximum GHG reduction and development goals, with priority being put on the production of low cost emissions reductions (Brown et al. 2004) and the business orientation of the projects (Sirohi 2007). Project developers are looking for larger scale opportunities to reduce emissions on an industrial scale. Therefore, renewable energy development projects which are small scale and do not include gases with high warming potential do not receive much funding (Pearson 2005). Olsen (2007) enumerates five reasons why CDM projects are not meeting their sustainable development objectives: 1) confusion over the definition of sustainable development, 2) the desire for low transaction costs, 3) problems with market management, 4) problems with project financing and the use of overseas development assistance (ODA), and 5) uncertainty about the post-Kyoto 2012 negotiations (Olsen 2007). Liverman (In Press) indicates that one of the main problems is that each host country has a different definition of sustainable development, and although these definitions may vary from the national to the local level, sometimes only one sustainability component is considered, specially the economic one (Liverman, 2010). Additionally, DNAs (Designated National Authorities) generally rubber stamp CDM projects for sustainable development because they want the investment

Other critics are concerned that market-based policy instruments created to mitigate climate change are not addressing equity issues (Brown, Corbera 2003, Tschakert, Coomes & Potvin 2007). However, the main concern about the development of CDM projects with high social impacts continues to be an economic one as the low carbon prices and the high transaction costs tend to favor industrial gas projects (Liverman In Press).

Besides the CDM, there is also a voluntary carbon offset (VCO) market, also known as the non-regulated market. The VCO includes a wider range of development projects than the CDM, including small-scale renewable energy projects, and sells offsets to firms and individuals. Even though rural development projects are included, authors argue that there is a need to create a clear set of guidelines to incorporate sustainable development objectives into the projects, a robust institutional framework across scales, and a verification and registration body (Brown, Corbera 2003, Kollmuss 2007, Taiyab 2005).

Equity is an area of concern in meeting the sustainable development objectives within the VCO market. Tschakert et. al. (2007) provides an example of fallow and forest management in Panama: despite the carbon offset potential in the region, there is an unequal distribution of resources within the community because of unequal access to assets and different livelihood strategies (Tschakert, Coomes & Potvin 2007). If climate change mitigation is to fulfill a triple objective that includes poverty alleviation they must also address sustainable development and climate change adaptation concerns.

There has also been much debate on the topics of additionality and baselines of CDM projects. *Additionality* is a CDM criterion that ensures that projects have 'real and additional emission reductions' (Mathur, Chikkatur & Sagar 2007), however, the standards and methodologies used to measure additionality are not sufficiently transparent and consistent (McNish et al. 2009, Schneider 2009) leading to doubts regarding the real additionality of many CDM projects (Paulsson 2009). Demonstrating additionality requires showing emissions reductions compared to the business as usual scenario or that the project would not happen without carbon finance. Schneider (2009) states that the current assessment of project additionality is highly subjective as it focuses on the project developers' motivation rather than on the 'market environment and current practice of the project type'. Additionality assessment can also be improved by providing guidelines prior to validation (Schneider 2009). Besides the debate surrounding project additionality, Paulsson (2009) adds that baselines also need to undergo a new process in order to maintain credibility of CDM projects as the amount of issued CER's depends on the procedure chosen for the baseline calculations (Paulsson 2009).

A study done by Alexeew et. al (2010) shows that there is often a trade-off between the additionality of a CDM project and its contribution to sustainable development goals, indicating that projects cannot maintain their sustainable development contributions while providing real, measurable and additional emission reductions (Alexeew et al. 2010). This finding emphasizes the need to carry out reform to create a more level playing field for all project types to participate in the CDM. Alexeew et. al. also highlight that although renewable energy projects, primarily wind and hydroelectric, are meeting sustainable development goals, it has not been to a large

degree. Their study graded sustainable development contributions in a scale with a maximum of 11, with the average punctuation of the projects being between 2.6 and 5. This signifies that there needs to be greater accomplishments within sustainable development goals. This study, however, does have one bias as the authors indicate their main source of information were the Project Development Documents (PDD's), in which project developers tend to highlight the positive impacts of the projects while minimizing or avoiding negative impacts. Keeping this in mind, if fieldwork was carried out in the sites included in the study, there is a probability the sustainable development grades would be lower.

To date, research has shown that renewable energy is capable of meeting climate change mitigation and sustainable development objectives or climate change adaptation and sustainable development objectives, but few have researched the role of renewable energy systems to simultaneously meet all three objectives (Venema, Rehman 2007, Sathaye, Shukla & Ravindranath 2006).

Among the gaps in the current literature are the criteria that need to be met for existing CDM and/or VCO rural renewable energy projects to achieve their stated sustainable development goals and the failure to look at DRE as an option to achieve the triple objective.

2.1.3 Decentralized Renewable Energy for Poverty Alleviation

Nearly two billion people around the world, mainly in developing countries, lack access to modern energy sources (UNDP/ESMAP/World Bank 2005), which hinders

their social and economic development (Ezzati et al. 2004). Renewable energy technologies can provide energy to rural populations to which it is technically or economically infeasible to extend the electricity grid. Electricity can be used for applications ranging from lighting to a wide array of productive uses to energy services supporting health, education, and sanitation (Cabraal, Barnes & Agarwal 2005). This dissertation focuses on renewable energy technologies that include small-scale solar, wind, hydroelectric and biomass energy. There is an extensive literature that has mainly focused on the impacts of renewable energy on poverty alleviation and sustainable development (Acker, Kammen 1996, Islam, Ruhul Amln & Sadrul Islam 2006, Hanley et al. 2002, Ley et al. 2006a, Ley et al. 2006b, Uddin, Taplin & Yu 2007, Ezzati et al. 2004, Cabraal, Barnes & Agarwal 2005, Biswas, Diesendorf & Bryce 2004, Carmody, Sarkar 1997, Chaturvedi 2004, England, Kammen 1993, England, Kammen 1993, Islam, Islam & Amin 2005, Jacobson 2007, Kammen 1999, Kammen, Hankins 2000, Li et al. 2005, Li et al. 2005, Martin 2002, Santosh 2003, Thompson, Saupin & Lang 1999, Yu, Taplin 1998), the barriers to broader implementation (Santosh 2003, Thompson, Saupin & Lang 1999, Alazraki, Haselip 2007, Gururaja 2003, Katti, Khedkar 2005, Zhang et al. 2003), and to a lesser extent, their potential to improve the adaptive capacity of the populations that are served by them (Venema, Rehman 2007, Sathaye, Shukla & Ravindranath 2006, Venema, Cisse 2004). The compliance of safety and quality codes and standards applied to the renewable energy system components, design and installation (Hanley et al. 2002, Ley et al. 2006a, Ley et al. 2006b) and importance of community-led organizations, such as committees or associations, responsible of the operation, maintenance and long-term sustainability of the renewable energy systems (Acker, Kammen 1996, Islam, Ruhul Amln & Sadrul Islam 2006, Uddin, Taplin & Yu 2007)

have been documented in case studies as necessary for the long-term sustainability of renewable energy projects.

The literature on the topic portrays a shift from a paradigm that was focused on technology to a more recent one focused on a needs assessment (Chaturvedi 2004); that is, the context in which the technology is being implemented is equally important, or even more so, than the technology itself. Approaches to the topic of the contribution of renewable energy systems to poverty alleviation include the Gross National Happiness (GNH), the Middle Path of Development (Uddin, Taplin & Yu 2007) and the Sustainable Rural Livelihoods (Chambers 1987, Chambers, Conway 1992). Del Rio, et. al. (2009) points out that literature on this topic tends to be empirically analyzed and mainly focused on case studies and lacks a theoretical framework, which in his opinion, should include the impact on the economic, environmental and social dimensions of sustainability, which is also discussed by Chambers (Chambers 1987) in his Sustainable Livelihoods Approach, and an analysis of local stakeholder perceptions. This can be carried out through a stakeholder analysis and the local actor network (del Río, Burguillo 2009, del Río, Burguillo 2008).

The development agendas of many countries have included implementing decentralized renewable energy. The use of DRE is considered the only cost-effective and environmentally sound option to provide access to electricity to many rural populations. Only recently has energy access been viewed as a necessary, though not sufficient, enabler for development, including the MDGs (CEPAL 2005, UNDP/ESMAP/World Bank 2005, Ezzati et al. 2004, Cabraal, Barnes & Agarwal

2005, Chaturvedi 2004, Islam, Islam & Amin 2005, Katti, Khedkar 2005, CEPAL 2007a, Energy (Norwalk 2004, Gan, Yu 2008, Mulugetta 2007, Peake 2002, Tunde 2005).

The lack of basic infrastructure, including energy, has prevented some countries from achieving the MDG's in rural areas (while meeting them in the urban sector). Guatemala and Nicaragua, two countries in which this dissertation bases its case studies, have stated that the MDG's are unlikely to be met in the rural sector (Guatemala 2006, Guatemala 2002, Nicaragua 2003, CEPAL 2007a), highlighting the need to provide energy infrastructure and services to these off-grid populations. Central American countries have the advantage of good renewable energy resources. According to the *Solar and Wind Energy Resource Assessment* (SWERA) there is potential for the development of solar and hydroelectric resources in Guatemala and Nicaragua, and for wind resources in Nicaragua and Costa Rica (SWERA 2006).

Renewable energy systems, ranging from large scale wind farms to small scale home lighting PV systems, have presented negative impacts. Although most case studies and lessons learned focus heavily on positive impacts, few reviews have detailed the negative ones and possible solutions. Schäffer et. al. (2011) explains this as 'a lack of systematic evaluation of experience with decentralized electricity systems in different cultural and geographic contexts and the transfer of this experience' and suggest the view of socio-technical systems helpful by integrating knowledge from different disciplines, including local knowledge, in order to improve research in this area (Schäfer, Kebir & Neumann 2011).

Brown (2011) presents the example of wind energy development in Brazil which is met with growing opposition as the local residents claim there are few local benefits but many local negative impacts such as blocked access to fishing areas and damaged homes (Brown 2011). Other wind energy studies have indicated their opposition mainly because of negative consequences to local environmental systems; however, this is mostly with large-scale grid-connected plants that do not always account for the local context (Clarke 2009). Biofuels have also met opposition, primarily because of the growing number of studies highlighting competition with the food sector amid food security concerns (Koh, Ghazoul 2008). Among the solutions presented are the use of second generation feed stocks and a comprehensive assessment of environmental and social impacts (Koh, Ghazoul 2008). This confirms the conclusion of other studies, including those claiming that CDM projects can have a greater potential on sustainable development, that benefits of renewable energy projects are only present at the regional scale.

Rural renewable energy systems can also negatively impact its users. A study done of Japan's rural energy programs point out that there are both positive and negative effects on the rural economy, with impact on indirect sectors such as construction and banking (Itoh, Nakata 2004). Despite wide-spread use of solar PV for rural electrification, there have also been limitations. A study of Ethiopian PicoPV systems indicates that 17% of interviewed respondents gave a negative evaluation to their systems either because of limitation of capacity or social issues (Müggenburg et al. 2012). At the communal level, the arrival of the project was perceived to create jealousy, envy and mistrust and, because of the illiteracy levels, not many additional

activities were enabled due to the electricdity (Müggenburg et al. 2012). This study concludes with the need to study users' behaviours in order to provide systems that will be able to benefit them more. In this sense, Yu and Taplin (1998) indicate that foreign donors who focus on poverty alleviation should promote 'recipient countries' capabilities in sustainable development' (Yu, Taplin 1998), reinforcing the idea that local context, together with the integration of social and economic development and environmental protection (Jusi 2010), need to be considered from the outset in order to maximize projects' benefits. For example, in the case of PV systems, solutions can be as simple as in pre-electrifying villages which will be receiving grid electricity in the short to medium terms and including applications such as street lights (Chaurey, Kandpal 2010).

The evaluation of Brazil's different rural electrification programs is perhaps the best overview thus far on the impacts of both off-grid and on-grid rural electrification efforts. Of relevance to this dissertation are the outcomes of two programs. The first is Prodeem (Energy Development Program for States and Municipalities) where a series of management problems caused systems to be lost or stolen/sold within a year of their installation. This outcome also derived from lack of training to the communities who were unprepared to receive the projects (Andrade, Rosa & Da Silva 2011). The Luz para Todos (Light for All) Program, their most recent and biggest rural electrification effort, prioritized grid extension and their success indicators were measured by the number of connections, therefore, little or no attention was put on renewable energy sources and there were no real prospects for sustainable development goals to be met. The grid extension brought hardships to a subset of the population it was supposed to benefit as it did not improve household

income and the electricity bills were very high, even for those classified as *low income* (Andrade, Rosa & Da Silva 2011). Andrade et. al. (2011) also cite that the creation of small businesses has not been possible due to inadequate energy supply and that future programs can improve by having a more efficient use of energy, increased employment and income potential, and decreased idleness. More motivation is needed as social problems have started, related to bars, drugs and alcoholism (Andrade, Rosa & Da Silva 2011).

Among the gaps in current literature is that the literature of renewable energy for sustainable development, especially for poverty alleviation, rarely looks at climate or carbon.

2.1.4 Mainstreaming Climate Change and Sustainable Development

The linkage between sustainable development and climate change mitigation and adaptation is an important new theme. The 2007/2008 HDR of the UNDP emphasized the '*integration* of adaptation planning into wider poverty reduction strategies,' as necessary if the world is to achieve the MDG's by 2015 (UNDP 2007). The challenge of *mainstreaming* adaptation with development policies and practices, and also with climate change mitigation, has been studied (Burton et al. 2007, Sperling 2003, Smith, Klein & Huq 2003, Olsen 2007, Michaelowa, Michaelowa 2007, Sathaye, Shukla & Ravindranath 2006, Beg et al. 2002, Bizikova, Robinson & Cohen 2007, Cohen et al. 1998, Dang, Michaelowa & Tuan 2003, Downing, Munasinghe & Depledge 2003, Grubb 2003, Halsnæs, Verhagen 2007, Huq 2003,

Huq, Reid & Murray 2006, Markandya, Halsnæs 2002, Metz et al. 2002, Najam et al. 2003, Swart, Raes 2007, Swart, Robinson & Cohen 2003, Wilbanks 2007) and noted in policy documents (Great Britain. Dept. for International Development 2004, IDS In Focus 2007, The World Bank 2008b).

Sperling (2003) makes a distinction between 'integration' and 'mainstreaming':

> '*Mainstreaming* indicates that climate issues are being used for planning and budgeting decision making while *integration* is used when specific adaptation measures are added to design and implementation strategies (Sperling 2003)

From these definitions, it would seem that in order to have an effective *integration*, *mainstreaming* is needed. That is, having the proper planning and decision making tools *mainstreaming* climate change with sustainable development will enable their *integration* in practice.

Klein, et.al. (2005) defines mainstreaming as 'making more efficient and effective use of financial and human resources than designing, implementing and managing climate policy separately from ongoing activities' (Klein, Schipper & Dessai 2005).

The argument that there should be a strong relationship between sustainable development and climate change policies has spanned at least 20 years; however, in practice, there have been very few links in policy and scholarship between the climate change community and the development community until recently. The

discourses, research and policies of these two arenas have been carried out independently (Huq, Reid & Murray 2006) and in parallel (Swart, Robinson & Cohen 2003), mainly due to the 'differences in conceptual frameworks, definitions, and languages' (Swart, Robinson & Cohen 2003).

The 1987 Brundtland Report was one of the first documents to recognize 'climate change as a major environmental challenge facing development' (Brundtland 1987). The notion of this relationship emerged again in the 1992 Rio Declaration and Agenda 21 (United Nations 1993) (Huq, Reid & Murray 2006) and in the 2002 Johannesburg World Summit on Sustainable Development (WSSD) (United Nations 2003) that produced the Water, Energy, Health, Agriculture, and Biodiversity (WEHAB) Initiative as one of its key outcomes. This initiative highlights not only the linkages between climate change and sustainable development, but also between the five sectors it covers. The IPCC TAR (IPCC 2001) stated that risks of extreme weather events should be included in the design and implementation of development initiatives in order to promote equity and development that is sustainable while reducing vulnerability to climate change. Notably, the two previous IPCC assessment reports did not mention development or adaptation. Swart et. al. (2003) and Beg et. al. (2002) go further by stating that such integration is a 'pre-requisite for successful climate change and development' (Beg et al. 2002, Swart, Robinson & Cohen 2003).

The linkage between development and adaptation has become more evident in many poorer countries. Developing countries suffer most from extreme weather events due to their low adaptive capacity (Beg et al. 2002), which could further

hinder their development efforts, including those to meet the MDGs (Sperling 2003). Downing et al (2003) states that climate and development 'interact in a circular fashion,' with climate change not only affecting current development work and prospects for ongoing sustainable development. Conversely, development paths will influence future adaptive capacity and mitigation (Downing, Munasinghe & Depledge 2003) (Swart, Robinson & Cohen 2003). Bizikova et. al. (2007) claim that in order to successfully integrate sustainable development, climate change mitigation and climate change adaptation at the local scale, local communities must implement the 'principles of participation, social learning and scenario development' (Bizikova, Robinson & Cohen 2007). They further propose a methodology, called AMSD (Adaptation, Mitigation and Sustainable Development) in which climate change mitigation and adaptation are a part of wider development goals, consisting of four stages: '1) identifying a local sustainable development scenario, 2) explicitly linking climate change impacts, 3) identifying linkages between adaptation and mitigation, and 4) developing an integrated AMSD implementation strategy' (Bizikova, Robinson & Cohen 2007).

The linkage between adaptation and mitigation has also been studied. The Working Group II to the Fourth Assessment Report of the IPCC identified four types of inter-relationships: 1) adaptation that has mitigation consequences, 2) mitigation that has adaptation consequences, 3) decisions involving trade-offs or synergies between them, and 4) processes that have consequences for both of them (Klein et al. 2007b). The implementation of adaptation and mitigation policies and strategies varies across scales and, although possible in practice, is also dependent on the

local and regional development pathways (Klein et al. 2007b). However, the IPCC chapter included very few examples and did not discuss renewable energy.

One common aspect among these studies is emphasis on the need for actions at the regional and local levels (Burton et al. 2007, UNDP 2007, Wilbanks 2003, Bizikova, Robinson & Cohen 2007, Swart, Raes 2007, Wilbanks 2007, Wilbanks 2007) before developing them at the global level. Working at the local level is key for both development and adaptation projects since they are case-specific, and assures that livelihood priorities are met. Assessments at the regional and local scales are important to address 'real vulnerabilities' (Downing, Munasinghe & Depledge 2003), create a 'rich basis of examples to push the actions at national and global scales' (Bizikova, Robinson & Cohen 2007), understand context and cultural specific matters (Burch, Robinson 2007), and develop practical applications for the development of national policies (Burton et al. 2007).

Recommendations for effective mainstreaming include that there should be a shift of emphasis toward sustainable development – a central topic throughout the IPCC Assessment Reports – both in climate change and development strategies (Bizikova, Robinson & Cohen 2007, Najam et al. 2003). The concern of the academic community has been the lack of a theoretical basis that could link sustainable development, climate change mitigation and climate change adaptation, since climate change and development research diverged due in part to different conceptual frameworks, as well as the different research and policy traditions developed within each field. Positive actions need a bottom-up approach in order for larger scale actions to be shaped and implemented, that is, small-scale actions will

enable large scale actions at the national and global scales to take place (Bizikova, Robinson & Cohen 2007). Halsnaes and Verhagen (2007) present an approach, 'inspired by institutional economics and development paradigms that emphasise human wellbeing, resource access, empowerment, and the arrived freedoms' (Halsnæs, Verhagen 2007). They conclude with the feasibility of applying wellbeing indicators, but indicate the lack of a linkage to national and regional scenarios.

Recent literature has also pointed out challenges, criticisms, and trade-offs for the mainstreaming of development and climate change policies. The main challenges identified by Klein, et.al (2007) are that the host country's development objectives should guide the priorities of the donor agency and that poverty alleviation does not necessarily entail decrease in vulnerability, either because of technology choices or conflicts, among other reasons (Klein et al. 2007a). Among the criticisms identified is the fact that the UNFCCC does not have development and equity promotion as one of its main objective, thus, the limited funding that exists for climate change mitigation and adaptation should not be diverted towards development activities, and viceversa, as the development community does not want their equally limited funding diverted to projects that will have small development impact (Klein, Schipper & Dessai 2005, Chuku 2010). Also viewed as a conflict, although only true when discussing budgets (of the host country and the donor) is that poor developing nations view development as a short-term goal while climate change is perceived as being longer-term (Klein, Schipper & Dessai 2005, Chuku 2010). This perception exists because, according to Klein, et.al (2005), current funding mechanisms are not designed to facilitate mainstreaming and that can be evidenced when reviewing the funding criteria of several donor agencies, such as those of the GEF (Klein, Schipper

& Dessai 2005). Besides the design of the funding mechanisms, mainstreaming may not always be possible because of the perceived trade-offs between climate change and development priorities (Chuku 2010, Agrawala 2005). For example, adverse development can happen by addressing climate change concerns when a hydroelectric plant displaces people by using land that used to be suitable for agriculture and by hiring an external workforce. Likewise, adverse climate change can happen through development activities, for example, when mangroves are converted thus increasing vulnerability.

Among the gaps in the current literature are a lack of case studies that show how this mainstreaming can actually be done and the role of renewable energy as an option for mainstreaming.

2.1.5 Theoretical Approach: Political Ecology and Common Property Resources

Political ecology has been used as a theoretical framework by many scholars to examine the relationship between political and economic structures (such as markets, development and aid), local communities and physical conditions. As such, it provides a useful framework for evaluating rural renewable energy projects by providing a focus on institutional structures (such as common property resources management systems) and markets, the local responses to development interventions as well as on the material effects of development on the physical environment (for example, water, soil, and carbon).

I apply a political ecology approach in order to answer my questions about the relationship between development, climate change mitigation and climate change adaptation, the ability of decentralized renewable energy to achieve this triple objective, and the underlying social and economic structures that enable or prevent the success of renewable energy projects. Political ecology highlights interactions across scale, especially the role of government and policies at different levels and their effects on the local level and the relationships between the state, private sector, NGOs and individuals. Critical approaches to political ecology highlight the importance of power relations and ideas promoted by powerful groups in framing resource management (Berkes 2008, Berkes 2004).

Political ecology has been used to understand nature-society relations and assess patterns of production and consumption of many different resources (Zimmerer, Bassett 2003, Young 1999, Richter 2000, Ravnborg 2003, Gareau 2004), including water, forests, and land but with few analysis of renewable energy. Political ecology can show ways in which 'environmental analysis and policy can be reframed towards addressing the problems of socially vulnerable people' (Forsyth 2008). This relationship is important in the countries studied because of the diverse cultural and religious conceptions of nature and their relationship with nature. The most common example found were the Mayan cosmology's views of nature and the use of natural resources, including those used in DRE systems. It can therefore be said that, through political ecology, environmental research will 'remain sensitive to political and cultural debates' (Batterbury, Forsyth & Thomson 1997) as political ecology studies include a range of methods from indigenous knowledge to scientific techniques (Forsyth 1996).

Feminist political ecology highlights the different experiences of men and women, in which women may be more vulnerable, have less access to resources and income, are overlooked by development projects and suffer differently the consequences of environmental change and degradation (Elmhirst 2011, Rocheleau 1995, Truelove 2011). Some studies, such as those carried out by Howitt (2012) demonstrate that these same inequalities are experienced by indigenous people (Howitt 2010, Howitt, Havnen & Veland 2012)

Schmink and Wood (1987) list the components that critical political ecology analysis should examine: 1) the 'ideology' that determines resource use and subsequently the groups that are more or less disadvantaged, 2) the interests of the financing institutions (donors, private companies or government) with regards to resource use, 3) the role of the state in defining and implementing resource use, 4) the class structure of the population and conflict over use of resources, 5) market relations and the extraction of surplus goods, and 6) the nature of production in a region (Schmink, Wood 1987). All of these factors are relevant to my analysis of renewable energy systems.

Political ecology studies of Latin America are mostly related to the relationship between poverty and environmental degradation, and include studies related to poverty with conservation efforts in protected areas (Ankersen, Regan & Mack 2006), development (Gareau 2004), land degradation (Ravnborg 2003, Hellin 1999, Horton 2004), conservation, wildlife and livelihoods (Nygren 2004, Logan, Moseley 2002), land use change (Richter 2000), land use and food security (Sheridan 1992), shrimp mariculture and fisheries (Stonich 1995, Stonich, Bort & Ovares 1997,

Chapman 1989), non-traditional export growth (Stonich, Murray & Rosset 1994), anti-poverty policy strategies (Breuer, Cruz 2005) and irrigation and water resources (Zimmerer 2000). The energy sector has been an area of study for political ecology and political economy, including the use of wood fuel (Cline-Cole 2007), the wind turbine industry (Brandt, Svendsen 2006) and U.S. energy policy (Orr 1979). There is scant literature on the political ecology of other renewable energy systems. I will contribute to reducing this gap by using political ecology as an approach to analyze the link between climate impacts and 'policies and institutions engaged in implementing environment and development' (Adger et al. 2001) by studying the social structures and historical backgrounds, and the agency of individual community members, project developers and others as key factors (Pelling 1999) that determine the success of rural renewable energy systems. The existence and type of local governance structures, the level of poverty, and population displacement due to civil wars are among the considerations important to the 'surrounding causes, experiences, and management of environmental problems' (Blaikie, Brookfield 1993) that will contribute to the debate around mainstreaming development with climate change mitigation and adaptation.

Political ecologists have drawn on institutional analysis to understand the political economy of resource management, especially the theories that examine the significance of property rights and institutional structures. One of the key debates is about the effectiveness of private versus common management and governance of energy and environment in terms of sustainability. Many of the renewable energy projects that I studied were managed as common property resources for the community rather than private projects for individuals. Common Property Resources

(CPR) theory is relevant to examining whether these commonly owned renewable energy systems can contribute to meeting the triple objective of climate mitigation, adaptation and poverty alleviation. CPR's have two common characteristics: '1) the exclusion or control of access of users to the resources is problematic, and 2) each user is capable of subtracting from the welfare of other users' (Berkes, International Union for Conservation of Nature and Natural Resources 1989, Feeny et al. 1990, Ostrom 2002).

Management of common property resources has changed over the centuries including the use of shared energy sources. Between 1350 and 1800, Central European rural societies were 'restricted by the amount of renewable natural resources available' with a local public law that prevented over-exploitation of natural resources of forests and pastures (Marquardt 2005). Hardin's (1968) 'Tragedy of the Commons' describes how users of a common over-exploit the natural resources upon which they depend, destroying the resources' sustainability and their livelihoods. He additionally states that the only two solutions to avoid this over-exploitation is for the commons to be privatized or kept as public property with rights of use based on wealth, merit, or some other system (Hardin 1968), that is, with a policy of 'mutual coercion, mutually agreed upon' (Hardin 1998) indicating the need for external authorities to impose rules (Ostrom et al. 1999). In his 1994 'The tragedy of the unmanaged commons' Hardin makes the distinction between managed, where the use of property rights ensures sustainable use of the resources, and unmanaged, where unsustainable use is inevitable, commons. He classifies the alternatives to unmanaged commons under *privatism*, when the resource is divided into a number of private properties, and *commonism* or *socialism*, when the property owners appoint a manager. Additionally, he points out the importance of the 'scale

effect'. Under this assumption, *commonism* of unmanaged commons will fail except in the smallest of communities (Hardin 1994). I explore if and how some of the DRE case studies, either considered as a commons or implemented within a commons, meet Hardin's theory as some of the communities visited can be categorized as 'smallest', some with only 27 homes.

Since the first essay of 'The tragedy of the commons', there has been an important debate and a number of empirical studies carried out regarding the management of commons and the role of technology, among other topics. Burger and Gochfeld (1998) observe that there is not one single management approach that can solve all the common resource problems that exist and that the first step towards a successful commons management is a clear definition of both the users and the resources as well as the effect of the users on the resources. Other important factors are the need for effective monitoring and enforcement and a 'sense of individual ownership' (Burger, Gochfeld 1998). Ostrom, et.al. (1999) believe that common-pool resources can be managed by restricting access and creating incentives (Ostrom et al. 1999). They also agree with Burger and Gochfeld that, although not sufficient, evolved norms including monitoring and sanctions are needed, as exemplified in several case studies. Lessons learned from a number of case studies indicate that stimulus to self-organized processes are helpful in local and regional CPR's and this in turn depends on the social setting and cultural diversity of each location, among other factors (Ostrom et al. 1999). Other studies have indicated that property rights are important in determining viable resource management alternatives. Feeny, et.al. (1990) define categories of property rights within which CPR's can be held and they include open access and private, state and communal property and portray the

importance of understanding these rights and other institutional arrangements that govern use and access of the CPR's (Feeny et al. 1990). McKean, et.al. (1995) add that the transfer of property rights from traditional user groups to others eliminates the monitoring, sanctions and incentives systems that contributes to the sustainability of CPR's, thus increasing resource use through unsustainable practices. This confirms once again that there are some cases in which communal management is the only viable solution (McKean, Ostrom 1995). Ostrom (2009) also points out that a number of empirical studies demonstrate that investment in the design and implementation of governance systems increase the likelihood of sustained CPR's (Ostrom 2009). Wade (1987) presents a case study of Indian villages and states that the theories of common property do not apply to village-scale resources as they themselves are able to locally sustain their resources and have a set of rules. One of the reasons Wade does not agree with Hardin's Tragedy of the Commons is because Hardin 'does not distinguish between commons where the resource is vital for the individuals' survival, and those where it is not' (Wade 1987).

Literature on CPR has covered topics surrounding natural resources and their uses, including aquaculture (Bailly, Paquotte 1996), trade (Bulte, Barbier 2005), forestry (Klooster 2000, Klooster, Masera 2000), neoliberalism (Liverman, Vilas 2006), ecotourism (Young 1999, Moreno 2005) and coastal livelihoods (Van Hue, Scott 2008). Energy use, including renewable energy, has also been studied through a CPR approach, mainly focusing on the optimal use of finite sources such as fossil fuels (Steininger 1994). Among other similar studies, Ghosh and Das (2003) present an example of common property resource use in biomass energy production: five unelectrified villages on an island of West Bengal were provided with electricity from

a wood-based gasifier and the feedstock was grown on common property (Ghosh, Das 2003). However, there has not been significant literature on other renewable energy sources.

Ostrom and colleagues have developed an important list of factors that contribute to the success of CPR management systems. Because I am trying to assess the success of renewable projects that happen to be managed as CPRs by communities as part of my research design, I will analyze whether the 'design principles for common property resources' identified by Ostrom (Ostrom 2002) also apply to community-owned renewable energy systems (see Table 3). In addition to Ostrom's list I also look at the idea of Wade (1998) who indicates that 'low-cost exclusion technology' is a facilitating condition for the management of common property resources (Wade 1988), an idea that Ostrom (1999) and Burnet (1999) also discuss as having some benefit to CPR management (Ostrom et al. 1999, Lundgren et al. 1999). I will test the validity of Wade's statement in the context of renewable energy systems.

Table 3. Ostrom's Common Property Resources Design Principles

1. Resource system characteristics a. Well-defined boundaries
2. Group characteristics a. Well-defined boundaries
(1 and 2) Relationship between resource system characteristics and group characteristics
3. Institutional arrangements a. Locally devised access and management rules b. Ease in enforcement of rules c. Graduated sanctions d. Availability of low-cost adjudication e. Accountability of monitors and other officials to users
(1 and 3) Relationship between resource system and institutional arrangements a. Match restrictions on harvests to regeneration of resources
4. External environment a. Technology b. State i. Central governments should not undermine local authority ii. Nested levels of appropriation, provision, enforcement, governance

(Ostrom 2002)

Political ecology and CPR provide the key theories that frame my analysis of renewable energy, climate and development in Central America. Figure 1 illustrates how these theories link conceptually.

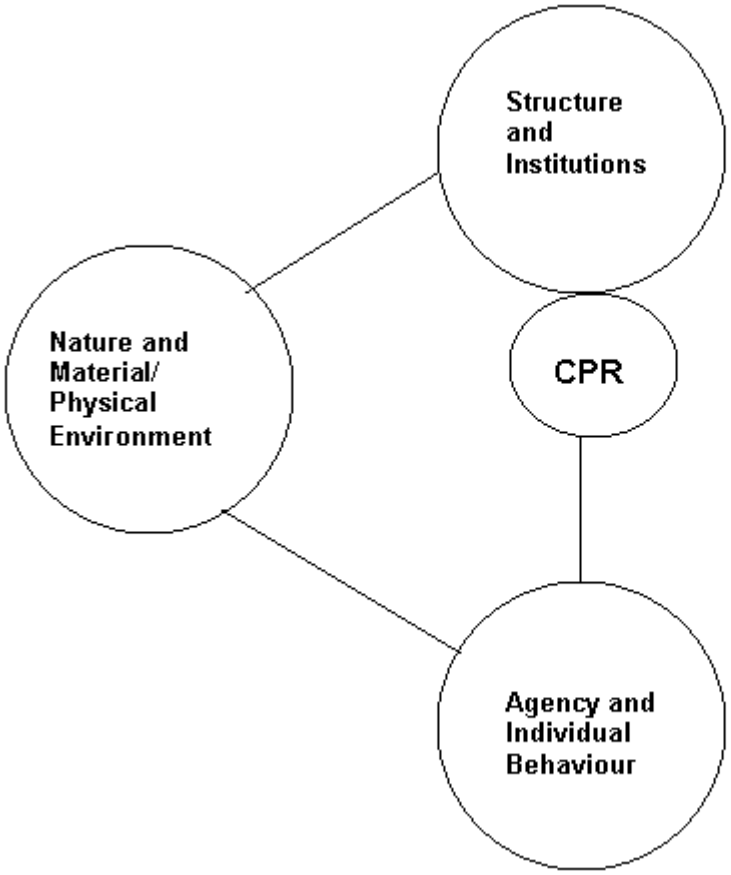


Figure 1. Conceptual link of Political Ecology and Common Property Resources

CPR appears as a major set of institutions for managing resources. However, agency does influence CPR's when the CPR rules are changed by the people/community.

Based on these theories I would expect that the success of projects would be explained by:

1. Political and economic structures that secure property rights, access to resources, equitable benefits, communal ownership and local management of the renewable energy system and the role and impact of local institutions and the influence of government and foreign and international donor agencies.
2. The agency of individuals in a community and project managers who seek the success of a project and work towards it.
3. Constraints and opportunities afforded by the physical environment, historical background, and cultural and religious diversity.
4. Relation to Ostrom's rules for successful CPR management, and defined rules, sanctions and incentives.
5. Wade's hypothesis that technology must be easily accessible.

2. Research Design and Methodology

2.1 Research Design and Fieldwork

I used a mixed-methods approach since I collected both qualitative and quantitative data on both physical and social systems, had both open and closed ended questions, and used statistical and qualitative analysis in order to answer my research sub-questions (Creswell 2003). The specific mixed-method design I used was the transformative strategy in which the qualitative and quantitative data was gathered at the same time; the integration of results was carried out in the interpretation phase and the theoretical framework guided the study questions (Creswell 2003).

The methods I used to gather the information included literature reviews, institutional document analysis, surveys, semi-structured interviews, direct observation and renewable energy system inspections (Mikkelsen 2005). I interviewed community members (individually and through community meetings and focus groups, and both users and non users of the energy systems), project developers, project donors, renewable energy system vendors, and municipal and federal government officials.

I used purposeful criteria sampling for the selection of the case studies, as detailed in section 2.1.1, and stratified purposeful and snowball sampling within each community, as detailed in section 2.1.2 (Patton 2002, Neuman 1996). I developed separate questionnaires for community members, donors, developers and government officials (Kvale 1996, Nardi 2003, Oppenheim 1992)

2.1.1 Selection Criteria of Projects

I chose Guatemala and Nicaragua because of their historical, cultural and religious background, their vulnerability to extreme weather events suffered throughout the years, and their experience with different DRE project schemes. The selection of these countries allowed the analysis of similarities and discrepancies within each country and between them. The main characteristics of each country through which I carried out these analysis are listed:

- Indigenous population: Guatemala has 23 different Mayan cultures, mainly located in the Highlands of the country. Within Guatemala, the comparison focused on DRE systems installed in areas of different Mayan populations as well as *ladino* (non-indigenous) populations. Nicaragua's Miskito indigenous

population is mainly located in the Atlantic Coast and the research focused on the Northern Atlantic Coast.

- Civil War: Guatemala's Civil war, which lasted approximately 30 years, was suffered mainly by Quiché Mayans in the Highlands of the country. Although other regions suffered consequences of the Civil War, the area of Quiché was one of the most affected. Several case studies took place in Quiché to compare different implementation processes of working in civil war stricken areas versus working in areas that have suffered other types of conflict or none at all. Nicaragua has also suffered from a Civil War and case studies within Nicaragua sought to compare installed DRE systems inside and outside civil war areas. A comparison between DRE systems installed in conflict areas in both countries was also carried out.
- Poverty: In both countries, areas with the highest poverty indexes coincided with those with a highest indigenous population. Analysis in each country compared system sustainability in areas with different poverty indexes. The same comparison was also done between countries. One of the main findings is related to the governance and tariff structure found in both countries.
- Extreme weather events: Both countries have a history of suffering through extreme weather events and hurricane reconstruction efforts have not always been successful or sustainable. By selecting these two countries I was able to compare the success of DRE projects in vulnerable indigenous and non-indigenous areas, as well as a comparison between the countries on how DRE has helped reduce vulnerability, if any, and how it has and can increase adaptive capacity in the future.

Table 4 summarizes the main social, poverty, education, health, environment and economic indicators of Guatemala and Nicaragua.

Table 4. Social, Poverty, Education, Health, Environment and Economic Indicators for Guatemala and Nicaragua

SOCIAL INDICATORS	GUATEMALA	NICARAGUA
Population, total (2010)	14,388,929.00	5,788,163.00
Population growth (annual %) (2010)	2.5	1.4
Population density (people per sq. km) (2010)	134.3	48.1
Rural population (2010)	7,266,409.10	2,471,545.60
Rural population density (rural population per sq. km of arable land)	0	0
Rural population (% of total population) (2010)	50.5	42.7
Birth rate, crude (per 1,000 people) (2009)	32.7	24.2
Death rate, crude (per 1,000 people) (2009)	5.5	4.7
Mortality rate, infant (per 1,000 live births) (2010)	24.8	22.6
Mortality rate, under-5 (per 1,000) (2010)	31.8	26.9
Life expectancy at birth, total (years) (2009)	70.6	73.4
Labor force, total (2009)	5,459,823.10	2,313,085.40
Labor force, female (% of total labor force) (2009)	37.9	38.7
POVERTY INDICATORS		
Number of rural poor (million, approximate) (2010)	5,122,818.40	1,678,179.50
Poverty headcount ratio at rural poverty line (% of rural population)	70.5	67.9
Poverty headcount ratio at national poverty line (% of population) (2005)	51	46.2
Income share held by lowest 20% (2005)	3.5	3.8
EDUCATION INDICATORS		
School enrollment, primary (% gross) (2010)	116.5	117.6
Literacy rate, adult total (% of people ages 15 and above) (2005)	74.5	78
HEALTH INDICATORS		
Health expenditure, total (% of GDP) (2009)	7.1	9.5
Improved water source, rural (% of rural population with access) (2008)	90	68
Improved sanitation facilities, rural (% of rural population with access) (2008)	73	37
ENVIRONMENT INDICATORS		
Land area (sq. km) (2010)	107,160.00	120,340.00
Forest area (% of land area) (2010)	34.1	25.9
Arable land (% of land area) (2009)	14	15.8
Irrigated land (% of cropland)	0	0
ECONOMIC INDICATORS		
GDP (current US$) (2010)	41,186,395,243.00	6,551,182,459.00
GDP per capita growth (annual %) (2010)	0.2	6.1
Inflation, consumer prices (annual %) (2010)	3.9	5.5

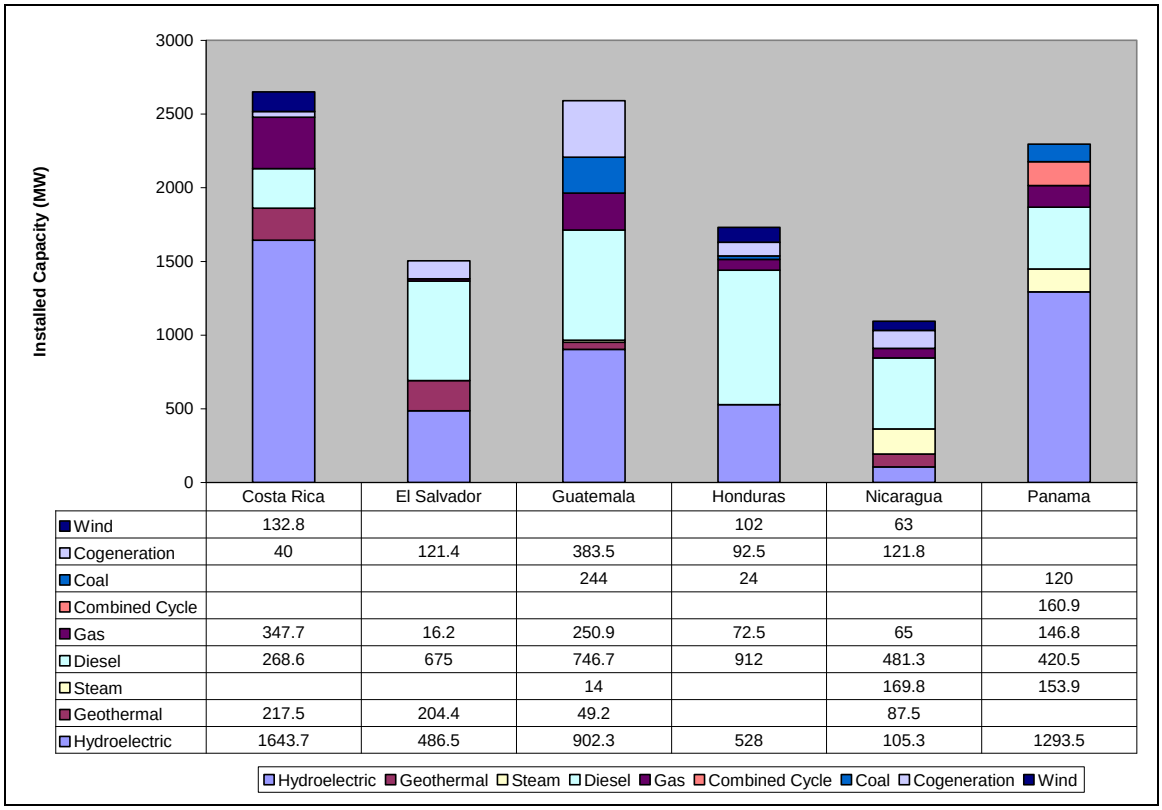
Source:http://www.ruralpovertyportal.org/country/statistics/tags/guatemala, http://www.ruralpovertyportal.org/country/statistics/tags/nicaragua, accessed August 13th, 2012

Guatemala and Nicaragua also share certain characteristics within the electric sub-sector primarily that, together with the Central American region, they are net oil importers. Of more importance to this dissertation, is their experience with grid connected and off-grid renewable energy projects

- Renewable energy projects: Both countries have had extensive experience with renewable energy projects. The different funding schemes found in each country (international, multilateral, private, and government) allowed for a comparison within each country and between them, for different renewable energy technologies, mainly solar photovoltaic and small-scale hydroelectric plants. The location of these projects in areas that coincide with the criteria listed above has also allowed to analyse the behaviour of DRE systems under different social and geographical locations.

- Electric Sector Structure and Market: The electric sector of both countries is privatized and although the structures are different in Guatemala and Nicaragua, I was able to research the behaviour of DRE systems interconnected to the national grids and of the populations surrounding the systems. Although there are certain similarities between the countries, there are also big differences. The main difference is the designation of a *concession* area in the areas covered by the national grid. Areas not covered by the grid are designated as a *non-concession* area, which are subject to different treatment under Nicaragua's Electric Reglament. This dissertation analyses the impacts this different treatment has on DRE systems installed in the *non-concession* area, but interconnected to the national grid in the *concession* area.

Figure 2 shows the installed capacity for each Central American country, divided by sources (fossil and renewable).



	Costa Rica	El Salvador	Guatemala	Honduras	Nicaragua	Panama
Wind	132.8			102	63	
Cogeneration	40	121.4	383.5	92.5	121.8	
Coal			244	24		120
Combined Cycle						160.9
Gas	347.7	16.2	250.9	72.5	65	146.8
Diesel	268.6	675	746.7	912	481.3	420.5
Steam			14		169.8	153.9
Geothermal	217.5	204.4	49.2		87.5	
Hydroelectric	1643.7	486.5	902.3	528	105.3	1293.5

Figure 2. Installed Capacity in Central America, CEPAL 2011

Tables 5 and 6 and Figures 3 and 4 show electrification statistics of both countries. As can be seen, both countries still have a considerable population that does not benefit from modern energy sources, who are most vulnerable to extreme weather events and who are mostly indigenous. This data, together with the country descriptions above, are the main reasons why I selected these two countries for my dissertation.

Table 5. Guatemala's Electrification Statistics, CEPAL 2011

Year	Population (1000)	People per home (Average)	Total homes (1000)	Residential Customers (1000)	Electrification Index (%)
1985	7935	5.8	1368	407.7	29.8
1990	89.8	5.9	1509.8	539.9	35.8
1995	10004	5.9	1701.3	778.5	45.8
2000	11225	5.8	1925.5	1328.1	69
2001	11504	5.8	1976.6	1523.1	77.1
2002	11791	5.8	2029.4	1575.3	77.6
2003	12087	5.8	2084	1643	78.8
2004	12391	5.8	2140	1743.1	81.5
2005	12701	5.8	2197.3	1790.2	81.5
2006	13019	5.8	2256.3	1875.8	83.1
2007	13345	5.8	2312.8	1936.8	83.7
2008	13678	5.8	2370.5	1985.5	83.8
2009	14017	5.8	2429.3	2040.3	84
2010	14362	5.8	2489	2123.5	85.3

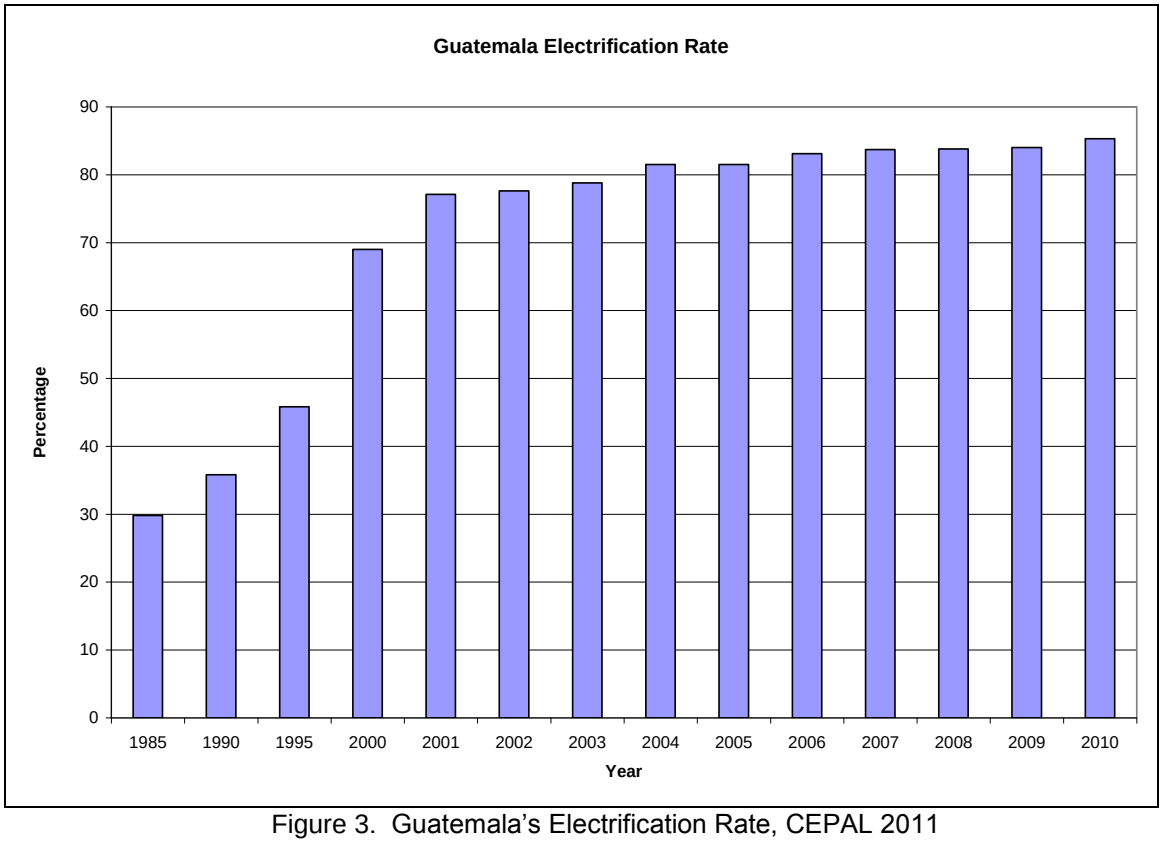


Figure 3. Guatemala's Electrification Rate, CEPAL 2011

Table 6. Nicaragua's Electrification Statistics, CEPAL 2011

Year	Population (1000)	People per home (Average)	Total homes (1000)	Residential Customers (1000)	Electrification Index (%)
1985	3400	6.2	548.5	256.4	46.8
1990	3824	6.2	620.7	277.5	44.7
1995	4658	5.9	788.1	357.9	45.4
2000	5098	5.8	879	406.4	46.2
2001	5174	5.8	893.6	422.6	47.3
2002	5245	5.8	907.4	435.6	48
2003	5313	5.8	920.7	461.5	50.1
2004	5381	5.8	934.1	509.3	54.5
2005	5450	5.8	946.2	542	57.3
2006	5523	5.8	958.8	563	58.7
2007	5596	5.8	971.4	597.2	61.5
2008	5669	5.8	984.2	634.3	64.5
2009	5742	5.8	998.8	664.8	66.6
2010	5816	5.7	1014.9	757.3	74.6

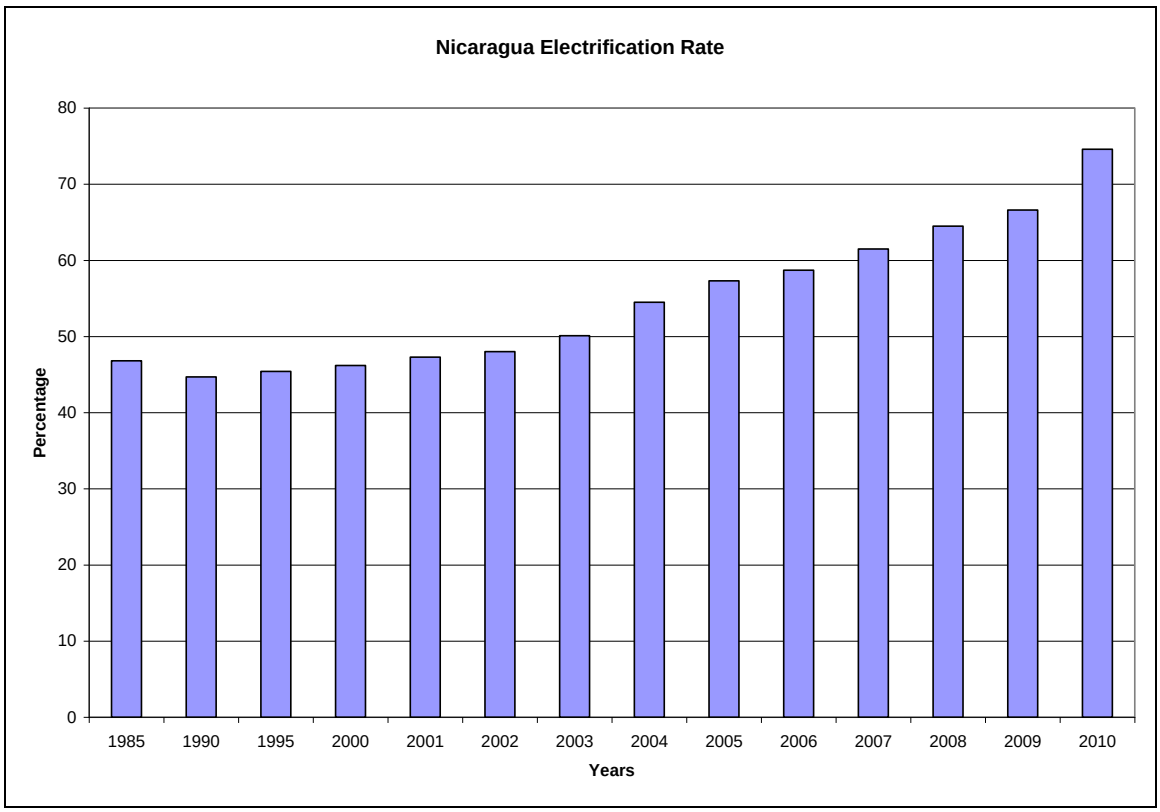


Figure 4. Nicaragua's Electrification Rate, CEPAL 2011

I selected small-scale (less than 5 MW) renewable energy (solar photovoltaic, wind energy, run-of-the-river hydroelectric, biogas) projects[3] based on their primary development, climate and relief objectives. I selected projects that covered a range of technologies, primary objectives and communities.

Following are the criteria for development project selection:

1. Located in a rural community
2. Productive-use (income-creating or enhancing) application
3. Implemented for at least two years and still working
4. Community-owned

The criteria for climate change mitigation project selection follow:

1. Located in a rural community
2. A Clean Development Mechanism (CDM), a Voluntary Carbon Offset (VCO) or an Early Warning System (EWS) project.

Disaster Relief projects were chosen following these criteria:

1. Located in a rural community
2. Developed as part of a relief program.

I added two projects because their governance structures provided useful answers to the research questions although they did not fit the criteria of being community owned and of a productive-use application. These two separate projects consisted of individual home lighting solar photovoltaic systems; one of them a loan program

[3] In some cases, evaluations were done on programs in which a donor worked in a number of communities. In these cases, a sample of communities was surveyed. The stars in Figures 5 and 6 indicate where the cluster of projects is located, and not necessarily the location of the communities surveyed.

implemented by the Ministry of Energy and Mines in communities which would benefit from the national electric grid extension in the short to medium terms and one implemented by a national NGO in isolated communities that would never benefit from grid extension.

The case studies, located in Guatemala and Nicaragua, are categorized by country, type and renewable energy resource in Table 7.

Table 7. Case Study Projects

Country	**Type**	**Renewable energy source**	**Name**	**Capacity**
Guatemala	Development	Hydroelectric Biodiesel Biogas	Nueva Alianza	16 kW 48 gal/48 hr N/A
Guatemala	CDM	Hydroelectric	San Isidro	3.92 MW
Guatemala	VCO	Hydroelectric	Chel	165 kW
Guatemala	Disaster Relief	PV	Cahabón Post-Mitch reconstruction*	40 W
Guatemala	Development	PV	Chapín Abajo women's coop	60W
Guatemala	Development	PV	Cancuén Archaeological Site	105 W (in 3 different locations)
Guatemala	Early-Warning Systems	PV	Early Warning Systems*	35 W
Guatemala	Development	PV	Ministry of Energy and Mines Loan*	45 W5

Guatemala	Development	PV	ADIM Quiché*	12 to 65 W
Nicaragua	Development	PV Battery Charging Station	Francia Sirpi and Awastingni	2.4 kW in 3 arrays
Nicaragua	Development	PV water pumping	El Trapiche	600 W
Nicaragua	CDM	Hydro	El Bote	930 kW
Nicaragua	Development/In process of CDM	Hydro	Río Bravo	180 kW
Nicaragua	Development	PV	Solar Women of Totogalpa	95 W
Nicaragua	Early Warning Systems	PV	Early Warning Systems*	35 W

NOTE (*): Although these are referred to as projects, these constituted programs with installations in diverse communities. I surveyed a sample of the populations within a sample of the communities served, as described in Section 2.1.2. The Ministry of Energy and Mines and ADIM Quiché programs were added because, although they do not meet the project selection criteria, they presented other community governance alternatives that were key to the results, as described previously.

I use a case study approach as I consider a case as an 'empirical inquiry that investigates a phenomenon within its real life context using multiple sources of evidence' (Noor 2008, Tellis 1997) and because of its usefulness when studying human affairs (Stake 1978). I specifically use the *explanatory case study research approach* as I analyse the process under which the DRE projects were implemented since their conception. The use of multiple case studies allows for consistent findings that will make results more robust (Tellis 1997) as well as enhance accuracy, validity, and reliability (Noor 2008).

The selection of the case studies firstly followed an *information-oriented selection* as I was looking for specific cases that met the selection criteria. Once compiled, I used

random selection to reduce the number of case studies to adjust for timing and budget contraints, and to make the sample balanced between countries, technologies, and types of projects (Flyvbjerg 2006). Although case studies might be looked at with disadvantage in certain social science fields, for this dissertation, it has enabled a holistic view of the projects and the surrounding populations (Tellis 1997). As found by Flyvbjerg, case studies have allowed for a cumulative development of knowledge (in this case, on the specific DRE projects selected) (Flyvbjerg 2006).

Each case study selected, besides meeting the selection criteria, focused on several characteristics (variables) being analysed (Tellis 1997).

In the early stages of this dissertation I had wanted to obtain a complete list of installed DRE systems; however, there is no institution that compiles this information. Furthermore, some institutions that work in this field do not have a complete list of their own installations. Other NGO's, such as Engineers without Borders, have also worked with DRE in the countries, but this information is only obtained through each NGO and the governments do not have a list of all the NGO's who work with DRE. In the case of hydroelectric projects, there are a number of private projects; however, the owners are not always willing to provide information or even confirm if the systems are still working; therefore, it was not possible to get a full list of projects. I did compile a list of projects installed by the Ministry of Energy and Mines of both countries, the US Agency for International Development, and multi-lateral organizations, specifically, the Inter American Development Bank and the World Bank. This information formed the basis of the 'master list' and it was complemented

during interviews with other NGO's and academia who have installed DRE systems in both countries. It is also important to keep in mind that while compiling the list of total populations of DRE systems, I did not take into account whether they were still working or not. That is, if a project was installed and stopped working years ago, but is currently recorded as installed, it was noted as existing.

Because of the reasons listed above, it is not possible to confirm a specific number of communal DRE systems; although some DRE experts in Guatemala suggest there are more than 1,000 PV systems. Considering this value, it can be said that I surveyed approximately 0.8% of PV systems. These same sources indicate that all the VCO projects are focused on reforestation and efficient stoves, with the exception of one micro-hydroelectric project (included in this dissertation). In terms of carbon projects, I surveyed 100% of projects that met the selection criteria.

In the first instance, I wanted to select ten DRE projects: five in Guatemala and five in Nicaragua, where in each country I would study two development projects, two carbon projects, and one disaster prevention project. The development and carbon projects were to be analysed and compared against each other (and by country) to determine if they can meet the triple objective and what specific contexts enabled them, or not, to meet their own stated goal. Disaster prevention projects were chosen to obtain insight into DRE's adaptation capabilities. Table 8 shows the initial breakdown of projects.

Table 8. Original classification of projects by type and country

	Guatemala	Nicaragua	TOTAL PER TYPE
Development	2	2	**4**
Carbon (CDM or VCO)	2	2	**4**
Disaster prevention	1	1	**2**
TOTAL PER COUNTRY	**5**	**5**	**10**

Because of the stated limitations in finding carbon projects that met the selection criteria, I opted to looking for case studies that would include projects where the carbon objective was secondary. I also include a disaster reconstruction project and projects focused on one of the success drivers analysed in this dissertation such as the funding sources of the projects and if they were installed within a commons. The final sampling includes the following changes:

- Two primary development projects were also analysed as carbon projects,
- One disaster reconstruction project was included to analyse adaptive capacity through the use of DRE systems
- Four projects were included to analyse the role of DRE systems in improving commons' management
- Four projects (including some that were in previous categories) were included to specifically analyse the role of funding sources.

Some of the case studies selected serve more than one main goal as illustrated in the tables below.

Tables 9 and 10 disaggregate the final sample of projects by type and country, while Table 11 disaggregates by technology.

Table 9. Classification of projects by type and country (number)

	Guatemala	Nicaragua	TOTAL PER TYPE
Development	6	5	**11**
Carbon (CDM or VCO)	2	1	**3**
Adaptation/Reconstruction	2	1	**3**
RE within a commons	2	2	**4**
Funding Source	4	4	**8**
TOTAL PER COUNTRY	**9**	**6**	**15**

The specific projects that belong in each category are listed below.

Table 10. Classification of projects by type and country (names)

	Guatemala	Nicaragua
Development	Nueva Alianza Chel Chapín Abajo Cancuén Guatemala MEM ADIM	PVBCS El Trapiche El Bote Río Bravo Women's solar center
Carbon (CDM or VCO)	San Isidro Chel	El Bote
Adaptation/Reconstruction	Cahabón PVEWS	PVEWS
RE within a commons	Chapín Abajo Cancuén	El Trapiche Women's solar center
Funding Source	Nueva Alianza San Isidro Chel Guatemala MEM	PVBCS El Trapiche El Bote Río Bravo

Although there is not an equal number of development and climate projects, the case studies present a variety from which the different dependent variables can be

analysed and compared between each other, between technologies and between countries.

Table 11. Classification of projects by type, country, and technology

	Guatemala	Nicaragua
Development	2 Hydroelectric 4 PV	1 PVBCS 2 PV 3 Hydroelectric
Carbon (CDM or VCO)	2 Hydroelectric	1 Hydroelectric
Adaptation/Reconstruction	2 PV	1 PV
RE within a commons	2 PV	2 PV
Funding Source	3 Hydroelectric 1 PV	2 Hydroelectric 2 PV

Within each case study project, interviews were carried out through a *stratified sample* (generalizing for specially selected subgroups within the population) and *extreme/deviant cases* (looking for specific respondents to answer outstanding questions or clarifications). I interviewed system users and non-users at random, as well as relevant groups (such as the community leadership) to analyse the existing relationship between them (Tellis 1997). Within each case study, *data source triangulation* was carried out to confirm the validity and reliability of the process. As part of the triangulation process, I used different information sources, including documentation, archival records, interviews, and direct observation.

For this dissertation, I took the approach of *interview data as topic* as 'the interview data collected are seen as (more or less) reflecting a reality jointly constructed by the interviewee and interviewer' (Rapley 2001) by enabling the respondents to 'think out loud' about the topics being studied.

Open-ended interviews and questions were included in order to obtain the respondent's opinion, which is also highly useful in the triangulation process and enables to obtain a 'real view' of the project, which might not always be reflected in project documentation (Tellis 1997, Burnard 1991) and are important to 'bring out the details from the viewpoint of the participants' (Tellis 1997). Rapley explains by adding that 'the data obtained are highly dependent on and emerge from the specific local interactional context which is produced in and through the talk of the interviewee and interviewer' (Rapley 2001). He furthermore indicates that this awareness of local context is central to the analysis of the case studies. Most of the interviews were semi-structured as it allowed the flexibility 'to approach different respondents differently while still covering the same areas of data collection' (Noor 2008). This allowed applying the questionnaires and covering the same topics with system users, non-users, leadership groups, technicians, and women's groups, among others.

Figures 5 and 6 below show the geographical distribution of the projects. As mentioned above, in the cases where I evaluated programs, the star indicates where the cluster of projects is located.



Figure 5. Location of systems in Guatemala



Figure 6. Location of systems in Nicaragua

Energy systems are comprised by supply, infrastructure and demand, and changes in energy supply consequently brought changes in infrastructure in demand. When referring to *energy infrastructure* throughout this dissertation, I am referring to the energy systems as a whole and not solely at the energy supply technology. The following table describes the changes in supply, infrastructure, and demand that occurred with each project. The changes in demand do not reflect the actual changes that occurred, rather, they are the ones the systems were designed for. Table 12 details this.

Table 12. Changes in supply, infrastructure and demand by project

Project	Change in supply	Change in Infrastructure	Change in demand
Nueva Alianza	From traditional biomass to biodiesel and micro-hydroelectric plant	Construction of the communal electricity grid and installation of internal electric home connections	Use of household and office appliances, and implementation of productive use projects
San Isidro	Grid-connected small-scale hydroelectric plant	None	None
Chel	From traditional biomass to micro-hydroelectric plant	Construction of a communal electricity grid, public lighting, and installation of internal electric home connections	Use of household and office appliances, and implementation of productive use projects
Cahabón	From traditional biomass to solar PV home lighting	Internal electric home installations	Use of basic household appliances (2 CFL's, radio, cell phone charging, and occasionally a black and white TV)
Chapín Abajo	The workshop had no energy source prior to the system (work was mainly carried out during daylight)	Internal electric home installations	Use of two CFL's
Cancuén	Ecotourism project started with PV system	Internal electric installations in offices and tourist bungalows	Use of radio-communications, CFL's and cell phone charging
Guatemala PVEWS	PVEWS formerly used diesel generators	Internal electric home installations	Radio-communications and CFL's
Guatemala MEM	From traditional biomass to solar PV home lighting	Internal electric home installations	Use of basic household appliances (2 CFL's, radio, cell phone charging, and occasionally a black and white TV)
ADIM	From traditional biomass to solar PV home lighting	Internal electric home installations	Use of basic household appliances (2 CFL's, radio, cell phone charging, and occasionally a black and white TV)
PVBCS	From traditional biomass to battery systems	Internal electric home installations	Use of basic household appliances (2 CFL's, radio, cell phone charging, and occasionally a black and white TV)
El Trapiche	Project started with the PV system	Pumping system, piping, tap	Pumping system
El Bote	Micro-hydroelectric plant, grid connection and traditional biomass	Construction of the communal electricity grid, public lighting, and installation of internal electric home connections	For those that had traditional biomass, they currently use basic household appliances (2 CFL's, radio, cell phone charging, and occasionally a black and white TV).
Río Bravo	From traditional biomass to mini-hydroelectric plant	Construction of the communal electricity grid, public lighting, and installation of internal electric home connections	Use of household and office appliances, and implementation of productive use projects
Women's solar center	Project started with the PV system	Internal electric installations in homes and the solar center	Use of basic household appliances (2 CFL's, radio, cell phone charging, and occasionally a black and white TV). The solar center powers several computers, printers and modem.
Nicaragua PVEWS	PVEWS formerly used diesel generators	Internal electric home installations	Radio-communications and CFL's

Note: CFL refers to compact fluorescent light.

Community Characteristics

I now summarize the background, context, and characteristics of the selected communities and their respective renewable energy projects. This summary aims to help understand the circumstances which enabled, or not, the success of the projects and their meeting their primary objective and if they have been able to meet other objectives.

Guatemala:

1. Comunidad Nueva Alianza

This community is located between the Pacific coast and the Western highlands of Guatemala and was originally a privately owned finca that commercialized coffee and macadamia. Due to social conflicts caused by injustices from the owners, the community members abandoned the ranch but remained organized with the idea of returning to the finca. The community members decided to obtain a loan to buy the finca back upon learning it had been abandoned by the original owner's son. They purchased and refurbished the finca, started processing coffee and macadamia, and started new projects such as pig and chicken farms, purified water, and an ecotourism hotel. This process of buying the finca and developing it again entailed a lot of community organization and trust between each other. The Nueva Alianza finca was severely affected by Hurricane Stan in 2005. For the immediate days after the hazard, rescue crews could not reach and emergency supplies could not be delivered to the affected populations.

I interviewed the community leaders to learn about community management, unity and organization; the women's group of the micro-hydroelectric project to learn of the role of women within the projects and the community in general; the different project leaders to learn how they each viewed the energy sources and how they were used differently; and users and non-users in general.

The community over-hauled the micro-hydroelectric plant the original ranch had. The previous owner had taken the entire infrastructure when he abandoned the property and the community obtained a grant from the UNDP Small Grants Program to refurbish the 16 kW micro hydro system, with two 8 kW Pelton turbines. They currently generate 8 kW since one turbine is being repaired. The community, through other support, also produces an average batch of 48 gal of biodiesel in 48 hrs using recycled kitchen oil. The renewable energy they produce is used to power the 50 homes in the community as well as the main offices of the finca, including office equipment; the eco-hotel, through which I was able to charge my laptop and recorder and work at nights; the coffee, macadamia, and purified water projects; and specifically for the biodiesel, as fuel for their trucks. When there is not enough water to power the micro hydroelectric project, or recycled oil to generate biodiesel, they recur to diesel. The use of these DRE systems has brought them considerable cost savings, except in the occasions when the price of the recycled oil is too high that it is cheaper to buy diesel than to produce biodiesel. In any case, with the electricity generated from the micro hydroelectric project there are cost savings.

Since it started operation, the micro hydroelectric project has been giving them a lot of trouble, which stems from a very poor and sub-code technical design. They have

not followed safety requirements nor used quality components. Macadamia nuts get stuck in the turbine quite often because the developer did not install a mesh at the entrance of the penstock to avoid the entrance of rubbish, which might be an indication that basic design criteria have not even been considered; despite the many lessons learned that already exist for community scale hydroelectric projects. There has been frustration among the users because they would like to use more appliances and have better quality energy. In conclusion, they did not just fail to meet industry standards; they have failed to provide simple solutions to the array of problems they have encountered. Despite the problems they have with the systems, the community does a good job of providing energy to the projects.

2. Cuenca San Jerónimo

In the San Jerónimo watershed, located in one of the poorest regions of the country, there are 3 hydroelectric projects in series: the two upper ones are CDM projects, and only one of them below 5 MW (San Isidro), and the last hydroelectric project is owned by the municipality and not a CDM project. An irrigation canal diverts water from the main river into a canal that feeds into the hydroelectric project. Interestingly, the development component of this project does not come from the energy produced by the hydroelectric plants, but rather from the water used for irrigation of the lower watershed. Over the years, there has been water use conflict as the two CDM hydroelectric projects tend to store water in their dam for peak hour generation, from 6 pm to midnight, and release their water after that. Therefore, the irrigation users get their water at approximately 4 am and do not receive any during the day. With a local NGO, an Irrigation Users Association (AURSA, for its name in Spanish) was

created and they have negotiated water use agreements with the hydroelectric projects. The interviews were conducted in communities that are affected, both positively and negatively, by the San Jerónimo hydroelectric and the irrigation canal, irrigation users and the municipal hydroelectric plant.

In order to meet the sustainable development component of the CDM, the project developer has worked mainly on health and education projects. Additionally to this, the communities are asking for the utility to pay its share of maintenance on the road it uses. The dirt roads need to be maintained periodically because of all the heavy transportation and they do not feel they should carry the burden of the maintenance. Since the hydroelectric projects sell electricity to the National Interconnected System, and the communities are grid-connected, they do not perceive the benefit of having the hydroelectric energy as they do not differentiate between a renewable and a fossil based energy source. Interestingly, even though these communities pay the same high electricity prices that are set nation-wide, they do not try to negotiate a reduced rate with the utility.

This is an important difference from the off-grid projects wherein these; the tariffs are usually set internally to cover the cost of operation and maintenance expenses. When the communities are connected to the grid, they are subject to the tariffs set by the national electricity regulation entity. Even if the renewable energy source has a cheaper generation, the electricity tariff is set depending on a number of factors, including the always rising cost of fossil fuels. As described in Section 2.1.1, Central America is a net importer of fossil fuels, and therefore, very vulnerable to all the price fluctuations which are reflected in the electricity tariffs. As a consequence, there are

no cost savings for those consumers connected to the grid. Additionally, they do not know the source of the electricity that is being dispatched at a given time.

3. Chel Micro Hydroelectric Project

This project consists of a 165 kW community-owned micro hydroelectric project that has sold, and is trying to sell additional, carbon credits under the voluntary carbon market. Besides being a VCO project, this community provided excellent case studies for DRE systems managed under a commons structure, the political ecology of a development project in a refugee community that suffered one of the worst massacres during the Civil War, and of DRE meeting the triple objective. As noted, this project is located in what is considered the heart of the region most affected by the Civil War. As a consequence of this, there was lack of trust among the community members and especially with outsiders, whether from Guatemala or foreigners. Consequently, the project took more than ten years to develop since its conception until its completion because the first years were dedicated to building trust among themselves and with the main development entity. This process, although long, was very fruitful as the community started getting more involved in the process.

In the early stages of the project, the local NGO in charge, who recruited community members, helped the community form an Association. Since then, the community, with progressively less support from the NGO, has been in charge of the management, planning, implementation and operation of the micro hydroelectric project and the subsequent projects that evolved from it, from their solar PV-run

satellite phone, to a new bridge. They are currently planning to start micro financing of productive use projects to better take advantage of the hydroelectric project resource. By increasing their energy demand, they will also be able to sell more carbon credits as one of the requirements they have yet to meet is to generate two thirds of their installed capacity. To date, there has been a big growth of stores opening, most of them selling cold products thanks to the purchase of refrigerators. You can find products that range from chocolate covered bananas to pirate DVD's and even a hot dog vendor that travels to other nearby communities.

At the time fieldwork was conducted, the project powered three communities. Since then, the Association has extended their grid to electrify ten additional communities, as they have excess capacity. These communities will also be Association members. In general, the plant has a sound technical design, although they have encountered a few technical problems that have been solved by replacing some components.

There has not been any climate hazard since the micro hydroelectric started operation; therefore, it is yet to be seen if the plant is robust enough. However, Chel provides good case studies for both social acceptance and community governance of the project, especially because of the long process and the transformation that took place during the *process* of building the micro hydroelectric project.

4. ADIM PV systems

This set of projects also focused on communities within the Department of Quiché, severely affected by the Guatemalan Civil War. A group of communities that are part

of the organization CPR-Sierra (Comunidades de Poblaciones en Resistencia - Communities of Populations in Resistance) requested energy and a national renewable energy NGO, with international funding, helped create a local Association (ADIM) to provide energy services, including the provision of PV panels for domestic and communal applications, to the CPR-Sierra 18 communities distributed within three municipalities. ADIM is the central facilitating institution that is in charge of the financial management and technical upkeep of the systems. Each community has an energy committee and technicians that work with and form part of ADIM. ADIM has been strengthened and has supported the communities to obtain other types of projects, such as efficient wood stoves.

The PV systems installed were mainly PV home lighting systems though there were a few households that opened stores since obtaining the panels. This project presented an ideological contrast as some people considered the systems as common resources while others viewed them as individually owned. They were considered as commonly owned resources because of the existence of ADIM, but as individually owned because they each own their own panel and domestic installations. Some users did not know that by paying their monthly fee to ADIM they were entitled to maintenance service.

5. Cancuén archaeological site

This solar energy project, located in the Cancuén archaeological site and visitor center, is jointly managed by three communities that form part of a Mayan tourism corridor. One community is in charge of providing transportation to tourists as the

only access is by boat. Because of the strategic location of this community, they benefited from an additional PV panel to power a store and the station where the boat is situated. The project comprises two visitor centers where the PV panels are located and are used for illumination and radio communications. This project provides a good case study of renewable energy managed under a commons structure. The interviews with community members of the three communities provided information on the many difficulties they have faced by jointly managing the site due to the special interest each community has within the project, which at times would appear to supersede the communal benefit and good of the project.

6. Chapín Abajo women's weaving cooperative

This project is located in one of the communities surrounding Lake Izabal. A local environmental NGO has worked with a number of communities promoting sustainable economic growth while protecting the Sierra de las Minas Biosphere Reserve, the Bocas del Polochic Wildlife Refuge (where the communities are located) and the biological corridor that joins the Biosphere Reserve with the Wildlife Refuge. Among the activities enhanced by the NGO is the creation of a women's weaving cooperative. The building they work in is electrified by a PV panel, allowing them to work longer hours. The downside is that the hours the women spend weaving are additional to their normal housework load, opening questions about fairness and equity. Because the PV panels are a part of the weaving cooperative project, no cost savings are considered.

7. Ministry of Energy and Mines (MEM) PV

The MEM installs PV home lighting systems under a loan system in communities that will receive grid electricity in the short to medium term, usually within five years. Although the main objective is home lighting, there were some good examples of the systems being used to charge cell phones, benefiting income producing activities as a consequence. Users of these systems did see cost savings as a consequence of the decrease in use of traditional biomass. The systems visited were those recommended by the Ministry as good and bad examples throughout the country. The communities labeled as successful were mainly located in the South and South East of the country, traditionally comprised of populations that have better levels of income and scholarity, mainly rich *Ladinos*; while the ones deemed as a failure are located in the Civil War stricken North and Central part of the country, where the population is mainly indigenous, with lower levels of scholarity, and higher levels of poverty and extreme poverty.

8. PV radio systems of the National Coordination for Disaster Prevention (CONRED)

CONRED has been installing early warning radio communication systems powered by PV panels (PVEWS) and are the pioneers in Central America with them. I carried out system inspections and interviews in the PVEWS installed in the Coyolate Watershed, the first watershed these were installed in. I also inspected systems located in a community in the Atlantic coast where they carried out a hurricane drill.

Nicaragua:

1. Francia Sirpi and Awastingni photovoltaic battery charging stations (PVBCS)

The seven PVBCS are located within five indigenous (four Miskito and one Mayagna) communities of Nicaragua's Northern Atlantic Region, which has the highest levels of poverty and extreme poverty in the country. I visited a total of 4 PVBCS in two communities, one Miskito and one Mayagna. The PVBCS are installed in centralized locations within each community, one of them having three. These locations were chosen by the communities in conjunction with a local NGO, hired by the Ministry of Energy and Mines (MEM) to provide on-the-ground technical and non-technical support and follow-up to the project.

At the time of the visit, about a third of families in each community were beneficiaries (at the beginning it was approximately 90% of families with illumination kits, however, population growth is high in this region). Once a week, each family is required to charge their battery in one of the central locations. This does not always happen as the families consider the cost of US$5 for each battery charge as excessive and on occasion, unaffordable. The PVBCS are managed by the community and supported by the local NGO. Although the main application is illumination, some families have used the light to work longer hours, increasing productivity, or used the batteries to power refrigerators for stores and bars or power TV and DVD players and use their home as a movie theater. These last uses are inadequate for the type of battery they use and have dramatically shortened their useful life. Because of this, real cost

savings are dubious: the cost of the battery recharges is more than what the families can afford which explains why batteries are not charged with the required frequency. Although at the beginning of the project the consumption of candles decreased, this increased as the life of the batteries decreased and illuminated the homes for fewer hours each night.

The PVBCS were badly damaged with Hurricane Felix in 2007 and, at the time fieldwork was carried out in early 2009, not all the home installations had been repaired.

2. PV radio systems of the National System for Disaster Prevention (SINAPRED)

Similar to the PVEWS installed by CONRED in Guatemala, Nicaragua's SINAPRED (Sistema Nacional de Protección contra Desastres) has also installed them. In sharp contrast to Guatemala's structure, SINAPRED delegates the decision to install PVEWS to each Department; consequently, their proper installation and use is subject to the budget each Department manages. This has created a gap in system quality design and installation that can increase the population's vulnerability to climate hazards. The PVEWS follow the same basic principle of their Guatemalan counterparts, however, electric codes and standards were not followed. This decentralization of functions with regards to PVEWS has also caused a communications gap with the national office as there is no clear record of what alert systems have been installed or not.

3. PV Water pumping system in the community of El Trapiche

A European professor with ties to a Nicaraguan solar vendor has been working on different development projects in the community of El Trapiche. Every summer, a student group joins the professor to implement the projects. The professor envisioned a project in which the community would work together and purchased a small piece of land for the 44 families to cultivate. The downside is that the piece of land provides enough crops for self-subsistence, but not enough for income generation, thus, most families have to work outside the community in order to earn a living. In addition to buying the land, the professor donated a solar one-axis tracking PV water pumping system to water the crops. Eventually, he provided individual water taps to each household. Finally, he installed individual PV home lighting systems.

4. Río Bravo Mini hydroelectric project

This 180 kW mini hydroelectric project, which currently electrifies 6 communities, is located the Northern Central region of Nicaragua affected by the civil war. Two other nearby communities are developing their own mini hydroelectric projects, which will eventually be connected to Rio Bravo. One of them, the 230 kW mini hydroelectric project of El Naranjo started operations approximately six months after I completed fieldwork, in August 2009, and has already been connected with the mini hydroelectric project of Río Bravo. Although I did not include the mini hydroelectric project of El Naranjo, the relationship between these two projects is very important

since the sustainability of both projects depends, in part, on their connection. At the time I carried out fieldwork, Río Bravo sold electricity to El Naranjo, and El Naranjo was their biggest customer, also causing electricity delivery disruption because on occasion, the demand of El Naranjo was more than what the Río Bravo mini hydroelectric project would generate. Currently, with El Naranjo producing their own energy, Río Bravo has to seek other income sources to avoid the utility from falling into deficit. A challenge that Río Bravo has undertaken is to continue extending its grid to other nearby rural communities that could benefit from the service. They could not do this previously as the main demand was from El Naranjo and Río Bravo did not have enough electricity to supply to further communities.

Because of a constitutional requirement in Nicaragua, all electricity generators need to form an energy concession. In the case of both Río Bravo and El Naranjo, community-run utilities were formed and have met their goals. Community members, besides being users, have the option of buying stocks. This energy governance structure differs considerably from Guatemala's association structure as only stock-holders have decision-making rights. The tariff charged is used mainly for the operation and maintenance of the mini hydroelectric project. The income that is generated from the stocks has been used to buy land from the upper watershed for protection and conservation, especially for the case of El Naranjo. El Naranjo is also giving incentives to the people who live in the upper watershed. They are too far to receive electricity from the hydroelectric, but the utility has purchased batteries for them to use and that they can charge at the machine house of the mini hydroelectric project. This is used as an incentive for the people to protect the watershed. The only discontent that seemed apparent derived from those families who could not

afford the connection fee and did not receive any financing mechanism to do so, despite the community utility indicating that they did provide this facility.

The beneficiary communities used to use candles and gas for lamps, and some of the richer people used a diesel generator for corn grinding and other productive uses, so they have benefited from cost savings. Respondents said security has improved, although the businesses that have prospered the most are bars, billiards and casinos.

5. El Bote mini hydroelectric project.

This 900 kW mini hydroelectric project, located in the community of El Bote, is the only small-scale RE project included in the research seeking CDM registration. At the time fieldwork was carried out, the validation process was taking place. The project electrifies more than 20 rural communities, including the municipality head of El Cuá. More than 20 years ago, El Cuá was electrified by a mini hydroelectric project, located in a nearby community that got damaged by a hurricane. Subsequently, they were powered by old diesel generators run by the state utility (ENEL) with the disadvantage of incurring high fuel costs. For a period of time, the population went back to using traditional biomass and those with higher income were able to afford a diesel generator. During the construction of the El Bote mini hydroelectric project, the national grid got extended, so El Cuá used grid electricity until the mini-hydroelectric started operation.

Besides El Cuá, the other big community electrified is Bocay, which used to be a community within the municipality of El Cuá, but is now its own municipality. They used to have their own mini hydroelectric project, but it also got damaged in a hurricane and it is currently being refurbished. After it got damaged, traditional biomass was used again until they got interconnected with the El Bote mini hydroelectric project. The population has complained that they have more blackouts with the El Bote mini hydroelectric project than when they had their own. The majority of the other beneficiary communities were not electrified before so have greatly benefited from the mini hydroelectric project, as it has displaced the use of traditional biomass.

El Bote has had a series of technical difficulties since it started operation, causing a number of blackouts that were first due to their connection to the national grid. Unión Fenosa, the Spanish utility company, has the monopoly of the electricity sector in Nicaragua and since privatization have not carried out their promised overhaul of the outdated transportation and distribution lines, making them highly unreliable as they can not carry the needed capacity. According to the NGO that promoted the El Bote project, which is now the energy concessionary, one of the reasons they connected to the national grid was to be able to sell electricity and help pay the World Bank loan they received in order for the project to be completed. Shortly after the fieldwork was completed, El Bote started working like an island (not connected to the national grid) and decided to continue extending their grid to other unelectrified communities rather than selling electricity to the grid as it was causing too many service disruptions. The problem they currently have is that, despite them not selling to the national grid, they are still having black-outs because of technical

malfunctions. The communities, especially those who used to rely on traditional biomass, are not big electricity consumers, and the energy concessionary is having difficulties paying the World Bank loan, endangering the sustainability of the project and their plans for future development.

6. Women's solar center, Totogalpa.

The Alternate Energy Sources Program of the National Engineering University created a women's group to work on renewable energy sources in Northern Nicaragua. The program started to help land mine victims from the civil war and in time, women started getting more interested in the work. Women from three different communities have learned, and now teach, how to build solar cookers and PV panels. They built a building they call the 'solar center' which serves as a workshop and is electrified with photovoltaic panels. A small percentage of women participate in the women's group, and the aim is to legalize the women's group so it can be autonomous and independent from the University.

2.1.2 Sampling of Participants

For each community, I spoke to everyone involved in managing the projects. This means that all those directly involved with the management, functioning, operation and maintenance of the renewable energy system were interviewed. Additionally, I surveyed a sample of system users that was representative of user groups and user types. For example, interviewees were chosen from their geographic location with respect to the energy system and the specific application of the energy system (for

example, productive use only or productive use and home lighting). The sample sizes differed by community and were defined upon arrival at each community. The samples were not defined *a priori* since I first needed to assess the layout of the community, especially with respect to the location of the energy system, the number of people as categorized by the specific uses they give to the energy and whether they are members of the energy system's governance structure. The first meeting I carried out in each community was either with the entire community or with the community leadership, where I explained to all the intent of the study and learn from them the layout of the energy system and community and schedule the rest of the activities (surveys, semi-structured interviews and system inspections) with them.

Since I carried out purposeful sampling, the sample size is not as relevant and 'should be judged according to the purpose and rationale of the study' (Patton 2002). In addition to those methods already indicated, I used triangulation[4] to verify the accuracy of data already collected by asking interviewees about other people and other systems they may know of.

I built a database in which all the information gathered was collected and analysed. Qualitative data was analysed using Microsoft Access and quantitative data was analysed through Microsoft Excel.

Interviews with project donors and developers were mainly carried out in Washington, DC, where most of the institution headquarters are located. Additional

[4] Method of cross-validation when two or more distinct methods are found to be congruent and yield comparable data (Jick 1979)

interviews were carried out by telephone and email with those staff members currently working on other tasks or located in other parts of the world.

There were some limitations to the each of the methods used as described. The limitations to the field interviews follow:

1. Timing. I carried out the fieldwork between August 2008 and March 2009. The beginning of my fieldwork coincided with the peak rainy season, so the order of and the number of communities visited had to change depending on road accessibility. Other months coincided with crop season, so at times it was difficult to find people in their homes and the most common time would be dinner time. The time of the day in which the interviews occurred also had an impact on the answers as it depended on who was home. For example, if the men were out in the fields, the women would answer and in some occasions, the men would come back for lunch and their answers would be totally opposite to their wives'. Other times I was just told to return later.
2. Gender. Although I sought to interview an equal balance of males and females, some women were very shy and would only nod. When a couple was at the home, the man would usually dominate the discussion. In the cases where there was only a woman, I would usually need an interpreter and in some cases they were too shy so I could not carry out a full interview.
3. Leadership. Some leaders, whether of the community or of the renewable energy system management, were very dominant and would influence the

answers of the respondents. This would happen in some communities when the ‘leader’ would insist in accompanying us to each interview. This influence was evident when the respondent would stare at the leader (as if seeking approval) before answering or when after responding, the leader would say something in their Mayan language, and the respondent would change the answer.

4. Availability and willingness. Interviews were always carried out depending on the availability and willingness of the respondents. If the household was busy or the person there preferred that someone else in the household answered the questions, I would return at a later time. If a household did not feel comfortable answering the questions or simply did not want to give an opinion, another home was surveyed.
5. Interpreter bias. Not all communities worked in spoke Spanish. Although most of the men would speak Spanish, I did not want to limit my interviews to only Spanish speakers, so an interpreter was used. Some bias was detected when the respondent would give very long answers and the interpreter would give me a short ‘yes’ or ‘no’ response, or vice-versa. Sometimes, women would be shy to respond to the interpreter.

Very few interviews were done by email since personal interviews were more effective and efficient. Email surveys were only intended for some NGO’s and government officials whom I was certain had a reliable internet service. Not everybody responded, some questionnaires were incomplete and had to be followed-up by personal visits. The same happened with phone interviews when I

wanted to obtain follow-up information. Because of the difficulty of getting answers after I left the countries, several follow-up trips were necessary.

Because of the reasons detailed above, some responses were not included in the data analysis, especially where I felt biased or coerced responses, based either because there was a dominant presence during the interview or because of the way the looked and sounded towards the interpreter and the response I got from the interpreter. In most cases, however, I felt respondents to be very open and honest about the project and the problems they encountered, and what they would do different today.

Following are the survey statistics[5]:

- People interviewed in-country:
    - Guatemala 203
    - Nicaragua 213
- Roles:
    - Collaborators[6] 9
    - Committee Positions 41
    - In-country developers 2
    - Former system users 23
    - Government 11

[5] This data indicates the raw number of communities visited and people surveyed in-country, thus, it does not include project donors and developers outside of Guatemala and Nicaragua.

[6] Collaborators refer mainly to people who are taking care of pv systems used for radio communications and early warning systems. Committee positions refer to people who hold a committee position either within the community or directly for the energy system. System users include domestic, productive and community uses and any combination of these, for example, people who use energy for domestic and community purposes.

- Non system users 67
- System users 260

2.2 Research Design and Results Analysis

The following section will describe the research design and methods used for each of the research sub-questions.

a) How well are the projects meeting the goals of sustainable development, climate change mitigation and climate change adaptation?

I order to analyze how well the projects are meeting these goals; the fifteen projects were evaluated against sustainable development, emissions reductions and climate change vulnerability and adaptation indicators. Figure 7 illustrates why each indicator is needed and what question it answers.

The sustainable development indicators included economic feasibility, social acceptance, poverty alleviation and environmental responsibility (Olsen 2007, Najam et al. 2003, Swart, Robinson & Cohen 2003).

As mentioned above, the use of DRE also has the potential to increase the adaptive capacity of populations. Because of the difficulty of measuring changes in adaptive capacity, especially in the short timeframe of this research, I will list the conditions

under which adaptive capacity could be improved because of the DRE (Smit, Pilofosova, Downing, Patwardhan 2005).

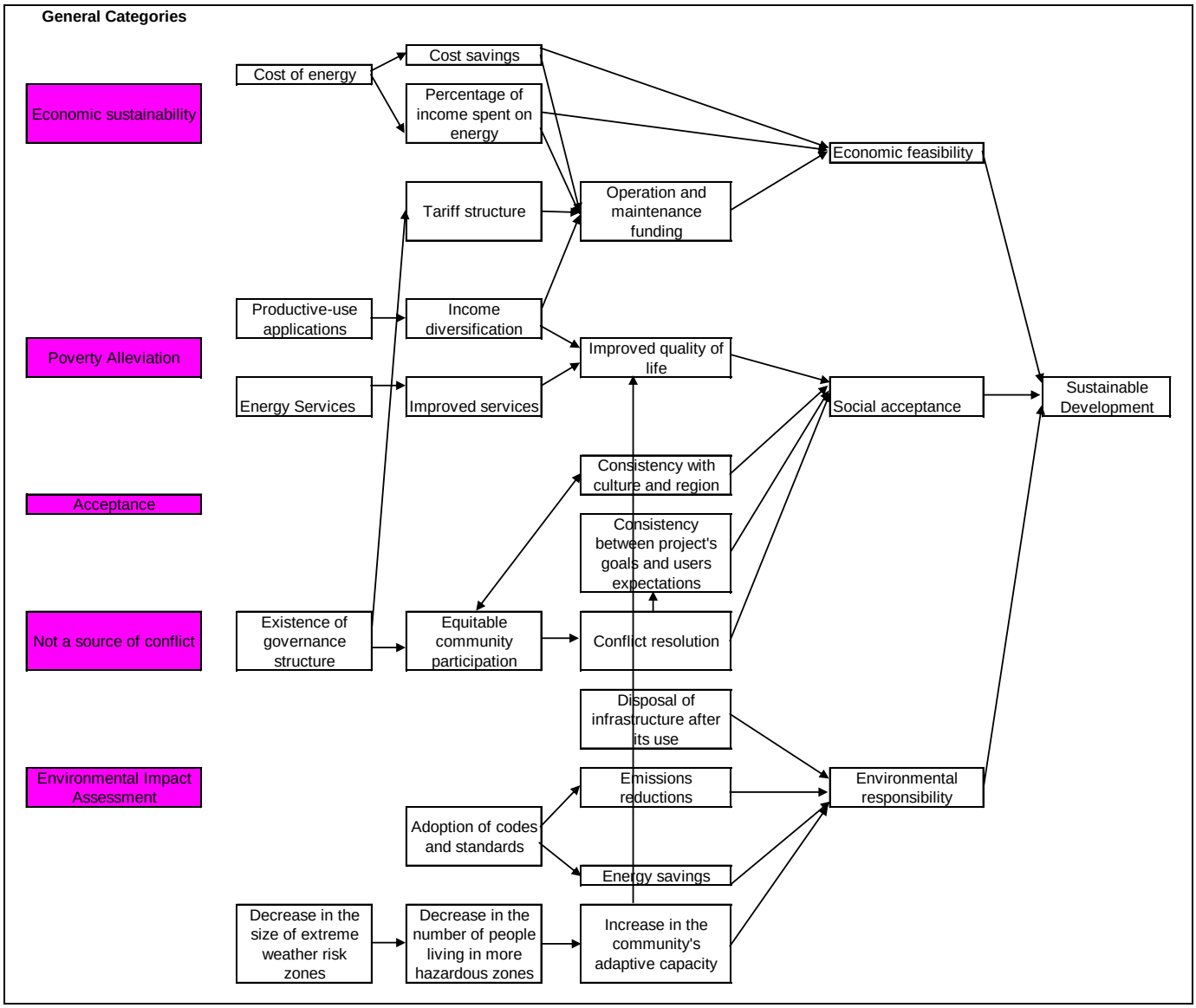


Figure 7. Sustainable development indicators

I measured each indicator listed in Table 13 using the qualitative and quantitative methods described.

Table 13. Indicators and methodologies

INDICATORS	METHODOLOGY
Sustainable Development:	
Policy objectives achieved (including National Action Plans Adopted). These policy objectives should have explicitly defined goals that can be measured.	Survey question to government officials and donor program managers. Official publications from governments and donor institutions.
Policy objectives maintained since project inception	Survey question to government officials, donor program managers, and community members
Local capacity developed: institutions	Survey question to government officials, donor program managers and community members
Local capacity developed: technical skills	Survey question to government officials, donor program managers and community members
People with increased access to energy services	Survey question to project implementer and direct observation
Homes adopting improved cooking/heating/lighting techniques	Survey question to project implementer and direct observation
Number of people with reduced exposure to combustion pollutants indoors	Survey question to project implementer and direct observation
Number of governance structures created and their functioning	Survey question to project implementer and community members. Focus groups
Improvement in livelihoods (natural, physical, financial, social and human capitals)	Survey questions on the five assets to community members. Survey questions to community members, and different levels of government and project implementers about the 'Transforming Structures and Processes'

Poverty alleviation:	
Reduction in the cost of energy	Survey question to community members and direct calculations
Reduction in the percentage of income spent on energy sources	Direct calculations
Increase in productive time	Survey question to community members
Diversification of income sources	Survey question to community members
Increase in number of microenterprises generated	Survey question to community members
Improvement in health and education infrastructure	Survey question to community members, project implementers and government
Improvement in health and education services	Survey question to community members, project implementers and government
Formalization of land rights.	Survey question to community members, project implementers and government

Economic feasibility:	
Existence of tariff or fee for electricity use	Survey question to community members
Existence of a bank account or other form of tariff management.	Survey question to community members
Use of the tariff or fee to cover operation and maintenance (O&M) costs (this includes preventive, short term and long term maintenance)	Survey question to community members

Social acceptability:	
Cultural and religious acceptance	Survey question to community members
Consistency between project goals and user expectations	Survey question to community members
Additional benefits (for example, spending more time with family)	Survey question to community members
Source of conflict (for example, misuse of tariff)	Survey question to community members

Environmental responsibility:	
Existence and implementation of an Environmental Impact Assessment	Survey question to project implementers and government agencies
Consideration for disposal of used components	Survey question to community members, project implementers and government.

Emissions reductions:	
Increase or decrease in CO2 emissions (tons of carbon)	Simplified estimate based on IPCC methodologies
Energy savings (tons of oil equivalent)	Simplified estimate based on IPCC methodologies
Cost Savings	Calculation
Standards Adopted and Implemented	Inspection of renewable energy systems following standard protocols and survey question

Adaptive Capacity:	
Change in the number of people living in more hazardous zones	Direct observation, survey question to community members and government
Decrease in the size of extreme weather risk zones	Direct observation, survey question to community members and government
Increase in the community's adaptive capacity (creation of social networks or increased knowledge of technologies that can help cope with disaster, through the use of renewable energy systems)	Direct observation, survey question to community members and government

The indicators were obtained from different sources:

- Global Village Energy Partnership (GVEP) of the Clean Energy Initiative (CEI) for sustainable development and emissions reductions indicators (GVEP 2008).
- Sustainable Livelihoods Approach for sustainable development indicators, drawing from the five capital assets (Great Britain. Dept. for International Development 2000)

- Millennium Development Goals for sustainable development (poverty alleviation) indicators (CEPAL 2007a).
- Intergovernmental Panel on Climate Change (IPCC) for vulnerability, adaptation, and adaptive capacity indicators (Downing, Patwardhan 2005)
- Sandia National Laboratories (SNL) and New Mexico State University photovoltaic and wind energy inspection protocols for the technical inspections of the systems (Risser, Post 1991, Architectural Energy Corporation 1991).(SNL 2002, SWTDI-NMSU 2002, Wiles 2002)(NMSU 1999)
- Intermediate Technology Development Group (ITDG) mini-hydro inspection protocols for the technical inspections of the systems (Inversin 1999 (1986)).

The range of methodologies I applied included surveys and semi-structured interviews with community members, project developers, project donor and municipal and federal government; stakeholder analysis; direct observation; system inspections and literature reviews. The technical inspection of the systems followed standard inspection protocols (Risser, Post 1991, Architectural Energy Corporation 1991) (Inversin 1999 (1986)). The emissions reductions and the energy and cost savings are calculated using standard methodologies (GVEP 2008).

The energy savings were calculated by comparing the energy profiles of the households before and after the renewable energy system. The consumption of each energy source was converted to Barrels of Oil Equivalent (BOE) according to the values given by the Latin American Energy Organization (OLADE, for the acronym in Spanish of Organización Latinoamericana de Energía).

Table 14. Conversion Factors used by OLADE Member Countries[7]

Original Units	10^3 ton	10^3 bbl	10^3 bbl	10^3 bbl	10^3 bbl
TO: BOE x 10 ^3	Firewood	LPG	Gasoline	Kerosene	Diesel
Guatemala	2.594	0.6989	0.8913	0.9453	0.9929
Nicaragua	2.594	0.6975	0.8906	0.954	0.9857

NOTE: 1 BOE = 5524.86 x 10^3 BTU

The conversion to CO_2 emissions is followed using the conversions of the Energy Information Administration 'Fuel and Energy Source Codes and Emission Coefficients'.

Table 15. Fuel and Energy Source Emission Coefficients[8]

Fuel	**Emission Coefficients**		
	Pounds CO2 per Unit Volume or Mass		**Pounds CO2 per Million Btu**
Petroleum Products			
Kerosene	21.537	per gallon	159.535
	904.565	per barrel	
Liquified Petroleum Gases (LPG)	12.805	per gallon	139.039
	537.804	per barrel	
Motor Gasoline	19.564	per gallon	156.425
	822.944	per barrel	
Natural Gas and Other Gaseous Fuels			
Propane	12.669	per gallon	139.178
	532.085	per barrel	
Fuel	**Emission Coefficients**		
	Pounds CO2 per Unit Volume or Mass		**Pounds CO2 per Million Btu**
Renewable Sources			
Biomass	Varies depending on the composition of the biomass		
Geothermal Energy	0		0
Wind	0		0
Photovoltaic and Solar Thermal	0		0
Hydropower	0		0
Wood and Wood Waste	3812	per short ton	195
Municipal Solid Waste	1999	per short ton	199.854

[7] www.olade.org
[8] http://www.eia.doe.gov/oiaf/1605/coefficients.html

The inspection protocol for the photovoltaic systems included the following:

1. System status and history:
    a. Previous technical inspections
    b. Previous and current failures
    c. Equipment replaced
2. Photovoltaic array
    a. Array technical specifications
    b. Mounting structure, orientation, inclination
    c. Damaged, shaded, dirty modules
    d. Status of cables, connectors, grounding system and lightning and surge protection
3. Battery bank
    a. Bank technical specifications
    b. Battery protections
    c. Status of connectors, terminals, electrolyte level
4. Charge controller and inverter
    a. Technical specifications
    b. Status of electrical connections and indicators
5. Lights and other loads
    a. Number and capacity of each light and appliance
    b. Indication of functionality of each light and appliance

b. What are the relative roles of local historical background and physical characteristics, type of community governance, and funding source and

project implementation process in the success of projects in meeting adaptation, mitigation and development goals?

This question seeks to explore some of the factors that contribute to the outcome of the rural renewable energy projects sustainable development, climate change mitigation, and climate change adaptation indicators, and to these projects meeting their stated goals.

The hypothesis states that the historical and environmental background of the community, the type of community governance structure and the implementation process of the project are key attributes that contribute to success in meeting these goals.

I argue that the historical and environmental background of a community will influence the outcome of projects. The background of a location will give insight into its current poverty, development and climate vulnerability status which may lead to a better project design and implementation process. For example, a background that includes previous conflict and displacement of populations can have an impact on trust, environmental degradation, and access to resources, which also shape project implementation process and outcome. As an example, trust can be very poor due to civil wars or other conflicts and must be rebuilt before a project could be implemented. Therefore, for a project to be successful, the users must take ownership of the project and participate in decision-making, building trust among community members and between the project implementers and the community.

I also argue that the physical environment has an impact as a factor that helps determine the most feasible type of technology to use, the energy supply risks that can arise and the vulnerability of the populations to disasters. Environmental degradation can impact the renewable energy system design and dictate other activities that the users will need to carry out for the system to continue working properly. A common example is reforestation activities in the upper watersheds of small-scale hydroelectric systems. The existence of previous conflicts can also play a role, especially if there are displaced populations that have had to survive in locations where resources are scarce and basic infrastructure and services are non-existent because of the difficulties of delivery.

Researching the existence and type of governance structure gave insight into the management system and sustainability process the communities currently have and how this can be applied to the energy system, and if a governance structure is really necessary for project sustainability. It will also serve to determine what different and specific rules apply to 'energy commons[9]', since these were not the basis of Ostrom's studies (Ostrom 2002). Included in the information that will be gathered is how and when the energy system was recognized as a commons resource and if the management structure for the energy system derived from previously successful management models of other commons. Through direct observation, documentation analysis, and semi-structured interviews I assessed if Ostrom's design principles are met and will analyze what other characteristics are shared among the energy commons in order to identify other principles that apply only to energy commons.

[9] I use the term of 'energy commons' to refer to DRE systems that are commonly owned and managed.

The quality of implementation process of projects is another hypothesized driver. Pre-feasibility studies must be conducted to determine if projects are technically and economically feasible, and to highlight relevant social concerns. The historical and environmental background can guide the development of governance structures by helping implementers understand community interactions, how community participation can enhance the project, and how the project must be designed for the users to take ownership of it. Having proper follow-up and operation and maintenance (O&M) plans will ensure that the system will continue working and providing benefits after the donor and implementers are gone. The fact that the development projects I assessed have been functioning for at least two years, was taken as a proxy for the existence of a governance structure, though it was not an indication of how well it works. A qualitative analysis of project documents together with a visual inspection of the current state of the renewable energy system, surveys and semi-structured interviews provided an explanation of the history of the project and the current status it is in.

Knowledge of the history of the project is also important. Knowing whether the project was donor-oriented or community-driven may suggest why a particular governance structure was implemented and how it functions, as well as highlight the roles of other donor-specified conditions. This can also explain the level of interest and incentive the users have to maintain the system. I gathered information through surveys and semi-structured interviews, besides doing a qualitative analysis of the project documents.

Figure 8 illustrates these drivers and the relationships between them. Appendix 1 lists the information that was gathered to answer each indicator and how it was gathered.

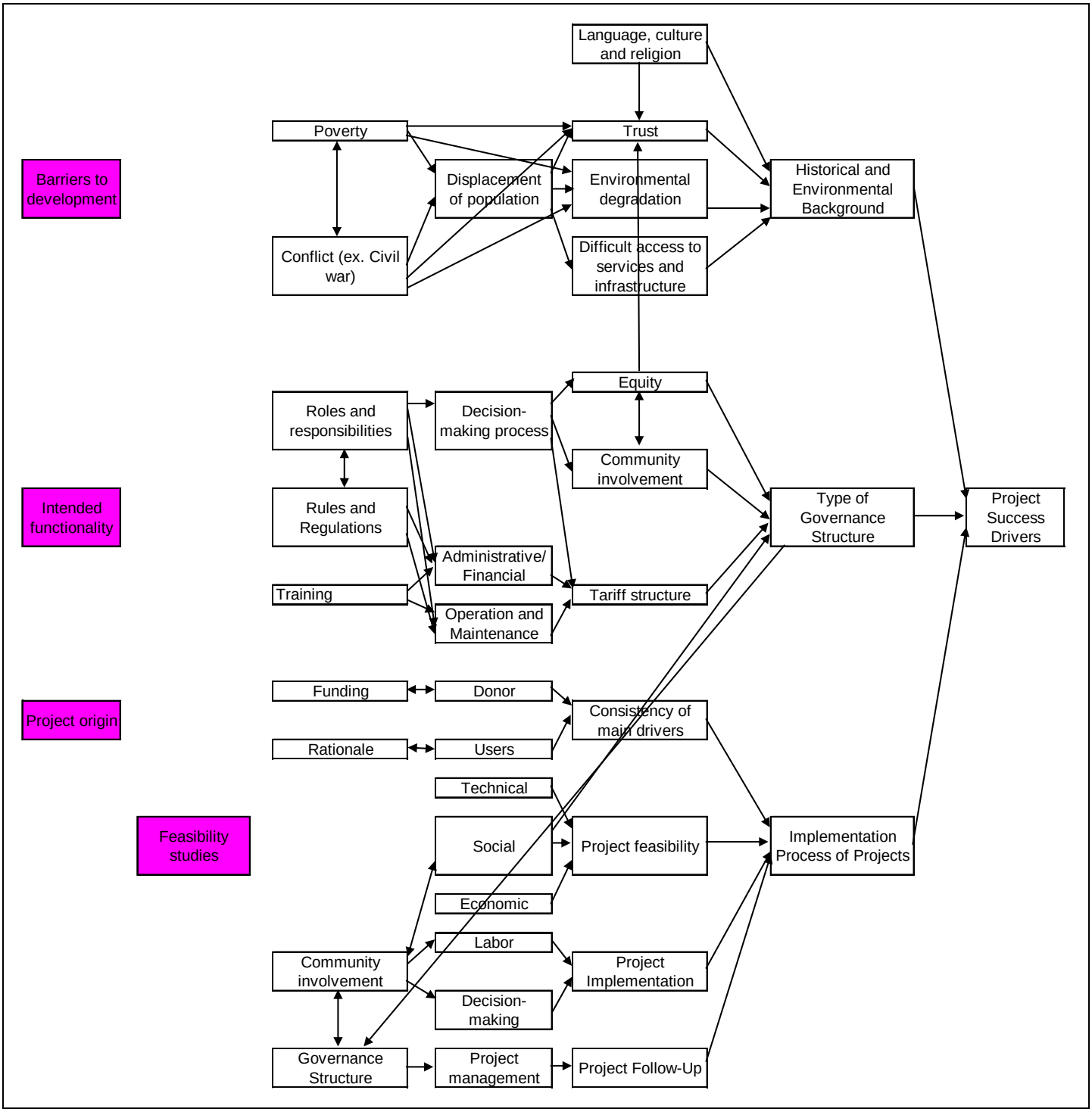


Figure 8. Hypothesized project success drivers

I measured each indicator listed in Table 16 using the qualitative and quantitative methods described.

Table 16. Indicators and methodologies

Historical and environmental background of locations:	
Previous conflict (for example, civil war)	Literature review and survey question (to who?)
History of extreme poverty/poverty	Literature review
Displaced populations	Literature review
Disenfranchisement due to language barriers	Literature review

Governance structure:	
Type of governance structure	Focus group and survey question to community members
Existence of other community governance structures	Focus group and survey question to community members
Functionality and effectiveness	Focus group and survey question to community members
Existence of internal rules and regulations	Focus group and survey question to community members
Equitable access	Focus group and survey question to community members

Funding sources and implementation process of project:	
Funding sources of the project	Project implementer, project documents
Existence of pre-feasibility and feasibility studies	Project implementer, project documents
Community socialization and training process	Project implementer, project documents
Existence of O&M plan	Project implementer, project documents
Monitoring and evaluation	Project implementer, project documents

In order to assess these indicators, I applied a range of methodologies that included semi-structured interviews, stakeholder analysis, and historical, institutional and project document analysis of the site and the project.

To organize and report this information I used the chronology and history approach.

c. What are the challenges in integrating development and climate change adaptation policies in rural Central America? How might the evolving international climate regime contribute to this integration?

For this sub-question, I analyzed the results of the two previous sections.

In the case that the projects are not meeting their stated goals, of either development or climate change, I 1) analyzed the reasons they have not been met, and 2) analyzed if the key indicators of sub-question b) were the main drivers for the goals not being met. In the case that the projects are meeting their goals, I 1) analyzed the factors that led to project success, 2) analyzed the role of the key indicators of sub-question b) in the success of the projects, and 3) analyzed the role of other indicators or factors not included in sub-question b) that come up during the fieldwork.

Since the projects were primarily development, climate change mitigation, disaster prevention or relief driven, I analyzed whether and how projects should try to meet the triple objective:

1) *Is imposing a climate change mitigation objective on development projects advantageous? Under what circumstances?*
2) *What are the implications for small rural communities of integrating climate change mitigation and adaptation objectives into development projects?*
3) *How might the evolving international climate regime afford governments' better abilities to achieve the Millennium Development Goals?*

For this sub-question, I will apply meta-evaluation and analytic induction. I will use meta-evaluation because I will do an evaluation of the results obtained in the first two sub-questions. Analytic induction will also be applied since the information gathered will be used to verify and complement the theoretical frameworks used, in this case, the political ecology of renewable energy systems and common property resources of energy commons (Patton 2002).

CHAPTER 3: RENEWABLE ENERGY AND CLIMATE CHANGE ADAPTATION

3.1. Introduction

This chapter analyzes the role that decentralized renewable energy (DRE) plays within climate change adaptation efforts. My hypothesis is that decentralized renewable energy projects have the potential to contribute to climate change adaptation by providing electricity that can be used both to prepare for and recover from disasters, and to provide additional income and livelihood opportunities, which can reduce poverty and dependency on vulnerable natural resources or outside assistance. For example, DRE can power early warning systems, telecommunication systems, health clinics and potable water systems. It can also provide power for irrigation for drought-vulnerable crops and electricity for other income-generation activities such as shops or sewing. In this way, renewable energy may be a response to climate change that meets the triple objectives of mitigation, adaptation and poverty alleviation.

As explained in greater detail in Chapter 1, there is very little literature on the potential role of DRE for climate change adaptation. Eriksen and O'Brien (2007) and Venema and Rehman (2007) are among the few authors that consider the possibility of DRE as a climate change adaptation strategy, although they do not detail how that will be achieved (Eriksen, O'Brien 2007)(Venema, Rehman 2007).

This chapter seeks to examine if DRE has helped users in Central America cope with climate hazards better and faster than their previous energy systems, explores community and user perceptions, and analyses whether there are differences between the technologies in their effectiveness in disaster response.

I start this chapter by introducing the Pressure and Release Model (PAR) and the theory of adaptive capacity, which I used to frame my research questions. In Section 4 I summarize my research and quality control methods. Section 5 presents the data analysis and results in five main parts: the first describes system user perceptions about renewable energy technologies' ability to help them better cope with climate hazards, the second describes the actual system response during climate hazards, the third briefly describes cross-cutting issues which are detailed in Chapter 6, the fourth presents some case studies that highlight the different roles that renewable energy technologies have played before, during and after climate hazards, while the fifth compares how the different project types, as categorized by their primary objective, met adaptation goals.

3.2. Research Questions

This chapter addresses the potential of DRE systems to increase the adaptive capacity of rural populations to climate variability and change through examining the impacts of climatic hazards on the renewable energy systems and the population who depend on them. The responses to current hazards can be seen as a proxy for possible adaptation to future climate change.

This chapter seeks to address the following main **research questions** outlined in Chapter 2. Sub-questions are those posed to community members

1. **Do renewable energy systems enable people to respond to hazards?**

1. Do you think that having a RE system is a better way of coping with disasters than your previous energy system?
2. Has the renewable energy system enabled you to create social networks and have these helped you better cope with the effects of climate hazards?
3. Do you believe that the RE system has helped you gain knowledge of technologies that can help you better cope with climate hazards?

2. Are renewable energy technologies more resistant to hazards than traditional energy sources?

1. How has the technology responded to recent natural disasters?
2. How can the technology better respond to future natural disasters?
3. If the system were lost or damaged, would you replace the system, go back to using your previous energy source(s) or acquire alternate energy source(s)?

3.3 Theory of Adaptive Capacity and the Pressure and Release Model

In this chapter, I evaluate the potential for adaptive capacity and adaptation to climate hazards through theories of adaptive capacity and through a vulnerability analysis using the Pressure and Release (PAR) model.

The PAR model examines the relationships between political and economic structures, the physical environment, and communities. It was developed by scholars who have worked using ideas from political ecology to understand 'processes that generate vulnerability' (Wisner, Blaikie 2004). Political economy and political ecology perspectives on risk and vulnerability 'have been synthesized in the "Pressure and Release Model" emphasizing the underlying causes of disaster and the social production of risk' (Eakin, Luers 2006). Political economy and political ecology analyze vulnerability through the social and economic processes that explain differences in exposure, impacts and ability to cope with previous or future hazards (Eakin, Luers 2006).

The PAR Model explains disasters as the 'intersection of the natural hazard and the processes that generate vulnerability' (Wisner, Blaikie 2004, Blaikie, Brooksfield 1993, Birkmann 2006). These processes, explained in part by political ecology, are categorized as root causes, dynamic pressures and unsafe conditions, as shown in Figure 9, and are based on physical, political, economic and social environments and variables.

Root causes are of economic, demographic or political nature and are considered 'distant' causes (Wisner, Blaikie 2004), both temporally and spatially. Quality of governance, previous or current conflict and military force, and power distribution in society are examples of root causes (Wisner, Blaikie 2004, Birkmann 2006). *Dynamic pressures* 'translate the effects of the root causes … into unsafe conditions' (Wisner, Blaikie 2004) and consist of factors such as urbanization and deforestation

as well as lack of local institutions, skills and markets. Finally, *unsafe conditions* are the manifestations of the vulnerability and include levels of poverty, unsafe livelihoods and living conditions, and lack of infrastructure, basic services, and disaster preparedness.

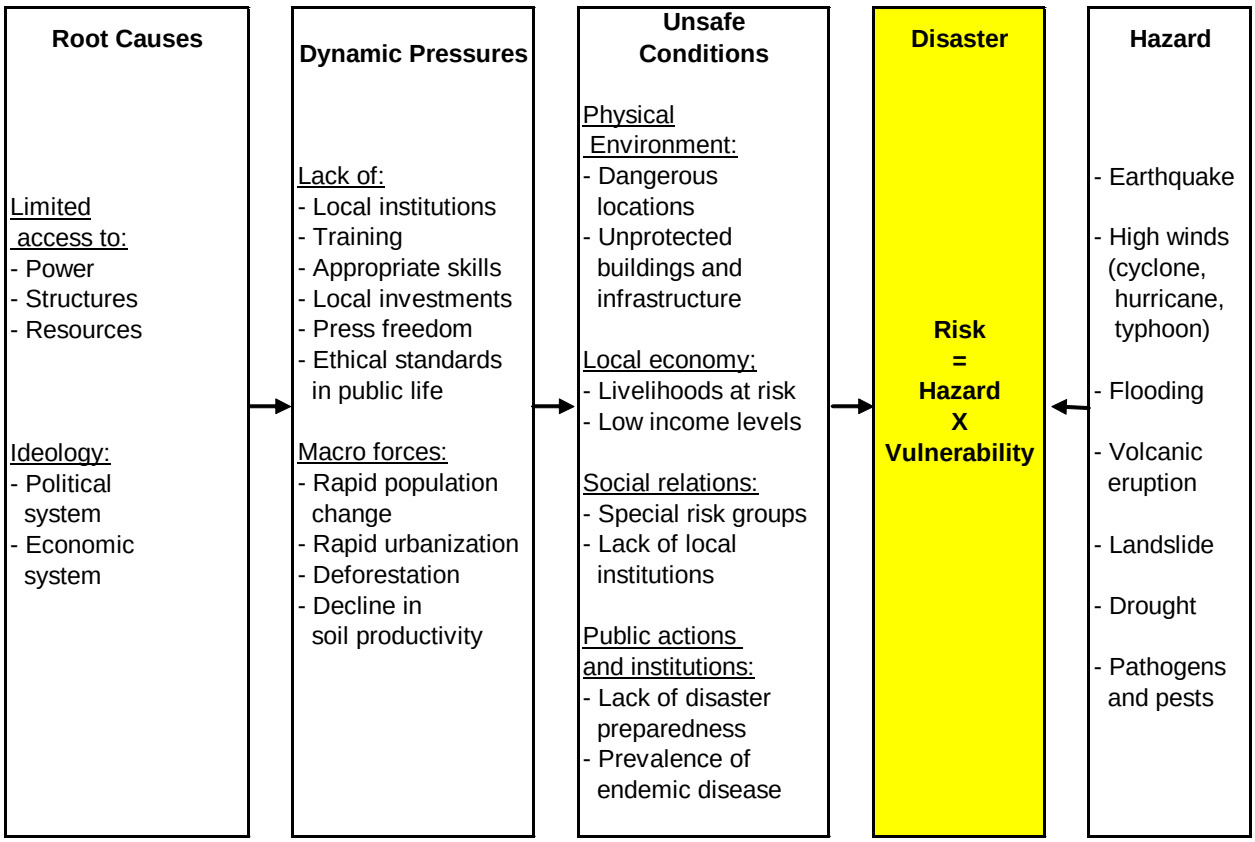


Figure 9. Pressure and Release Model (Wisner, Blaikie 2004)

As discussed in more detail in Chapters 1 and 2, the case studies evaluated in my study have many of the characteristics Wisner, et. al (Wisner, Blaikie 2004) identify as root causes that increase vulnerability and therefore risk. Wars and military force (Beyrer 1998, Bunce, Rosendo & Brown 2009) have proved to have as great an impact on communities as have climate and non-climate related disasters. Guatemala continues to suffer the legacy of the civil war that displaced thousands of indigenous people, who continue to live under conditions of poverty and extreme

poverty in particularly vulnerable areas in the different mountain ranges of the country. These impacts can be exacerbated through extreme weather events. An example of this is the hunger crisis (*Risk*) that affected the dry corridor of Guatemala starting August 2009 and has continued to threaten local populations (Oliva 2009a, Oliva 2009b). A number of studies show the impact on agricultural productivity because of the El Niño Southern Oscillation (ENSO) (*Hazard*), which is said to be exacerbating this crisis (Berlato, Farenzena & Fontana 2005, Chen, McCarl & Chang 2008, D'Arrigo, Wilson 2008, Reilly et al. 2003, Salafsky 1994). As the hunger crisis deepens, DRE can help diversify income sources (*Dynamic pressure)* through productive uses that will help families purchase food when their own crops, either for sale or for self-subsistence, are lost. In 2008, when families lost their crops they could not feed their families nor purchase food from other places. Providing alternate income sources will at the very least allow them to have some reliable income. Some of these applications, such as textiles and carpentry, are explored in some of the case studies visited. Another example is the floods suffered almost annually in Nicaragua, especially in the Atlantic coast, where poverty is rampant. In conclusion, DRE's can alleviate and might improve existing dynamic pressures and, in the long term, may be able to transform them.

The IPCC defines vulnerability as 'the function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity,' where adaptive capacity is defined as 'the ability of a system to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences' (Klein et al. 2007).

Adaptive capacity therefore constitutes an element of vulnerability. These definitions indicate that different adaptation options to modify the root causes, dynamic pressures and unsafe conditions of the PAR Model may provoke a change in vulnerability. Indicators or elements of adaptive capacity vary according to the vulnerability discourse chosen (Adger 2006) and the climate impact (Yohe, Tol 2002, Downing, Munasinghe & Depledge 2003). The vulnerability analysis followed through political ecology in the PAR Model, and in this dissertation, is based on the poverty alleviation and livelihoods discourse and will therefore use parameters suitable to the development arena (Swift 1989, Chambers 1988). Klein (2002) lists wealth, information and skills, infrastructure, institutions, social capital, and equity as factors that determine adaptive capacity (Klein 2002). Other factors include access to and availability of resources, which includes the role of scientific information in decision making, both at the community and policy levels (Brouwer et al. 2007, D FORD et al. 2008, Pelling 1997, Reid et al. 2007, Smith, Klein & Huq 2003). The Third Assessment Report of the IPCC also states that technology plays a role in climate change adaptation, and technologies that provide energy services are no exception (Klein et al. 2007). The physical structures that are needed for these technologies may be vulnerable to climate hazards (Lovins, Lovins 1982) and their roles as climate change adaptation solutions merit further analysis.

The adaptive capacity factors listed by Klein (Klein, 2002) address some of the dynamic pressures and unsafe conditions listed in the PAR Model, therefore, as elements of vulnerability, the improvement of these factors can constitute viable climate change adaptation options. The PAR model can be used to study climate change adaptation in the form of disaster preparedness, relief and reconstruction

and to identify how to reduce the causes of vulnerability through reducing the unsafe conditions, improving the dynamic pressures (as they not need always be negative pressures (Wisner, Blaikie 2004) and understanding the root causes that lead to the population's vulnerability in order to create viable solutions in accordance to the local context and needs.

Renewable energy technologies can be included among adaptation and adaptive capacity elements that can reduce vulnerability modeled by the PAR Model. Keeping in mind that communities without DRE systems can also meet PAR model criteria, results in this chapter are set against a counterfactual of the PAR model as a baseline. That is, where DRE projects help meet PAR model criteria, it is considered as a proxy for the positive role of DRE systems to meet climate change adaptation goals. The creation of alternate income sources that rely on renewable energy, can diminish dynamic pressures by reducing pressure and dependency on vulnerable natural resources, facilitating local investment and creating more knowledge and appropriate skills. The energy systems and the applications they power may also require the creation or strengthening of local institutions for their governance and management. Alternate income sources enabled by renewable energy technologies also play a role in improving unsafe conditions through increasing income levels or decreasing risks to livelihoods. Social relations may also be improved by the creation of social networks through better organization and governance systems. Finally, disaster preparedness can be improved through the use renewable energy technologies to power early warning and other communications systems.

To conclude, this chapter examines the feasibility of renewable energy as an adaptation and adaptive capacity option by providing alternative livelihood sources, powering communication for disaster preparedness, and providing electricity for health centers to reduce the impact of diseases. It also examines the role of DRE in fostering governance structures and other communal institutions, and reducing other environmental pressures that can increase vulnerability such as deforestation. It can also reduce some of the root causes associated with dependency on others outside the region by reducing energy imports. It may reduce conflict by poverty alleviation, and if ubiquitously accessible, promote equity within a community. These last concepts are discussed at length in Chapter 5.

3.4. Methods specific to this chapter

Chapter 2 explains in greater detail the methods I used throughout my research. To review, I analyzed fifteen case studies of projects in Central America, only three of which had specific climate change adaptation goals: two different solar PV early warning system (PVEWS) programs and a relief and reconstruction program. Data sources included interviews with community members (N=397), government officials, project developers, donors, technical experts and technical reviews of projects.

As all communities visited had a DRE system (either previously or currently), results could not be compared to climate change adaptation responses of locations without a DRE system. As mentioned previously, the role of DRE systems within the PAR model elements is considered a proxy for DRE contributions towards vulnerability, and therefore, disaster reduction.

During the data analysis phase, several quality control measures and adjustments were made with regards to the data collected in the field. The measures taken are detailed as follows:

- I received exact or very similar responses to the questions: a) Do you think that having a renewable energy system helps you cope faster with natural disasters? and b) Do you think that having a renewable energy system is better to cope with disasters than your previous energy system? For data analysis purposes, these two questions were merged into one.
- Most of the questions relevant to this chapter consisted of a yes/no question followed by a qualitative question that sought further explanation. In a few cases, the follow-up answer did not correspond with the initial answer. For example, the first response would be a yes, but the open-ended question would indicate a no. The yes-no responses were adjusted for consistency where the follow-up response was concrete and detailed or considered as 'I don't know' in cases where the follow-up response was inconsistent or incoherent.
- In very few cases there may have been translator bias. This was noted down while doing the interviews and the responses were included in the data analysis, taking into account the potential for distortion. This is a problem for only a dozen or so of the 397 interviews.
- One survey was eliminated because at the time of the interview, I realized the interviewee was not giving coherent answers. The data was not discarded, but was eliminated from the statistical analysis.

- Half of one survey was discarded as the adult respondent had a child continue the survey half way through; only the adult's responses were included in these analyses.

3.5 Results

My results do show that distributed renewable energy (DRE) may enable people to cope with climate hazards faster and better than with their previous energy source. Some systems are effective whilst others do not appear to help people in certain locations. I first sought to understand people's perception of the role of renewable energy in helping them cope with climate hazards, including how renewable energy technologies compared with their previous energy source(s) during hazard events. I then looked at how the systems actually performed during climate hazards or how the users thought their systems would fare if their systems had not yet suffered a climate hazard.

3.5.1 Perceptions

The perceptions users had of risks, climate hazards, and their renewable energy system were important to my analysis as I used them as a proxy to determine whether DRE systems could be considered as a climate hazard coping mechanism.

3.5.1.1 Renewable Energy as a Coping Mechanism

Most respondents (75%) with renewable energy systems in place when a climate hazard occurred had a positive perception of the role of renewable energy

technologies in coping with hazards. Positive and negative perceptions of the role of renewable energy systems were based on the different experiences of the users with the systems and/or the particular responses of the technologies to the climate hazards.

Table 17 compares the perceptions by community or project type, categorized by technology and by country. Responses received for the biodiesel project are not listed as the biodiesel and micro-hydroelectric systems, together with the diesel generation, feed into the same grid; thus, users do not differentiate the energy source they are receiving at a given time. Responses of 'Don't know' include places where the systems had not been installed when a hazard occurred. In these cases, follow-up questions were not asked so there are fewer responses to subsequent questions, including the role of renewable energy systems to enable social networks and other technologies. Importantly, respondents expressed different perceptions of what constitutes a climate hazard. Some families considered heavy rains in which they lost their crops to be a climate hazard, even if the rains were not defined as a tropical storm or hurricane. Others only considered tropical storms or hurricanes as climate hazards. Therefore, the responses obtained are based on the respondent's perceptions of the renewable energy systems performance during what they perceive as a climate hazard. My findings coincide with the literature on risk perception that indicates that perceptions are constructed based on culture, context-specific situations, whether the respondents have been in a threatening situation (in this case, during an extreme weather event), and other factors (Slovic, Peters 2006, Slovic et al. 2005, Västfjäll, Peters & Slovic 2008, Wolf et al. 2010, Whitmarsh 2008). As detailed in this section, these were also my findings.

Table 17. Perceptions, by technology, of renewable energy as an option to better cope with climate hazards

Research question: Do you believe that your renewable energy system helps you cope with climate hazards better and faster?

	Yes		No		Don't know		No response
Chel, GT	7	70%	2	20%	1	10%	28
Chuisibel, GT	2	50%	2	50%	-	-%	-
El Bote	28	80%	6	17%	1	3%	99
Nueva Alianza	10	71%	3	21%	1	7%	1
Rio Bravo	7	78%	2	22%	-	-%	34
Grand Total Hydro	**54**	**75%**	**15**	**21%**	**3**	**4%**	**162**
ADIM donation project	5	100%	-	-	-	-	14
Tourism	3	60%	1	20%	1	20%	7
Disaster Recovery	8	67%	3	25%	1	8%	8
Gov't Community projects	9	69%	4	31%	-	-	2
MEM	17	74%	6	26%	-	-	11
PVBCS	3	60%	2	40%	0	0%	8
El Trapiche PVWPS	7	88%	1	13%	0	0%	1
Solar Center	5	100%	0	0%	0	0%	3
Grand Total Solar	**60**	**75%**	**18**	**23%**	**2**	**3%**	**56**
	Yes		No		Don't know		No response
Guatemala	70	72%	23	24%	4	4%	85
Nicaragua	51	81%	11	17%	1	2%	145
Grand Total	**121**	**76%**	**34**	**21%**	**5**	**3%**	**230**

As can be appreciated from Table 17, perceptions of solar and hydroelectric systems were similar.

In Guatemala, the lone biodiesel project studied was considered to be the best system in coping with climate hazards as it received 100% positive responses. For example, a user responded that they had a positive perception of the system because '*We could buy a TV and see the news, or get a radio and be better prepared,'*[10] while another user indicated that *'if DEOCSA* (the national utility) *grid suffers, everybody is without light. For us, it is very easy if anything happens, among*

[10] Biodiesel user in Nueva Alianza, Guatemala

ourselves we go out and see how to solve the problem and we have our own light.'[11] The access and availability of information was considered to be one of the main benefits of having renewable energy, as explained by a user, '*There is information, there is light, there is television, one can be prepared.'*[12] Fuel costs were another benefit noted by biodiesel users. This benefit is not limited to climate hazards. One user said '*the biodiesel reduced our fuel costs and we were able to recuperate economically from Hurricane Stan's destruction by producing energy with biodiesel.'*[13] Two responses summarize the range of benefits the community of Nueva Alianza received from its biodiesel plant, and the interest in renewable energy garnered in neighboring communities: '*While there is biodiesel, if there are mudslides or other dangers, we have other ways to continue working. With Hurricane Stan, there was a lot of interest from other places to see what we were doing, in case of emergencies.'*[14] and '*If all businesses planted and generated their own energy, the planet would be saved from all disasters."*[15]

Table 18 lists the main reasons respondents gave for their positive and negative perceptions. Although reasons are varied, some responses predominated over others. The table indicates the number of responses received for each reason.

Lighting is seen as the predominant benefit to cope with hazards. Users enjoyed the quality of light from compact fluorescent lamps as compared to candles or gas lamps and indicated that '*the light illuminates the way and one knows where to go to, the*

[11] Biodiesel user in Nueva Alianza, Guatemala
[12] Biodiesel user in Nueva Alianza, Guatemala
[13] Biodiesel user in Nueva Alianza, Guatemala
[14] Biodiesel user in Nueva Alianza, Guatemala
[15] Biodiesel user in Nueva Alianza, Guatemala

light guides and we know how to get there,'[16] '*I turn it on for lighting and to see where the water level is inside the house when it is raining outside,'*[17] and *'The light is brighter than with a candle. With a candle, the wind comes and blows it out.'*[18]

Users also enjoyed the ability to be informed and have better means of communications. *'Communications are easier,'*[19] was an oft-repeated claim, with users emphasizing ease of communication as a major benefit of their DRE's during emergencies. One user stated that, *'The wind and mudslides make the grid cables explode; the solar energy is more important for communications.'*[20]Others noted specific communications devices, such as cellular telephones: *I use my system to charge my cell phone; you can't do that with a candle. I have adapted to the phone.*[21]*'I like the hydroelectric plant because of the information we get through the radio,'*[22]was an unsurprising claim given the prevalence of radios as a means of communication in the developing world.

[16] Hydroelectric user in Chel, Guatemala
[17] Solar PV user in Baldío Xalaché, Guatemala
[18] Solar PV user in La Bolsa, Guatemala
[19] Hydroelectric user in Peñas Blancas, Nicaragua
[20] Solar PV user in Sepóm, Guatemala
[21] Solar PV user in Sta. Cecilia, Guatemala
[22] Hydroelectric user in El Naranjo, Nicaragua

Table 18. Reasons for positive and negative perceptions of RES as an option to better cope with climate hazards.

	Safety		Communications		Lighting		Reliability		Potable Water		Cost		Ease of use		Capacity building		*Not safe*		*Not reliable*		No response
Chel Hydro	-	-	-	-	4	36%	2	18%	-	-	-	-	2	18%	1	9%	-	-	*2*	*18%*	27
Chuisibel Hydro	-	-	1	100%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
El Bote Hydro	2	5%	2	5%	7	19%	11	30%	-	-	5	14%	2	5%	2	5%	*2*	*5%*	*4*	*11%*	102
Nueva Alianza Hydro	-	-	2	14%	2	14%	5	36%	-	-	2	14%	1	7%	-	-	*2*	*14%*	-	-	4
Rio Bravo Hydro	1	10%	1	10%	3	30%	1	10%	-	-	-	-	-	-	1	10%	*3*	*30%*	-	-	33
Grand Total	**3**	**4%**	**6**	**8%**	**16**	**22%**	**19**	**26%**	**-**	**-**	**7**	**10%**	**5**	**7%**	**4**	**5%**	***7***	***10%***	***6***	***8%***	**169**
ADIM Solar	2	100%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17
Tourism Solar	2	33%	-	-	1	17%	2	33%	-	-	1	17%	-	-	-	-	-	-	-	-	7
Disaster	2	17%	-	-	6	50%	1	8%	-	-	-	-	1	8%	-	-	*1*	*8%*	*1*	*8%*	10
GovtComm	-	-	1	10%	7	70%	-	-	-	-	-	-	-	-	-	-	*1*	*10%*	*1*	*10%*	5
MEM	-	-	1	6%	7	44%	3	19%	-	-	-	-	1	6%	-	-	*2*	*13%*	*2*	*13%*	20
Other	-	-	-	-	1	33%	-	-	-	-	-	-	-	-	-	-	-	-	*2*	*67%*	3
PVBCS	-	-	1	33%	2	67%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
El Trapiche PVWPS	-	-	-	-	-	-	1	13%	7	88%	-	-	-	-	-	-	-	-	-	-	2
Solar Center	-	-	-	-	3	75%	-	-	-	-	-	-	-	-	1	25%	-	-	-	-	4
Grand Total	**6**	**9%**	**3**	**5%**	**27**	**42%**	**7**	**11%**	**7**	**11%**	**1**	**2%**	**2**	**3%**	**1**	**2%**	***4***	***6%***	***6***	***9%***	**79**
	Safety		Communications		Lighting		Reliability		Potable Water		Cost		Ease of use		Capacity building		*Not safe*		*Not reliable*		No response
Guatemala	8	10%	5	6%	29	35%	15	18%	-	-	6	7%	5	6%	1	1%	*6*	*7%*	*8*	*10%*	108
Nicaragua	3	5%	5	8%	15	24%	13	21%	7	11%	5	8%	2	3%	4	6%	*5*	*8%*	*4*	*6%*	152
Grand Total	**11**	**7%**	**10**	**7%**	**46**	**31%**	**28**	**19%**	**7**	**5%**	**11**	**7%**	**7**	**5%**	**5**	**3%**	***11***	***7%***	***12***	***8%***	**260**

Note: Columns in red indicate responses received for negative perceptions

Some communities, like Chel in Guatemala, took special pride in protecting the environment and using a renewable source of energy. For example, one user said '*We want to be an example for others by conserving the mountain, educating the population and planting more trees. The energy, just like the environment, has to improve*'[23]. Users in El Bote, Nicaragua had similar perceptions as exemplified by these responses: '*The reforestation project that took place with the hydro plant has helped take care of trees and water and protect the people by protecting the watershed*'[24] and *'It's natural and it's promoted by water. With diesel we pollute and the candles don't illuminate. We did a balance to propose the project, we spend a lot of money on gas and candles, and the gas and candle tariff keeps going up. There is more benefit with the electricity*'[25]

The use of DRE in public places was considered a major benefit during climate hazards as these public buildings, mainly schools, could be used as a refuge for those families who had to be evacuated from their homes. For example, a respondent indicated that '*People near the Polochic take refuge here; they sleep in the classrooms and use the solar energy*'[26] and another user said that '*We use the school as an evacuation center and can see the level of water with the light from the panel*'[27].

Cost considerations were also important: '*The grid electricity has problems. It goes off and the tariff collectors come*[28]*.'* Ease of use was important. Users liked being able to

[23] Hydroelectric user in Chel, Guatemala
[24] Hydroelectric user in El Bote, Nicaragua
[25] Hydroelectric user in Peñas Blancas, Nicaragua
[26] Solar Pv user in Chichipate, Guatemala
[27] Solar PV user in Selempín, Guatemala
[28] Solar PV user in Bocancha, Guatemala. The main complaint here is that they have to pay high electricity tariffs for service they are not even receiving.

turn on the light with a switch rather than having to prepare the gas lamps. Additionally, with the DRE systems, users do not have to worry about fuel supplies. One respondent exclaimed *'How do you get diesel when there's a disaster!'*[29]

Finally, users with a solar water pumping system indicated their main benefit as having a potable source of water despite climate hazards: *'When there is a disaster, the water gets polluted, it gets dirty and yellow, but our well is sealed and it doesn't get polluted'*[30]. Another user indicated that *'The floods come and we still have water'*[31].

A manager of a solar PV early warning system summarized the different benefits received from their system, which are not limited to extreme weather events: '*During Hurricane Felix, we alerted Siuna and Bonanza* (two nearby municipalities) *of the rain that was going to come. Delinquency rates have declined, there is less drug consumption and there is more communication between families'*[32].

The negative perception of solar systems, also shown in Table 8, is related to the discharge and loss of power of the batteries during long periods (of more than 3 or 4 days) of heavy rains or cloud cover. Therefore, respondents considered that they can not use their solar system when they need it most for disaster recovery. For example, one user said '*The grid is better. With the panel, you reach a certain amount of hours, it*

[29] Hydroelectric user in El Bote, Nicaragua
[30] Solar PV water pumping system user in El Trapiche, Nicaragua
[31] Solar PV water pumping system user in El Trapiche, Nicaragua
[32] Solar PV early warning system manager in Ayapal, Nicaragua

goes off and we have to wait for another day before it starts charging again'[33] and another respondent indicated that *'the diesel generator is better, the grid electricity goes away and then there isn't enough sun for the panels'*[34]*.* As detailed in Chapter 6, reliability of solar PV and other DRE systems depends on the location, system design and operation and maintenance practices; therefore, these responses can not be generalized for the technology.

'The combination of light and water is dangerous. The candle is better,'[35]said one user, reflecting a sentiment expressed primarily among women respondents who were afraid of electric systems during climatic disasters. *'Candles are better,'* concurred another woman who used the same hydroelectric system. Women who used PV panels held similar opinions: *'When there is rain there is lightning that will burn the cables.'*[36] *'I am afraid of lightning hitting the panel.'*[37] *'I'm afraid that my system will burn like the other family's panel,'*[38] said a respondent in reference to a PV system that was struck by lightning, causing an explosion inside the house. Because of this fear, some system owners preferred to turn their lights off during a climate hazard: '*I turn everything off, I'm scared, I'm better in the dark.'*[39]Others disconnected their systems during extreme weather events to protect the systems from damage rather than the users from harm. This behavior may be supported by institutions created to manage energy systems: *'We were told by ADIM* (the local NGO that implemented the project) *that the panel will burn*

[33] Solar PV user in Chapín, Abajo, Guatemala.
[34] Solar PV user in Chichipate, Guatemala
[35] Biodiesel and hydroelectric user in Nueva Alianza, Guatemala
[36] Hydroelectric user in Nueva Alianza, Guatemala
[37] Solar PV panel in Chapín Arriba, Guatemala
[38] Solar PV panel in Baldío Xalaché, Guatemala
[39] Solar PV user in Los Horcones, Guatemala

if you use it during a hurricane'[40]. One user indicated that he was recommended to *'turn everything off and disconnect the panel during a storm''*[41] in order to protect his system. However, the fact that a disconnected (and therefore unusable) solar system was not damaged or destroyed during a hazard event was viewed as positive.

For hydroelectric systems, the main problems identified stem from events that occur when the rain becomes strong enough to provoke slides or cause debris to get stuck in the penstock and turbine, stopping generation. For example, the community of Chuisibel in Guatemala has had to reconstruct their micro-hydroelectric twice as it suffered major damages in two different hurricanes. Although the users do not think it is the best option during a climate hazard, they have a good perception of hydroelectric energy in general. The fact that this hydroelectric plant has been twice reconstructed indicates the faith in the technology on behalf of the users. They are comfortable using their system and despite its multiple problems, want to continue having it as their main energy source.

The single solar photovoltaic battery charging station (PVBCS) project, which consists of 7 PVBCS, included in this research received the highest percentage of negative perception responses of all the renewable energy technologies. In 2005, during Hurricane Felix's journey through Nicaragua's Northern Atlantic coast, one of the PVBCS was completely destroyed as the base broke and the entire structure collapsed. In another PVBCS, one PV panel was shattered and an estimated 50% of homes, together with their lighting kits, were blown or washed away. As detailed in Chapter 5,

[40] Solar PV user in Nueva Amajchel, Guatemala
[41] Solar PV user in Caserío el Zapote, Guatemala

the users have a general negative perception of this project due to several factors including the performance of the system during the hurricane.

While renewable energy systems are perceived as helpful in coping with climate hazards, 50% of the respondents in both countries reported that it is best to have several energy sources available during a hazard and use whatever is available at the moment. For example, a user said that '*the best is to have a complement, have several sources*'[42] and another indicated that *'I prefer the hydroelectric because it doesn't go off, but it's better to have several sources. If one goes, then I have the other. There is no public lighting, so we still need flashlights*'[43]. As no energy source is 100% reliable, the most reliable solution perceived to be maintaining a combination of traditional biomass (candles, kerosene, pine torch), flashlights and renewable energy systems.

Tables 19 and 20 summarize some of the reasons people think renewable energy systems help them cope better or worse with climate hazards.

[42] Hydroelectric user in El Bote, Nicaragua
[43] Hydroelectric user in El Bote, Nicaragua

Table 19. Reasons for having a positive perception of renewable energy systems to better cope with climate hazards.

Reason	Explanation
Safety	Candles and gas lamps can either tip over and start a fire or blow out with strong winds (mainly a male response). Electricity is safer since there is no danger of fire
Communications	RE provides electricity for radio communications and charging of cell phones without having to walk hours to the nearest town. Some of the projects have enabled cell phone companies to expand coverage as well.
Lighting	People can see and be aware of their surroundings, see how much the water levels have risen, which way to go for refuge and have lighting in the evacuation center itself. Street lighting provides added security.
Reliability	The national electricity grids in both countries are quite unreliable, especially in rural areas. In most cases, the renewable energy systems have worked more consistently than any other source
Potable water	In communities with PV water pumping systems there is a reliable source of potable water yearlong as long as the well is sealed to avoid contamination during the

	rainy season and is cleaned periodically during the dry season
Cost	Renewable energy is cheaper than fossil fuels for small scale applications (as detailed more in Chapter 5). The cost of maintaining the renewable energy system is cheaper than traditional biomass and can be used in more applications
Ease of use	Renewable energy requires users only to flip a switch, rather than preparing the candle, gas lamp or pine wood, which takes a longer time, especially in the rainy season.
Capacity building	The capacities and strengths that have been built within the communities will remain and help in their progress as the population grows, with the help of ongoing socialization, training and education. Since the arrival of the DRE systems, users are empowered to do new things.

Table 20. Reasons for negative perceptions of renewable energy systems to better cope with climate hazards

Reason	Explanation
Safety	Some people (mainly females) are afraid of the 'electricity-water' combination and of lightning, considering renewable energy more dangerous than traditional biomass, where they do not have to worry about getting electrocuted.
Reliability	Renewable energy works when the natural resource upon which it depends is available: when there is no sun or no water, the solar panel or the micro-hydroelectric will not work. Some people complained that during the time of the year when they most needed their panels, the batteries do not charge because there was not enough sun. Responses to this question were much divided, varying based upon the renewable resource, the initial design and installation of the system and the maintenance that users were providing. User expectations also played a role. Unrealistic expectations of system abilities can lead to user dissatisfaction. These responses are due to the controllability of the supply and their storage as

	DRE systems rely on intermittent energy sources. Biodiesel and hydroelectric sources (independent of their scale) are more controllable than solar energy as there is more ease in the form of energy storage.

One particular finding is the difference in responses by gender. The majority of males considered renewable energy sources to be safer than traditional energy sources while the majority of females had an unfavorable response with regards to the safety of DRE systems. Although I do not have an explanation for this difference, I hypothesize that it is relevant enough to merit future study.

One key reason for the difference in responses between technologies is that hydroelectric plants generally have greater capacity[44] than solar PV panels. Solar PV systems are limited in their capacity by the design and selection of hardware by the original installer, while the capacity of a hydroelectric plant is usually limited by the water source. As such, solar users are limited to planned capacity – generally enough for a few lights and a cell phone or radio – and, if users do not have an inverter, can only use direct current appliances. Small-scale hydroelectric users have the ability to use more appliances, within certain limits, as they have greater availability of energy and alternating current plugs. This enables them to be able to have greater use of televisions, radios, sound equipment, DVD players and radio communication equipment, explaining the more favorable responses obtained for communications that hydroelectric users gave. During periods of rainfall including climate hazards, water

[44] In this case, capacity refers to the size of the DRE

resources increase and hydroelectric systems will continue functioning, unlike the solar systems which afford less power during cloudy periods. The centralized or decentralized nature of the technologies also created a difference in the responses of ease of use. While hydroelectric plants are centrally located with trained operators in charge, users are responsible for the maintenance and care of their own solar systems, although there may be communal governance structures for system maintenance (as explained in Chapter 6).

Responses differed because of the contexts in which the projects were installed. For example, PVBCS users had only used traditional energy sources before and are located in the poorest region of the country, where there have not been many rural electrification or other development projects. With the arrival of the PVBCS project, community members were trained as system operators, technicians, administrators and accountants.

The reference points respondents used are also important as they explain how their responses were shaped. This is especially true for the hydroelectric users who had previously used another hydroelectric system or a diesel generator rather than traditional energy sources. For example, Hurricane Felix was the first climate hazard in which the beneficiaries of the PVBCS had electricity, highlighting even more the differences in lighting between candles and kerosene lamps and compact-fluorescent lights. This is not the case of users that had already experienced the use of electricity and whose perceptions are based on the number of appliances they could use, their

monthly electricity tariff, and the number of blackouts they have, which are all due to a number of factors.

In the case of the small-scale hydroelectric respondents, better lighting, safety, capacity building and cost were the main reasons for having a positive perception of renewable energy systems in helping them cope with climate hazards. For those who had electricity through a centralized municipal diesel generator, they are now able to enjoy a more reliable flow of electricity, as there are not as many voltage fluctuations and black-outs. Additionally, some of these projects helped introduce cell phone coverage in the communities.

The results show the different ways in which the DRE systems help users cope with climate hazards by alleviating some dynamic pressures – including local capacity building – and improving unsafe conditions -- such as improved communications -- of the PAR model. The responses discussed above show how DRE has helped reduce the risk to livelihoods by providing communication, training, and illumination that enables people to be better prepared for disasters. We can conclude then, that in these cases information, skills and infrastructure are factors of adaptive capacity as pointed out by Klein (Klein 2002).

3.5.1.2 Social Networks

Putnam (2005) defines social capital as ‘features of social life – networks, norms and trust – that enable participants to act together more effectively to pursue shared

objectives' (Putnam 1995). For rural communities with a high vulnerability to climate hazards, the shared objective may be an increased adaptive capacity. Klein (2002) identifies institutions, social capital, and equity among the factors that build adaptive capacity that can serve to reduce vulnerability according to the PAR Model (Wisner, Blaikie 2004). For example, the lack of local institutions is considered a dynamic pressure and a contributor towards unsafe conditions. Additionally, Pelling and High (2005) analyzed social networks and norms as a form of adaptive capacity (Pelling, High 2005). In my research I did ask questions to identify if the DRE systems helped create social networks and if these were perceived by the users as a good option for climate change adaptation. I found that renewable energy systems were perceived to help create or strengthen social networks that also enable people to better cope with climate hazards. Table 21 shows these responses categorized by community, technology and country.

Table 21. Perceptions, by technology, of the role of RES to create social networks

Research question: Do you believe that your renewable energy system helped you create social networks that help you better to cope with climate hazards?

	Yes		No		Don't know		No response
Chel	11	100%	-	-	-	-	27
Chuisibel	2	50%	1	25%	1	25%	0
El Bote	16	84%	3	16%	-	-	116
Matanzas	-	-	-	-	-	-	3
Nueva Alianza	11	85%	1	8%	1	8%	2
Rio Bravo	6	100%	-	-	-	-	37
Grand Total Hydro	**46**	**87%**	**5**	**9%**	**2**	**4%**	**185**

	Yes		No		No response
ADIM	2	100%	-	-	17
Tourism	2	50%	2	50%	8
Disaster Recovery	-	-	-	-	20
GovtComm	5	83%	1	17%	9
MEM	12	86%	2	14%	20
Other	4	100%	-	-	3
PVBCS	5	83%	1	17%	7
El Trapiche PVWPS	5	100%	-	-	4
Solar Center	6	86%	1	14%	1
Grand Total	**41**	**85%**	**7**	**15%**	**98**

	Yes		No		Don't know		No response
Guatemala	56	86%	7	11%	2	3%	119
Nicaragua	38	88%	5	12%	-	-	166
Grand Total	**94**	**87%**	**12**	**11%**	**2**	**2%**	**285**

The main benefit has been an increase in communal unity and organization. For example, a user stated that *'The project helped unite people. Everybody worked during the day and met during the extra hours for school meetings, etc.'*[45]. In the case of climate hazards, this unity facilitated the creation of emergency brigades and the use of evacuation centers as exemplified by two users: *'What we have done is very useful for*

[45] Hydroelectric user in Chel, Guatemala

the community. We formed the emergency committee to look after disasters. The committee gives information to the Red Cross to announce events'[46] and *'We started using the school like an evacuation center since the school was created and powered with solar panels'*[47].

The creation of local radio stations and the improvement of other communication means to disseminate information has been one of the most valuable contributions of the DRE systems. One community in Guatemala now uses a central speaker system to disseminate news. In Nicaragua, a user said that *'There is a telephone, we can call the ambulance to get sick people out, and the injured people have also benefited a lot'*[48].

Some communities in which the DRE systems were introduced were able to replicate their experiences in neighboring communities that were interested in obtaining renewable energy. For example, community members of Nueva Alianza proudly share their experience: *'After Hurricane Stan, we trained other communities. There wasn't a way for food to come in and we cleaned up the mudslides that were blocking the road. The whole community went with the truck to clean the road and look for food'*[49]. This specific example highlights the high level of unity and organization that the DRE project helped enable. In other projects, trained workers were able to get jobs easier. Other interested community members were able to participate, generating more local jobs either directly related to the DRE project or their own business. Likewise, the energy

[46] Solar PV user in Chapín Abajo, Guatemala
[47] Solar PV user in Chapín Abajo, Guatemala
[48] Hydroelectric user in El Bote, Nicaragua
[49] Hydroelectric and biodiesel user in Nueva Alianza, Guatemala

enabled income generating activities that overall increased the median income level of the communities, as reported by respondents[50]. For example, a user indicated that *'The impact has been very important to have more work and more development projects'*[51]. In the community of Chel, the development of the micro-hydroelectric project enabled other development projects that would not have been possible had it not been for the level of organization the communities acquired because of the renewable energy project. The municipality and outside aid agencies facilitated the construction of a four-wheel drive vehicle accessible road as well as a new bridge and the newly formed community association was able to obtain funding for a solar PV powered satellite phone. This communal effort would lead to people forming groups or associations that lead to more social interaction. This social interaction, together with the increased income are seen by the respondents as enabling to better cope with climate hazards. For example, a user indicated that *'If we weren't organized and didn't have solar energy, nobody would call us, we have support networks and people look for us for training. Networks are important, we have more connections with other people and we have more help'*[52]. Finally, the sense of happiness and pride of being able to accomplish and complete the projects was seen: *'When we work together, we are stronger, there is more support and everything is facilitated'*[53].

[50] A better appreciation of income levels is in Chapter 5. While some project beneficiaries increased their income, others lost income because of diverse situations like loss of produce during a black-out or system malfunction.
[51] Hydroelectric user in Chel, Guatemala
[52] Solar PV user in Sabana Grande, Nicaragua
[53] Hydroelectric and biodiesel user in Nueva Alianza, Guatemala

Table 22 summarizes the four main reasons users gave as to why social networks enabled by the DRE helped them better cope with climate hazards.

Table 22. Main reasons social networks help cope with climate hazards

Reason	Explanation
Unity, organization and evacuation centers	The labor that many community members put in for the construction and repairs of their energy systems has created more unity and organization: families talk more among themselves and neighbors have gotten to know each other better. This organization has prompted some communities to form brigades and emergency plans that help members seek cover during climate hazards and have been used for incidents that range from birth and medical emergencies to floods and heavy rains.
Communication and information	The fact that they have light now enables families and neighbors to visit each other at night and creates a stronger social network and more communication. A greater use of cell phones and radios has facilitated the transmission of news inside communities and has paved the way for people to get organized in the case of an emergency. Some hydroelectric community companies[54] in Nicaragua created radio stations in

[54] In Nicaragua, the governance structures are similar to energy concessions, and each community (or group of beneficiary communities) formed a concessionary or community company, explained in more detail in Chapters 5 and 6.

	which they broadcast news, including storm and hurricane alerts.
Social interaction and job generation	The successful introduction of renewable energy in some communities has prompted nearby communities to request their own energy projects, creating jobs as new energy projects are introduced. Additionally, a number of productive uses have been generated using renewable energy, which has prompted families, groups of women, co-ops, and other groups to work together and create partnerships. Socially, the communities have been strengthened since acquiring their energy systems.
Happiness	People are happier since they have energy and there is a sense of 'we can accomplish what we set out to do'

Unity, organization and evacuation centers were seen as the main reason social networks helped cope with hazards for both technologies. Forty nine percent of respondents said that the communal meetings and labor that took place during the planning and implementation phases of the projects helped the communities reap several benefits; among them, strengthened relationships between community members and improved communal organization, not limited to issues related to the DRE project. *'We work better when we are united. With the repairs the project requires, it is necessary to get organized and work together'*[55]*, 'There is a common benefit. There is no unity without light, through the project there is unity'*[56]*, 'We were very divided and*

[55] Hydroelectric user in Nueva Alianza, Guatemala
[56] Hydroelectric user in Xesaí, Guatemala

now we work more united'[57] and *'The community is changing and we are all making a joint effort'*[58] are responses that exemplify the importance of unity for community progress and subsequently, for a better communal response to climate hazards. A user in Nueva Alianza summarized with this statement: *'All the people are aware, informed and they want the community to be developed. While we maintain ourselves united, any problem, disaster or conflict that arises, the community will progress because the community is united and strengthened'*[59]*.*

Communication within families and community members saw an enormous improvement, especially among hydroelectric users (33%) as compared to PV users (23%). *'News travels from family to family and information is shared,'*[60]said one respondent, emphasizing inter-family communication. Another emphasized the relationships within her own family: *'We get along better, we have more communication, we can see each others' faces during dinner'*[61]*.* Some small-scale hydroelectric plants, such as in Nueva Alianza and Chel, were seen as having a greater impact in this area because they require much more labor and team work that enable greater and deeper communication. For example, in Chel, the local NGO implemented different social communication, leadership, and trust building exercises. Afterwards, the three beneficiary communities were divided in different sectors and organization was carried out at the sector level. This facilitated the construction of the power plant as each sector had its leader and duties. Within each sector, members were able to get to know each

[57] Solar PV user in Sta. Isabel, Guatemala
[58] PVBCS user in Awastingni, Nicaragua
[59] Hydroelectric and biodiesel user in Nueva Alianza, Guatemala
[60] Hydroelectric and biodiesel user in Nueva Alianza, Guatemala
[61] Solar PV user in el Zapotal, Guatemala

other better, creating and/or strengthening trust. A user said *'Before there weren't sectors, now it is easier to work, the people are united. It is good to work together.*[62]*'.* Small-scale hydroelectric plants also facilitate the creation of small businesses and the mechanization of other activities, such as agricultural product processing. While solar systems enable stores to have lighting, the hydroelectric systems additionally enable stores to have refrigerators and freezers as well. A store owner stated that *'Now I can open my store at night and have light, it is safer, people come by in the evening and we talk, this didn't happen before the project'*[63]*.*

In conclusion, the impacts of electricity on communications are not limited to communications technologies; better illumination sources have direct impacts on other interactions within the community.

Additionally, the DRE systems enabled different degrees of information and communication technology (ICT) use. Benefits ranged from disaster preparedness to better marketing and commercialization of local products. The greater capacity of small-scale hydroelectric plants, as compared to solar PV systems, makes it possible to power more equipment, including computers, internet and fax machines. This was particularly seen in the micro-hydroelectric plants of Nueva Alianza, El Bote and Río Bravo. Most of the communications technologies we actually saw were radios, two-way radios, cell phones, and other things that can equally be powered by PV.

[62] Hydroelectric user in Chel Guatemala
[63] Hydroelectric user in Chel, Guatemala

Finally, DRE system users expressed "happiness." *'We are happy to have illumination,'*[64]said some. *'There is so much happiness in the house now that we have light'*[65], and '*It is better with electricity, people are happy'*[66] were other comments that showed people view happiness as an explicit result of DRE projects

It is important to note that poverty alleviation is the main goal of many of the projects included in this research, as summarized in Chapter 2. The full range of poverty alleviation benefits is discussed in Chapter 5. Although many of these benefits also impact climate change adaptation, these linkages are discussed in Chapter 6.

Table 23 summarizes the responses received for the role of social networks as an adaptation option. Because of the small number of responses received, it is difficult to draw conclusions from these tables.

[64] Solar PV user in Sta. Clara, Guatemala
[65] Solar PV user in Las Bolsas, Guatemala
[66] Solar PV user in El Zapotal, Guatemala

Table 23 Summary of social network responses by community, technology and country.

	Unity, organization, evacuation centers		Communication, information		Social interaction, job generation		Happiness		No response
Chel	7	64%	-	-	4	36%	-	-	29
Chuisibel	-	-	1	100%	-	-	-	-	3
El Bote	5	33%	8	53%	1	7%	1	7%	125
Matanzas	-	-	-	-	-	-	-	-	3
Nueva Alianza	7	64%	2	18%	2	18%	-	-	6
Rio Bravo	1	14%	4	57%	2	29%	-	-	38
Grand Total Hydro	**20**	**44%**	**15**	**33%**	**9**	**20%**	**1**	**2%**	**204**

	Unity, organization, evacuation centers		Communication, information		Social interaction, job generation		Happiness		No response
ADIM	1	50%	-	-	-	-	-	-	18
Tourism	2	67%	-	-	-	-	-	-	10
CONRED	-	-	-	-	-	-	-	-	9
Disaster	-	-	-	-	-	-	-	-	20
GovtComm	3	75%	-	-	1	25%	-	-	11
MEM	5	38%	4	31%	3	23%	1	8%	23
other	3	50%	-	-	3	50%	-	-	3
PVBCS	4	67%	2	33%	-	-	-	-	9
El Trapiche PVWPS	2	100%	-	-	-	-	-	-	7
Solar Center	3	38%	2	25%	3	38%	-	-	2
Grand Total Solar	**23**	**52%**	**10**	**23%**	**10**	**23%**	**1**	**2%**	**112**

	Unity, organization, evacuation centers		Communication, information		Social interaction, job generation		Happiness		No response
Guatemala	29	57%	9	18%	12	24%	1	2%	136
Nicaragua	15	39%	16	42%	6	16%	1	3%	182
Grand Total	**49**	**49%**	**25**	**25%**	**23**	**23%**	**2**	**2%**	**318**

The social networks formed in some of the projects fit Putnam's definition of social capital, as there has been a trust-building process that has enabled the creation of norms. This aspect is detailed in Chapter 6; however, it is important here to point out that the creation of these social networks, as stated by the respondents and summarized in Table 15, have helped the communities pursue shared objectives

(Putnam 1995) and achieve more than they had originally anticipated, such as the creation of emergency brigades.

Social networks were found to play an important role in the development of the DRE systems and their long-term sustainability by providing an organized means for their continuous upkeep. Results confirmed Klein's (2002) findings that institutions and social capital are adaptive capacity elements. These social networks additionally contributed to building capacity, not only for climate change adaptation (Pelling, High 2005), but for emergency preparedness not limited to climate hazards. Social networks, including through the creation and strengthening of communal governance structures, have helped vulnerable groups have more open communication among themselves, create emergency brigades and other communal organization means, and in some cases, have a decision-making role in disaster management, confirming Adger's finding that 'social networks play a primary role in adaptation and recovery' (Adger 2003). This is especially true of the Nueva Alianza case study and is clear example of what Adger (2003) describes as 'some groups within society may be less at risk than modeling studies have portrayed because of their latent ability to cope in times of stress' (Adger 2003). Rural communities are usually considered a key vulnerable group; however, the example mentioned above suggests that having strong social networks reduces apparent risk.

Other studies have found that social networks could compromise adaptation. One example is the research carried out by Wolf et al. in which strong social networks had a

negative impact on health adaptation among groups of elderly people, considered a particularly vulnerable group, during heat waves. The groups of elderly people interviewed did not consider themselves especially vulnerable to heat waves stating that common sense would help them survive. Their relatives considered them to be independent and no one contradicted their points of view (Wolf et al. 2010). Although this was not the case of this specific research, I did find that social networks can shape responses to climate hazards and, together with perceptions, may create barriers to adaptation. The clearest example of a positive response of social networks shaping hazards responses is through the creation of emergency brigades and the organization to get the most vulnerable families to evacuation centers, which had not occurred prior to the arrival of the DRE system.

The negative impacts of DRE on adaptation came from the poor quality of system design and hardware and lack of proper operation and maintenance protocols. Especially in the case of PV systems that did not have proper lightning protection, one user complained of suffering a nervous breakdown when her system was struck during a storm. Neighbors also grew fearful of using their systems, creating lack of trust in the DRE technology that could spread to the entire community.

The above results demonstrate how social networks can alleviate dynamic pressures such as by promoting communal organization and the use of appropriate skills and training, and reduce unsafe conditions such as by increasing community disaster preparedness strategies and creating or reinforcing local institutions, such as those in

charge of the upkeep of the DRE systems, two of the three causes of vulnerability according to the 'Pressure and Release Model' (Wisner, Blaikie 2004). The case studies exemplify the role of social networks in creating and strengthening community-level institutions and improving disaster preparedness. Such is the case of the PVEWS and community organization networks set in place by the Guatemalan government, which helped decrease the number of injuries and casualties during Tropical Storm Agatha.[67] Systems installed with a primary objective of economic growth have also helped build skills and diversify income generation opportunities, improving the overall local economy. The women's weaving cooperatives enabled by solar lighting systems, described in detail in Chapter 2 provide a good example of vulnerability reduction through the use of DRE: '*We have helped each other with income from the textiles we create when there are disasters*[68]'.

3.5.1.3 Renewable Energy Enhancing Other Technologies

Respondents indicated that the DRE systems were useful in enabling the use of technologies that have played a role in disaster preparedness and recovery and non climate related emergencies. Case studies showed that technologies have also been used to provide additional income sources by enhancing local skills, lessening the dynamic pressures present in the community. At the same time, they have helped improve disaster preparedness, as is explained in this section. Following the PAR Model, improvement in these two areas will help reduce vulnerability to hazards

[67] Although this has not been quantified, CONRED stated that the radio systems have been a success.
[68] Solar PV user in Chapín Abajo, Guatemala

(Wisner, Blaikie 2004). Other studies have researched the adaptive impact of technologies as a response mechanism to climate change challenges (Barbier et al. 2009, Belliveau, Smit & Bradshaw 2006, Moss et al. 2010, Nunn 2009, Turral, Svendsen & Faures 2010), stating that technologies can be considered an adaptation option. The results below indicate that DRE systems can also enable technologies that can respond to climate hazards.

Table 24 summarizes the responses received when asking if DRE systems enabled the use of technologies that might help people better cope with climate hazards.

Table 24. Perceptions, by technology, of the role of RES in enabling other technologies

Do you believe that your renewable energy system has enabled your use of other technologies that help you in the event of climate hazards?

	Yes		No		Don't know		No response
Chel	-	-	-	-	-	-	38
Chuisibel	3	75%	1	25%	-	-	-
El Bote	8	89%	1	11%	-	-	126
Matanzas	-	-	-	-	-	-	3
Nueva Alianza	7	70%	2	20%	1	10%	5
Rio Bravo	1	100%	-	-	-	-	42
Grand Total Hydro	**19**	**79%**	**4**	**17%**	**1**	**4%**	**214**

	Yes		No		No response
ADIM	-	-	-	-	19
Tourism	1	100%	-	-	11
CONRED	-	-	-	-	9
Disaster	4	67%	2	33%	14
GovtComm	2	100%	-	-	13
MEM	5	83%	1	17%	28
other	3	100%	-	-	4
PVBCS	1	100%	-	-	12
El Trapiche PVWPS	-	-	-	-	9
Solar Center	-	-	-	-	8
Grand Total Solar	**16**	**84%**	**3**	**16%**	**127**

	Yes		No		Don't know		No response
Guatemala	29	81%	6	17%	1	3%	148
Nicaragua	10	91%	1	9%	-	-	198
Grand Total	**39**	**83%**	**7**	**15%**	**1**	**2%**	**346**

The technologies considered to be most beneficial were those that allowed or improved communication, primarily radio communications and cell phone charging. Users said that *'Radio communications have helped a lot'*[69]*.* Users also enjoyed improved access to health care by being able to call for outside medical assistance when needed. Having electricity in health centers also enabled the use of medical equipment that

[69] Solar PV user in Caserío El Zapote, Guatemala

previously was available only in urban centers[70]. Respondents explained that *'With light, doctors and nurses can see better and treat the patients'*[71]. In Guatemala, scientific knowledge was perceived as important as people became aware of the technologies listed above. They also became aware of other renewable energy sources because of their own renewable energy system. A user explained his perception of the main benefit as *'Scientific knowledge because before, panels weren't used and now we can use them in a disaster and we know how to access them'*[72]. In some of the Mayan communities in Guatemala that use solar systems, the meaning of scientific knowledge gains a new dimension as it can also mean that the beneficiary communities and the donor agencies and project implementers have acquired knowledge of how to integrate the use of natural resources through DRE in a way that is compatible with local beliefs and culture, such as the Mayan Cosmology. This aspect is discussed further in Chapter 6. Finally, access to information technologies was also considered beneficial by Nicaraguan communities with small-scale hydroelectric plants, which made considerable use of internet. Users expressed that *'Now we can use computers and have access to more information'*[73]. In contrast, DRE users in Guatemala made minimal use of the internet.

These responses are summarized in Table 25. Although not all the items included in the list below are *technologies*, they are included as they constitute the responses received and the rationale for them.

[70] Although illumination is considered one of the most important benefits of renewable energy systems, including for climate hazards, it was not considered a 'technology' for many respondents.
[71] Solar PV user in El Carmen, Guatemala
[72] Solar PV user in Chapín Abajo, Guatemala
[73] Hydroelectric user in Nueva Alianza, Guatemala

Table 25. Main technologies enabled by renewable energy systems that help users cope with climate hazards

Reason	Explanation
Health care	The use of nebulizers to treat asthma and refrigerators to preserve medication have greatly decreased the number of deaths[74] and having light helps treat patients more effectively, as detailed in Chapter 5
Communication	Radios and cell phone charging have allowed people to communicate and make each other aware of emergencies, organize themselves, and work together when needed. Some communities already had radios and cell phones, but the existence of a more reliable energy source has made these communication means more effective (people need not walk an entire day to the nearest town to charge their cell phones) and less expensive (people no longer need to purchase batteries for their radios). One community bought a cable and transmits radio news to the entire community through a speaker system
Scientific knowledge	System users perceive they have gained 'scientific knowledge' as before they were not aware of renewable energy technologies or their benefits. This

[74] As reported by the local doctors and nurses, although they have not quantified this.

	knowledge has benefited them because they are now aware of and have better access to communications and other technologies that may benefit them. In conclusion, the knowledge buys them the other benefits described.
Information technology	Computers, internet and TV programs show how to take cover from a disaster. Before, people had to buy batteries to turn on the radio and listen to what was happening. Now, some communities have their own radio stations through which they can transmit news.

Table 26 shows the variation of these responses.

Table 26. Summary of technology responses by community, technology and country

	Health care		Communications		Scientific knowledge		Information technology		No response
Chel	-	-	-	-	-	-	-	-	38
Chuisibel	-	-	-	-	2	67%	1	33%	1
El Bote	-	-	-	-	-	-	-	-	129
Matanzas	-	-	-	-	-	-	-	-	3
Nueva Alianza	-	-	2	29%	3	43%	2	29%	9
Rio Bravo	-	-	3	100%	-	-	-	-	40
Grand Total Hydro	-	-	**11**	**58%**	**5**	**26%**	**3**	**16%**	**220**

	Health care		Communications		Scientific knowledge		Information technology		No response
ADIM	-	-	-	-	-	-	-	-	19
Tourism	-	-	1	100%	-	-	-	-	11
CONRED	-	-	-	-	-	-	-	-	9
Disaster	2	100%	-	-	-	-	-	-	18
GovtComm	1	50%	-	-	-	-	1	50%	13
MEM	2	50%	2	50%	-	-	-	-	30
other	-	-	-	-	1	100%	-	-	6
PVBCS	-	-	-	-	-	-	-	-	13
El Trapiche PVWPS	-	-	-	-	-	-	-	-	9
Solar Center	-	-	-	-	-	-	-	-	8
Grand Total Solar	**5**	**50%**	**3**	**30%**	**1**	**10%**	**1**	**10%**	**136**

	Health care		Communications		Scientific knowledge		Information technology		No response
Guatemala	5	24%	5	24%	6	29%	5	24%	164
Nicaragua	-	-	9	100%	-	-	-	-	200
Grand Total	**5**	**17%**	**14**	**47%**	**6**	**20%**	**5**	**17%**	**364**

Improved communications have been instrumental in providing better access to health care. For example, a user said that *'There is a telephone, we can call the ambulance to get sick people out; the injured people have benefited a lot'*[75] Radio communications have also been important in coping with climate hazards. As mentioned previously, broadcast radio, two-way radio communications, the use of cell phones, and the ability to charge them at home have significantly improved health care and rescue activities.

[75] Hydroelectric user in El Bote, Nicaragua

For example, a user stated that *'We have been able to use early warning systems'*[76] and another indicated that *'We can watch TV programs that show how to take cover from a disaster, and we also listen to the radio'*[77].

Users of the Chuisibel micro-hydroelectric plant and the Nueva Alianza biodiesel and micro-hydroelectric plants stressed the importance of scientific knowledge when talking about technologies. This may be due to the background of their projects, as summarized in Chapter 2, and is certainly reflected in their outlook of their respective projects. A user in Chuisibel explained that *'It gives us the idea that "we can" make a better use of natural resources. We may not know what they are, but we know there are other technologies that can help us'*[78]. A Nueva Alianza user concludes that *'All communities should use renewable energy; if they had, they would not have suffered during Hurricane Stan. Help was sent to Nueva Alianza after Stan, and we sent it to another community that was in more need. Right here we solved our problems'*[79].

The users of the communal solar powered workshop and water pumping systems said they have never suffered through a climate hazard and did not know what technologies would be useful in the event of one. On the other hand, users of the PVBCS considered information technology as the most important. This is an unexpected response as most users benefit only from lighting and radio communications and these were not listed among the responses for this question. Because the PVBCS suffered different degrees

[76] Hydroelectric user in Chuisibel, Guatemala
[77] Hydroelectric and biodiesel user in Nueva Alianza, Guatemala
[78] Hydroelectric user in Chuisibel, Guatemala
[79] Hydroelectric and biodiesel user in Nueva Alianza, Guatemala

of damage during the 2005 Hurricane Felix, I speculate that the responses given expressed their expectations of the system.

The previous responses confirm the hypothesis that DRE can enable technologies that are options for climate change adaptation. Within the PAR Model, these technologies have helped improve disaster preparedness and disease prevention and care. Some technologies have had the additional benefit of helping increase income levels, improving the overall local economy, all of these considered unsafe conditions that increase vulnerability to hazards. Finally, the investment in improved communication means, information technologies, and medical equipment have provided new skills to the populations that also alleviate dynamic pressures.

3.5.2 How did different project technologies fare during prior disasters?

The renewable energy technologies included in my research, except for the PVBCS, seem to offer adaptations to climate hazards; however, their effectiveness for adaptation depends on a number of cross-cutting issues including technical quality of the system and robustness; and transparency of community governance structures. The different technologies responded in different ways to the diverse climate hazards to which they were subjected, and these responses can alter users' perceptions and increase or decrease vulnerability. This section analyzes the response of the renewable energy technologies to previous disasters, if the systems could respond better to future natural disasters and if users would continue using renewable energy systems if their current system was lost or damaged.

I examine the response of each technology, the reasons those responses occurred, and how they differed across countries. Table 27 shows these responses.

Table 27. Performance of DRE systems during climate hazards

	Well		Occasional failures		Frequent failures		No response
Chel	-	-	-	-	-	-	38
Chuisibel	-	-	-	-	4	100%	-
El Bote	3	100%	-	-	-	-	131
Matanzas	-	-	-	-	-	-	2
Nueva Alianza	7	78%	1	11%	1	11%	6
Rio Bravo	1	100%	-	-	-	-	42
Grand Total Hydro	**11**	**65%**	**1**	**6%**	**5**	**29%**	**219**

	Well		Occasional failures		Frequent failures		I disconnect it		It was stolen		No response
ADIM	1	50%	1	50%	-	-	-	-	-	-	17
Tourism	-	-	-	-	-	-	1	100%	-	-	11
CONRED	-	-	-	-	-	-	-	-	-	-	10
Disaster	-	-	-	-	-	-	-	-	-	-	20
GovtComm	2	50%	-	-	-	-	1	25%	1	25%	11
MEM	11	79%	3	21%	-	-	-	-	-	-	20
Other	1	50%	-	-	-	-	1	50%	-	-	4
PVBCS	-	-	-	-	6	100%	-	-	-	-	7
El Trapiche PVWPS	3	100%	-	-	-	-	-	-	-	-	6
Solar Center	-	-	-	-	-	-	-	-	-	-	8
Grand Total Solar	**18**	**56%**	**4**	**13%**	**6**	**19%**	**3**	**9%**	**1**	**3%**	**114**

	Well		Occasional failures		Frequent failures		I disconnect it		It was stolen		No response
Guatemala	25	64%	5	13%	5	13%	7	8%	1	3%	143
Nicaragua	7	54%	-	-	6	46%	-	-	-	-	195
Grand Total	**32**	**62%**	**5**	**10%**	**11**	**21%**	**7**	**6%**	**1**	**2%**	**338**

Results show that those systems that have suffered through extreme events performed satisfactorily. For the small-scale hydroelectric plants, the only system that had frequent failures is the Chuisibel system, as stated previously. The occasional failures refer to

short blackouts mainly caused by storm debris causing technical problems in hydroelectric plants.

For the solar PV systems, the failures were mainly related to the batteries' being drained after several days of bad weather. Three systems reported being struck by lightning, two of them suffering major damage including the burning of their charge controllers. One of them continues working satisfactorily, albeit with a lower capacity. One system is disconnected and at the beginning of each rainy season to protect it from the frequent floods, as explained below. Finally, 10% other solar PV systems were reported stolen. The theft of the systems was not related to climate hazards.

3.5.2.1 Current Response of Technologies

Solar

The main problems these systems encountered during extreme weather events were: 1) destruction during particularly strong hurricanes, 2) burning by lightning strikes, and 3) disconnection by users to avoid accidents during bad weather. Here I highlight two cases of PV systems burnt by lightning. The first case is from a household located in the community of Chinebal, Guatemala in which the owner had a nervous breakdown after the charge controller exploded inside her house and has since refused to replace her PV system: '*I'm afraid to use the system, I don't want to use it again, it's bad'* [80]. In sharp contrast to the previous case, in Las Bolsas, Guatemala, another PV system was

[80] Solar PV user from Chinebal, Guatemala

struck and shattered by lightning, but the owner is happy that his system can still generate electricity and takes even more care of it: '*Lightning struck my panel, it shattered, but it still works, I'm very happy it still works, I can get a few hours of light each night'*[81]. As mentioned above, some users preferred to protect their PV systems rather than use them during severe storms. In the case of a PV panel located in the ecotourism visitor's center of Cancuén in Guatemala, next to a river that increases its level dramatically during the rainy season, the operator decided to disconnect and remove it at the beginning of each rainy season. This ensured that the system remained protected and usable at the beginning of the dry season, but made it unusable as a means of coping with hurricanes and other rainy season weather hazards. A user explained that '*For us, it's more important to have the panel work during tourism season'*[82], which coincides with the dry season.

A fourth problem identified by users is that the batteries do not charge properly after extended periods of time with overcast weather. Depending on the system design, battery size, quality of installation, number of sun hours, and battery care, some systems did well after eight days of rain whilst others lost all charge after only three days. It is important to note here that this is considered normal operation of solar systems: loads can only be served when there has been sufficient insolation to charge the batteries. Although this is a problem for the users, it does not necessarily indicate technical failure. Some cases did suffer from operator abuse and are detailed below.

[81] Solar PV user from Las Bolsas, Guatemala
[82] Solar PV user in Cancuén, Guatemala

Technical system inspections proved that those systems damaged by lightning lacked adequate protection systems. Having a grounding rod protects the system as it provides a path to ground that helps protect the system as well as the users and the dwelling. The interviews revealed that in many cases the project developers did not want to increase the project cost and decided to do without the protection systems. A vendor indicated that '*Those systems are very small, and grounding systems are too expensive*'[83]. Appropriate application of technical codes and standards and their impact on system performance is further detailed in Chapter 6.

It is normal for batteries of solar systems to be discharged after a number of cloudy days that varies based on system design; however, in some cases, there was a faster discharge due to the use of cheaper components or inappropriate use of the system. Inadequate socialization and training in some cases led to a lack of consistency between users' expectations and systems' capacities. Whilst the PV system was designed for a specific and limited load, some users connected additional appliances. For example, some users of PV Early Warning Systems had connected TV's and refrigerators to systems that were only designed to power radio systems, resulting in fast battery discharge, battery life reduction, and ultimately, operators not being able to power the radios when needed.

Small-scale Hydroelectric

Small-scale hydroelectric users said the systems work better during rains, including extreme weather events, and were happy with system performance.

[83] Solar PV vendor in Nicaragua

Only one micro-hydroelectric plant visited suffered major damage due to two strong hurricanes. The micro-hydroelectric of Chuisibel has been destroyed and rebuilt twice after hurricanes, indicating commitment to the technology. After the two reconstructions, the current plant is more robust than earlier designs. Although the national grid has already reached this community, users have not wanted to connect to it[84]. Other micro-hydroelectric plants have suffered slightly during the rainy season, for example, from a fallen tree or a minor slide, but have been able to continue generating after minor clean-up and maintenance work. As observed during the inspections, and as detailed in Chapter 6, compliance with safety and quality standards influenced whether a system was robust enough to withstand a disaster. The micro-hydroelectric plant of Nueva Alianza is an example of a system that does not follow basic design, installation and operation safety standards, is not operational half the time (independently of climate hazards), and operators have suffered injuries. Because of these reasons, and although it has not occurred yet, this plant may provide an example of how renewable energy technologies can increase populations' vulnerability as compared to their previous energy system, despite the acceptance or perceptions of its users. An example of this is the well-being of the technicians and operators. If they are in danger of being hurt while doing routine operation and maintenance procedures under normal circumstances, they might be in bigger danger under adverse conditions.

[84] Chapter 6 details the use of this micro-hydroelectric between Catholics and Evangelicals. Catholics use the micro-hydroelectric plant while Evangelicals prefer the use of the national grid.

One additional comment that many users indicated was that the turbines were not big enough to generate electricity with all the water available during the rainy season.

Photovoltaic Battery Charging Stations (PVBCS)

I visited four PVBCS in two communities out of a total of seven PVBCS installed in five Northern Atlantic indigenous Nicaraguan communities. One charging station structure in a nearby community which I did not visit was completely destroyed by a Category 5 hurricane[85] and one panel was shattered by a flying object, such as a coconut, that hit the panel during high winds. Of the PVBCS I visited, I observed that many electrical home installations had to be replaced, often because homes had been destroyed. Some of these houses collapsed during the hurricane because of poor construction practices. In these cases, the quality of the electric home installations was of secondary importance to home construction. However, some installations in homes that were in good repair did not meet the minimum technical requirements that could have minimized the damage to the installation, as detailed in Chapter 6.

The poor response of PVBCS during the hurricane was due in part to the poor original construction and component quality; the PVBCS had to be re-installed shortly before the arrival of the hurricane. Users' desire for individual domestic lighting systems rather than a communal PVBCS contributed to respondents' negative perceptions, a problem detailed in Chapters 5 and 6.

[85] It was recommended that this community not be visited due to the conflicts between two families who were fighting over the leadership for the PVBCS project.

Biodiesel

One biodiesel system was visited as a part of this study and it did extremely well during Hurricane Stan in 2005. After many failed tests during the months prior to the hurricane, the Nueva Alianza community, together with a local university, was able to successfully generate its first batch of biodiesel the day the hurricane hit. With this biodiesel they were able to continue their productive processes, such as coffee and macadamia processing and generation of purified water for themselves and other surrounding communities that were also 'isolated from the outside world'. Prior to their biodiesel generation, the community used diesel for its trucks and productive processes, which they were unable to obtain when the hurricane struck as roads were blocked. As with some of the micro-hydroelectric user responses, the only complaint of the users regarding their biodiesel system was that they would like to increase the generation capacity of their plant. This case study is detailed in section 5.4.1.

3.5.2.2 Suggestions to Improve the Response of Technologies

Respondents suggested solutions that might improve the response of their renewable energy systems to climate hazards, based on their experiences with the systems. Some general responses for all technologies, independently of how they responded to climate hazards, included the use of better quality and more resistant materials, and more training to enable users to better care for their systems and repair them more quickly. For both solar and micro-hydroelectric, users wanted systems that would not be affected by lightning. This problem can be alleviated by providing proper grounding and

lightning rods; however, these only minimize the damage resulting from a lightning strike and do not eliminate its occurrence.

Users of PV systems were mainly concerned with protecting their systems from floods. As mentioned above, some users disconnected the panels and put them away during the rainy season as they knew the water levels would rise above the level of the panel. For these users, disconnecting the panels in order to ensure their functionality for the rest of the year was the priority.

Micro-hydroelectric users requested more periodic system inspections and improved maintenance, both preventive and reactive, of the system. Users said that: *'If they gave more maintenance, we wouldn't have so many blackouts during the rainy season'*[86]. In some cases, they claimed this should be done every three days. In other instances, users wanted to continue having a micro-hydroelectric but with a *better technology*[87] and increased capacity. Because of the increased stream flow during the rainy season, users of the Nueva Alianza micro-hydroelectric system want a bigger turbine so they could generate more. This action would not make the system more robust during a climate hazard, but would enable them to power more appliances only during the rainy season. This aspect deserves more study as it is unknown if having users depend on certain uses during the rainy season will decrease their adaptive capacity during the dry season. As previously explained, they will not be able to generate their installed capacity when the flow decreases.

[86] Hydroelectric user in Nueva Alianza, Guatemala
[87] Indicating here a turbine of better quality. More details regarding technical quality are addressed in Chapter 6.

In the lone biodiesel case study evaluated, the only recommendation from the community was to increase the system's capacity, for which they already had plans.

Finally, for the PVBCS, the recommendation was to have better concrete support structures and bases since they did not have a good response during Hurricane Felix. A user of a PVBCS said that *'If they had built the system properly it wouldn't have been destroyed. We need better construction'*[88]. According to one of the developers, the original technical specifications, which asked for support structures that could withstand 160 km/hr winds, were not followed. It was pointed out repeatedly to the government entity in charge that the structures were deficient. In this specific case, category 5 hurricanes were considered during the design phase of the PVBCS but these design specifications were not met during installation.

[88] PVBCS user in Francia Sirpi, Nicaragua

Table 28. Suggestions for improved performance of DRE systems during climate hazards

	Nothing		More maintenance and protection		Better technology and construction		More capacity		No response
Chel	-	-	-	-	-	-	-	-	38
Chuisibel	-	-	-	-	1	100%	-	-	3
El Bote	-	-	-	-	-	-	-	-	134
Matanzas	-	-	-	-	-	-	-	-	2
Nueva Alianza	1	17%	1	17%	2	33%	2	33%	9
Rio Bravo	-	-	-	-	-	-	-	-	43
Grand Total Hydro	**1**	**14%**	**1**	**14%**	**3**	**43%**	**2**	**29%**	**229**

	Nothing		More maintenance and protection		Better technology and construction		No response
ADIM	-	-	-	-	-	-	19
Tourism	-	-	1	100%	-	-	11
CONRED	-	-	-	-	-	-	9
Disaster	-	-	-	-	-	-	20
GovtComm	-	-	-	-	1	100%	14
MEM	1	100%	-	-	-	-	33
other	-	-	-	-	-	-	6
PVBCS	-	-	-	-	2	100%	11
El Trapiche PVWPS	-	-	-	-	-	-	9
Solar Center	-	-	-	-	-	-	8
Grand Total Solar	**1**	**20%**	**1**	**20%**	**3**	**60%**	**140**

	Nothing		More maintenance and protection		Better technology and construction		More capacity		No response
Guatemala	2	18%	2	18%	4	36%	3	27%	171
Nicaragua	-	-	-	-	2	100%	-	-	206
Grand Total	**2**	**15%**	**2**	**15%**	**6**	**46%**	**3**	**23%**	**377**

3.5.2.3 Future Use of Technologies

Most respondents were satisfied enough with the performance of their systems that, if damaged, they would repair or replace them if able. For example, the sentiment expressed by a user that *'We got used to the illumination and brightness, we can't go back to using candles, it will be difficult to adjust'*[89] was widely shared by many of the respondents. This indicates that renewable energy technologies are seen as a viable option for climate change adaptation and have provided a better option than traditional energy sources, which constituted the previous energy source for the majority of the respondents. This question was included to gauge users trust in their systems and continued use of this technology.

A subset of PV respondents indicated they would like to buy additional panels to make their systems more robust. As detailed in Chapter 5, renewable energy was cheaper and more reliable than other energy sources. However, some respondents also stated that they would not be able to afford a system repair or replacement because of their low income: *'We are very poor, we can't afford a new solar panel, but if someone donates one, we will use it. We like the light'*[90]. Income levels pose a problem for system maintenance and upkeep, which can have a negative consequence on the ability of renewable energy systems to perform satisfactorily during a climate hazard. For example, the majority (68%) of the solar users had not replaced the batteries after the life of the first battery ended. This aspect is explored in Chapter 5.

[89] Hydroelectric user in Chel, Guatemala
[90] Hydroelectric user in Sonora, Nicaragua

In some cases, mainly among small-scale hydroelectric users, respondents preferred to be connected to the national electric grid as they could then use more appliances: *'Our current system is small and we can't use all the appliances we want to. If we have the grid, we can buy microwaves and refrigerators'*[91]. This response was not related to system reliability and reflected the under-deployed system capacities, as perceived by its users. Although grid connection is mentioned as a better option, it is unknown if the users would be able to afford the service and if the quality would meet their needs. However, some users indicated they would be just as happy increasing the capacity of their existing system.

Lastly, users of PVBCS preferred stand-alone PV panels. They described their experience with the battery charging stations as generally bad. They stressed that they had originally requested and been promised stand-alone panels, but PVBCS were installed instead. Independently of this, PVBCS proved inadequate in coping with climate hazards. Besides the poor quality of the charging structures, during a hurricane it is impossible for the users to bring their batteries to the charging stations. This action poses a big danger to the users and to the battery, which can increase the populations' and the system's vulnerability during a hazard. For example, a female user indicated that *'I had to walk in the rain to recharge my battery and I fell down in the mud. I hurt my back and the battery hit a rock and it got damaged, the battery is very heavy* (weighing approximately 70 lb).[92]*'.* The increased vulnerability is mainly for women as they are the

[91] Hydroelectric user in Nueva Alianza, Guatemala
[92] PVBCS user in Francia Sirpi, Nicaragua

ones who most frequently have the task of bringing the batteries to the charging stations. As described in more detail in Chapter 5, the government had originally planned on having the male community members carry the batteries so it would not be a burden on the women. Among the main problems observed in this case study are the faulty construction practices that caused the damage to the systems, and the lack of consistency between the users' expectations and what was originally promised to them and the donor's objectives and what they were able to budget.

These responses are shown in Table 29.

Table 29. Actions users would take if their current DE systems were lost or damaged

	Replace/Expand		Grid connect		I don't know		No response
Chel	1	100%	-	-	-	-	37
Chuisibel	-	-	-	-	-	-	4
El Bote	10	91%	1	9%	-	-	123
Matanzas	-	-	-	-	-	-	2
Nueva Alianza	2	100%	-	-	-	-	13
Rio Bravo	4	80%	-	-	1	20%	38
Grand Total Hydro	**17**	**89%**	**1**	**5%**	**1**	**5%**	**217**

	Traditional energy source*		Replace/ Expand		Sell		Dump		Grid connect		I don't know		Diesel generator		Other		No response
ADIM	1	14%	4	57%	-	-	-	-	2	29%	-	-	-	-	-	-	13
Tourism	1	13%	3	50%	-	-	-	-	1	17%	1	13%	-	-	-	-	6
CONRED	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9
Disaster	2	29%	1	20%	1	14%	1	14%	-	-	-	-	-	-	-	-	15
GovtComm	4	31%	4	31%	-	-	-	-	1	8%	2	15%	2	15%	-	-	3
MEM	7	24%	15	56%	-	-	-	-	2	7%	1	3%	2	7%	-	-	7
other	-	-	2	67%	-	-	-	-	-	-	1	20%	-	-	-	-	3
PVBCS	-	-	4	67%	-	-	-	-	-	-	-	-	-	-	2	25%	7
El Trapiche PVWPS	-	-	3	100%	-	-	-	-	-	-	-	-	-	-	-	-	6
Solar Center	-	-	4	80%	-	-	-	-	1	20%	-	-	-	-	-	-	4
Grand Total Solar	**15**	**21%**	**40**	**53%**	**1**	**1%**	**1**	**1%**	**7**	**9%**	**5**	**7%**	**4**	**6%**	**2**	**3%**	**73**

	Traditional energy source*		Replace/Expand		Sell		Dump		Grid connect		I don't know		Diesel generator		Other		No response
Guatemala	15	23%	33	51%	1	2%	1	2%	6	9%	5	8%	4	6%	-	-	119
Nicaragua	-	-	25	89%	-	-	-	-	2	7%	1	4%	-	-	2	7%	179
Grand Total	**15**	**16%**	**58**	**62%**	**1**	**1%**	**1**	**1%**	**8**	**9%**	**6**	**6%**	**4**	**4%**	**2**	**2%**	**298**

Note: * Indicates respondents who would like to replace or repair their system if lost or damages but who know they can not afford it and will go back to using their previous source of energy unless they have external aid.

3.5.3 Cross-cutting issues

Political ecology can explain how governance structures help systems user's and donor's meet their stated goals and show the importance of the types and roles of such structures. It can also prove useful to show the differential impact of development and relief programs and the different influences of the physical and geopolitical environments on both the renewable energy systems and populations. Although Chapter 6 details these cross-cutting issues as they equally affect development, emissions reductions and climate change adaptation goals, there are some key findings that apply to the role of renewable energy technologies for climate change adaptation.

Renewable energy systems put in as part of disaster relief efforts (normally PV systems) have shown a low probability of long-term sustainability because the implementation process, and therefore the outcome, is different than the one traditionally used for development projects. The planning and implementation phase is much slower, in the order of a year or two after which programs are not considered as disaster relief. The case studies showed a sharp difference in the project implementation timing requirements, leading to less social acceptance and training and lack of follow-up as to the people's needs and priorities. Consequently, systems stop working because of lack of proper operation and maintenance procedures and either are not repaired or replaced or are sold or stolen. A case study is provided in section 5.4.2.

Systems with a centralized infrastructure, for example micro-hydroelectric plants, were seen to create a greater sense of communal unity and organization than decentralized stand-alone systems, mainly PV, even if they were initially designed to be managed communally. In part, this can be explained due to the greater communal labor that is required during the implementation phase of a hydroelectric project. The increased communal organization has led to the creation of emergency brigades and other social networks that have strengthened the community during weather and non-weather related emergencies. As explained in greater detail in Chapter 6, community participation (and how this is perceived in each case) also plays an important role in how involved the users become with the system and within the community.

The decentralization of government offices can also make a difference in the quality and reliability of information, and the development and quality of projects, as was evidenced during this study. Such is the case of the Disaster Prevention Offices in the countries visited. In one country, all radio systems use the same quality of components, the same maintenance protocols and are overseen at the national level. In the other country, the implementation of these early warning systems managed on the departmental (state) level, and I observed a variety of component qualities and much unreliable information, including ambiguous information on whether specific systems exist or not. As explained above and in Chapter 6, the lack of quality and safety code compliant designs can increase the vulnerability of the users to hazards.

3.5.4 Case Studies

Three case studies are used to illustrate the main points above. The first case study is the best example of the successful use of renewable energy to cope with a hazard included in this study. It demonstrates the how the use of DRE strengthened local institutions, enabled the community members to receive multiple training in different areas, and improved crop productivity and their local economy, among other benefits. The actions of this community were, in part, shaped by their social and cultural background, as detailed in Chapter 1. The second case study corresponds to the evaluation of renewable energy as part of a disaster relief program. This example details one of the cross-cutting issues mentioned in Section 5.3 regarding the difference between development and reconstruction programs and how these can affect future development and adaptation efforts. Finally, the third case study is a comparison of the early warning programs of the two countries included in this research, highlighting another cross-cutting issue.

3.5.4.1 Successful use of renewable energy, Post Stan Hurricane

The community of Nueva Alianza is located in the region between the Pacific coast and the Western highlands of Guatemala, called *bocacosta*, and was severely affected by Hurricane Stan in 2005. For the days immediately after the hazard, rescue crews could not reach the community and emergency supplies could not be delivered to the affected populations.

In 2005, prior to the arrival of the Hurricane, Nueva Alianza, was in the process of overhauling its micro-hydroelectric plant and trying to produce biodiesel with the support of a foreign volunteer. After several failed attempts to produce biodiesel, and some damaged motors, they started collaborating with a local university and got new generation equipment four days before Hurricane Stan hit. The day the Hurricane arrived in the community, they successfully produced their first batch of quality biodiesel. Although the community homes did not suffer major damages, the community was mostly affected from loss of coffee and macadamia crops.

Their biodiesel production enabled them to survive and cope with Hurricane Stan's destruction. At the time the hurricane struck, they had only a two-day supply of conventional diesel fuel, and they were cut off from their usual supply by damaged roads. They used their first batch of biodiesel for the coffee, macadamia and purified water projects that constitute the bulk of the community's economically productive activity, and were able to use it in generators for home lighting. They were able to use the biodiesel for their vehicles and supplied purified water to neighboring communities that had not fared as well as they had. Because of their belief in renewable energy and their efforts to produce it, the community of Nueva Alianza was able to help themselves and neighboring communities that were cutoff from the 'outside world'. In the view of Nueva Alianza, 'the rest of the world was cutoff from us.'[93]

Nueva Alianza has since improved its biodiesel production. Their refurbished 16 kW micro-hydroelectric plant, completed after Hurricane Stan, was working at the time of

[93] Biodiesel user in Nueva Alianza, Guatemala

this study, albeit only at half capacity since one of the two 8 kW turbines was being repaired. The energy from both renewable sources is used to power the community's approximately fifty homes, the main offices of the community-owned finca (including its computers), the eco-hotel (where guests can power their laptops), the coffee and macadamia processing plants, and the water purification project. When there is not enough water to power the micro-hydroelectric plant and generate the necessary energy, they switch to biodiesel using the diesel motors they have. And on the occasions in which they do not have either micro-hydroelectric or biodiesel power, they use diesel fuel. Biodiesel is also used in their trucks to deliver purified water to their customers.

This case study highlights the importance of renewable energy as an adaptation strategy, and shows that good adaptation measures can lead to development. In delivering purified water free of charge to neighboring communities during the aftermath of Hurricane Stan, they gained considerable market share in the area, displacing sales from the country's largest purified water producer. The community's commitment to using renewable energy was derived from its first successful use of biodiesel. Among its near-term plans, the community wants to increase the capacities of both generating systems, and although some people would like to have access to the country's electrical grid in order to use more appliances, they still remain committed to renewable energy because it is a more reliable source and they believe in its environmental benefits. The use of biodiesel and micro-hydroelectric energy has dramatically cut their production costs and they have been able to use their income differently, as detailed in Chapter 5.

3.5.4.2 Post-Hurricane Mitch Reconstruction

This case study highlights that not all relief and reconstruction programs lead to good development or to better adapted communities. In the aftermath of Hurricane Mitch in 1998 in Guatemala, several disaster relief and reconstruction programs were carried out using renewable energy. One of these programs, funded by international donors and implemented through local NGO's, consisted in the provision of efficient stoves, seeds for new crops and individual photovoltaic home lighting systems in a number of affected communities within one affected municipality. Because of the one year time frame the developers had to implement the program, many of components usually included within development programs, such as socialization and training for the operation and maintenance of the PV systems, were accelerated and abbreviated. Within a year of installation, most beneficiaries had sold their PV systems. The lack of effective training led them to sell their systems to a 'PV system recycler' at very cheap prices as they had the belief that after a few months, or perhaps a few years, the systems would be inoperable and they would not benefit from them in any way. The majority of the few households that kept their systems were not able to afford the first change of the battery, making the systems unusable. At the time of the evaluation, almost ten years after the execution of the program, less than a handful of projects still functioned. The project developer stated that if proper training had been carried out, similar to what is done with development programs, the number of functioning systems would have been greater. Additionally, and as explained in more detail in Chapter 5, the users may not

have valued the systems because there was no buy-in from them. However, in this case, the argument can also be made to the priority of the affected populations were their lost crops and not the provision of energy.

In disaster relief programs, the short time frame under which the budget needs to be allocated and implemented constitutes an impediment for development and climate change adaptation goals to be met. This case study highlights this problem as not enough resources were spent on planning and implementing, leading to almost 70%[94] of the systems not functioning or sold less than a year after their installation. Therefore, in order for DRE to have greater benefits for climate change adaptation, future research should focus on how reconstruction efforts can also be conceived as development efforts and what balance can be achieved in order for reconstruction efforts to be sustained and strengthened with future development work.

3.5.4.3 Early Warning Systems

This last case study explains shows how renewable energy technologies can also be used successfully for disaster prevention, using photovoltaic early warning systems (PVEWS) as an example. Disaster prevention entities exist in both countries and both use PVEWS. Guatemala is the pioneer in the region on the use of these systems and its experience has been mostly positive. PV can provide a reliable source of energy during disasters: it can be used as the sole energy source in off-grid communities and as a back-up in communities that have a diesel or gas generators or grid access. Grid-

[94] As reported by the local project implementer

connected communities face two problems with regards to energy supply reliability: the grid may be unreliable on a normal basis, or the grid may suffer damage because of the disaster, leaving communities without communications during their greatest moment of need. To meet adaptation goals, communities with generators must have sufficient fuel supplies on hand during disasters as supply chains can be interrupted during disasters.

The PVEWS have brought additional benefits to the communities: they are used for any type of emergency and have made community organization necessary as they need to work together in the case of a hazard. The disaster prevention entities work with a volunteer family in each community (almost always the community leader) and provide training to the family, besides providing all the funding for the maintenance and operation. The volunteer normally agrees to take and report regular readings of river levels, and periodically the institution will send a technician to check the system and perform necessary maintenance. Shorter than expected battery life was observed due mainly to delayed maintenance checks (almost always related to budget short falls within the institution), inappropriate maintenance (for example, using non-distilled water for the batteries), and misuse of the systems (for example, causing an over-discharge when users connect TV's and sound systems directly to the battery rather than through the charge controller).

In Guatemala I visited the first watershed in which the PVEWS were installed. I inspected the EWS and interviewed volunteers in a sample of communities within the upper, middle and lower watershed. Activities in the upper watershed mainly focus on

monitoring rainfall levels and when they increase, they alert communities in the middle watershed. In the middle watershed, they focus on monitoring the level of the river and when it is high they alert the communities in the lower watershed so they can prepare for the flooding. Unfortunately, due to changes in government priorities, the systems had been abandoned for some years when Hurricane Stan struck, so there was no coordinated response even though the systems existed. In fact, the government had publicly stated that Stan would not hit Guatemala. Technically, the systems inspected were functioning properly, although minor improvements are needed if they are expected to meet their design lives. The institution seems very diligent in keeping the systems maintained and volunteers appear committed and take good care of the systems.

Institutional aspects played an important role in the effectiveness of the PVEWS. The Guatemala EWS program appears to work because all activities are coordinated and budgeted at the national level; all systems have the same type and quality of design, components and maintenance protocols. Nicaragua's EWS program is decentralized and each department (state) is in charge of its own program, whose set-up is theoretically similar to the one in Guatemala in which each community has a volunteer. One female volunteer complained that two of her fruit trees had been struck by lightning since the PV and radio antenna were installed[95], causing a negative perception of the system and a fear of using it. Therefore, this specific PVEWS is not meeting its main function. Despite good intentions at the department level, local expertise on PVEWS is lacking and poorly designed systems are installed. The department-level government

[95] The antenna would have reduced the probability the trees were hit

entities seem very eager to improve their systems; however, limited budgets also dampen their efforts. Although these results are not enough to state that a centralized institutional structure is better than a decentralized one, it was one of the aspects that made the Guatemalan program more successful than the Nicaraguan program.

3.5.5 Are Poverty Alleviation, Mitigation and Adaptation Projects meeting Adaptation Goals?

To summarize, I make a comparison of how the projects, based on their primary objective, met climate change adaptation goals. Table 22 summarizes the response to date of the projects that have suffered through an extreme weather event and what improvements could be made to them so they could improve their performance during a future climate event.

The degree to which both adaptation and non-adaptation projects met the goals is varied. The PVEWS program in Guatemala was the only climate change adaptation project that closely met its goals to date. One of the main problems this project encountered was its de-funding by the central government in 2005, before Hurricane Stan's landfall in the country. Government officials had not expected Stan to affect the country, so no preventive precaution measures were carried out, including the activation of the EWS. The best example of renewable energy as an adaptation is from the community of Nueva Alianza with their biodiesel project, conceived as a development project rather than an adaptation one.

The contrast in project response to extreme weather events, independently of their primary objectives, indicates that poverty alleviation, emissions reduction, and disaster prevention and reconstruction projects can meet adaptation goals if implemented following certain guidelines. Poverty alleviation DRE projects have a strong potential to meet adaptation goals as they help create options and elements of adaptive capacity that reduced vulnerability, according to the PAR Model. Despite climate change adaptation projects not fully meeting adaptation goals, they have the potential to do so. These projects can also help meet poverty alleviation goals, such as better health care access. The adaptive capacity and PAR Model analysis carried out in this chapter confirms the strong linkage that exists between climate change adaptation and poverty alleviation goals and that it is not necessary to only have a climate change adaptation project in order to meet adaptation goals.

Table 30. Comparison of Adaptation and Non Adaptation Projects

Adaptation Projects	**Suffered through hazard**	**Response after hazard**	**Additional comments**
Hurricane Mitch Reconstruction	N		More then 70% of systems stopped working or were sold by their first year of installation. This case study provides a number of lessons learned for future reconstruction projects
Guatemala PVEWS	Y	Good	CONRED generally provides good O&M of the systems and they helped in evacuating families during Tropical Storm Agatha. This program needs the constant support and funding from the central government to avoid repeating their failure to work during Hurricane Stan because the program had been de-funded that year.
Nicaragua PVEWS	Y	Bad	System design and components could improve, as well as the training provided to the users. There is willingness from the municipalities, but more resources need to be allocated and more coordination needs to happen at the central government level.
Non-Adaptation Projects			
Nueva Alianza	Y	Good	The biodiesel system helped the community in the aftermath of Hurricane Stan. Since then, progress has been made within the community to increase/improve their electricity supply with renewable sources of energy. Their micro-hydroelectric plant needs to be overhauled and improved as it currently could pose a danger to the operators. Overall, this is the best

			example of the use of renewable energy as an adaptation.
Chel	N		At the time fieldwork was carried out, the system had not suffered through hazards. In recent phone calls to community leaders, the system continues to operate well despite the tropical storms that have come through the country this year.

Non-Adaptation Projects	Suffered through hazard	Response after hazard	Additional comments
Chuisibel	Y	Bad	The micro-hydroelectric has been reconstructed twice after damaged caused by two different hurricanes. Although their current system is more robust than the previous ones, that is not an indication that it will not suffer through the next extreme weather event.
El Bote	N		At the time fieldwork was carried out, the system had not suffered through hazards. The system has not been affected by the recent storms of this year
Matanzas	N		The main impact of extreme weather events on this small-scale hydroelectric is the lack of peak capacity generation when there are droughts. This does not have a great impact on electricity tariffs as it's a small-scale plant. The plant has not been damaged by climate hazards.
Rio Bravo	N		At the time fieldwork was carried out, the system had not suffered through hazards. The system has not been affected by the recent storms of this year
ADIM	Y	Varied	As with all solar PV systems, after a number of days of overcast weather, the batteries discharge and users can not power their appliances. Users need to be better trained on operation and maintenance procedures, and systems should have a grounding system or a DC disconnect to protect it from lightning strikes.
Tourism	Y	Varied	Systems have not been damaged as they are disconnected and put away where the flood waters can not reach them. Users need to be better trained on operation and maintenance procedures, and systems should have a grounding system or a DC disconnect to protect it from lightning strikes.
MEM	Y	Varied	As with all solar PV systems, after a number of days of overcast weather, the batteries discharge and users can not power their appliances. Two systems were struck by lightning. Users need to be better trained on operation and maintenance procedures, and systems should have a grounding system or a DC disconnect to protect it from lightning strikes.
PVBCS	Y	Bad	One PVBCS was destroyed with Hurricane Felix, one panel was shattered by a flying object (presumably a coconut). Home installations were destroyed. This was partially caused by the faulty construction of the systems. In the future, technical specifications need to be followed property as to not compromise user safety.
El Trapiche PVWPS	Y	Good	System users have been supplied with potable water throughout different storms and the system has been operating satisfactorily.
Solar Center	N		The solar center has the potential to be an evacuation center if needed, and has the advantage its powered by solar panels.

3.6. Summary

The results and case studies illustrate how renewable energy systems can both decrease and increase vulnerability to climate hazards and help with adaptation. It is possible to affirm that renewable energy can be used as a means to adaptation if certain criteria are met. The evaluation of these projects confirms the initial hypothesis that the use of renewable energy to improve the 'driving forces and root causes' of people's vulnerability, according to the PAR Model (Wisner, Blaikie 2004, Birkmann 2006), can decrease their risk to hazards.

The results show how renewable energy can help solve some of the root causes identified by creating 1) alternative livelihood sources, therefore decreasing dependency on the natural resource base, and 2) social networks that improve community communication, unity and organization. At the very least, these two aspects help provide a more secure income source and improve power relations and governance structures within the communities. Recognizing the fact that there are other ways in which climate change adaptation can be achieved; the role of DRE systems within the PAR model elements inicates that DRE, by positively impacting dynamic pressures and unsafe conditions, can reduce vulnerability.

Renewable energy also played an important role within the dynamic pressures 'that translate the effects of root causes … into unsafe conditions' (Wisner, Blaikie 2004). In

many cases, the dynamic pressures of the PAR model are historically embedded, for which a political ecology analysis was required in order to understand the relationship between political and economic structures, the physical environment and the communities. In the case of some of the micro-hydroelectric plants visited, different reforestation and upper watershed management efforts were started with the goal of curbing deforestation and maintaining water production. Alternately, the use of renewable energy has helped create local markets since the energy has been used to create a value added within the production chain by mechanizing different processes (for example, drying of coffee, cardamom and macadamia) as well as non agricultural income sources, such as carpentry and weaving cooperatives.

Unsafe conditions were seen in most of the communities visited. Renewable energy again played a role reducing many of the risks that Wisner et. al (Wisner, Blaikie 2004) characterize as unsafe conditions. When renewable energy was used for a productive use, there was an increase in the local economy because of the creation of alternative income sources. For example, all of the renewable energy technologies evaluated – especially hydroelectric systems – enabled an increase in stores, pharmacies, and other types of small commerce. Users perceived that renewable energy played an important role in increasing their income. In most cases, the renewable energy projects fostered more unity and organization within the communities; and the governance structures created helped increase trust and community involvement in project management and decision making. Lastly, the use of PVEWS radio communication systems has improved disaster prevention and preparedness in several key watersheds prone to floods,

especially in Guatemala. These radio communication systems have proved to be important, not only for extreme weather events, but also for other emergencies. Furthermore, the use of these systems has promoted community organization during emergencies.

In most cases, renewable energy systems proved to be useful to prepare for and recover from disasters. The benefits received by the users confirm the linkage that exists between climate change adaptation and development goals. For example, the use of early warning systems' radio communications has helped populations prepare for disasters and respond to non-climate related emergencies, for example reducing maternal and infant mortality.

In summary, the main benefits identified in my study of renewable energy for climate change adaptation, and consequently, for development goals, include the following:

1. Providing a means for improved communications, including radio communications, such as Early Warning Systems and cell phone charging;
2. Lighting communal places that can serve as evacuation centers;
3. Providing alternate income sources that people can rely on if crops are damaged, such as women's weaving cooperatives; or mechanizing other processes, such as coffee and cardamom processing, providing an added value to the products;

4. Lighting roads and households, providing the ability to see and increasing awareness of surroundings, of children, elders, and others;
5. Increasing energy supply reliability. Electricity does not blow out with the wind like open flame candles and gas lamps do, reducing the risk of fires caused by an open flame. Electricity generated through DRE was also seen to be more reliable than the interconnected grid as users did not have to worry about downed power lines, except when the small-scale hydroelectric plants were interconnected to the national grid.
6. Improving community unity and organization especially in cases where a centralized infrastructure required joint labor by community members. People now communicate better, work together and are organized and better prepared in the case of weather or non-weather related emergencies; and
7. Providing a reliable source of potable water in the case of enclosed PV water pumping systems.

In a few other cases, renewable energy proved to be more of a liability than a benefit by increasing vulnerability, not only to extreme weather events. An example of this is the fractured finger of a micro-hydroelectric plant operator because the plant did not follow construction safety standards. The main causes identified to explain this increase in vulnerability are listed:

1. Lack of protection mechanisms, such as grounding of systems or the existence of a direct current (DC) disconnect, may increase the danger of the

system and the user in the event of a lightning strike (Risser, Post 1991, Architectural Energy Corporation 1991).(SNL 2002, SWTDI-NMSU 2002, Wiles 2002)(NMSU 1999). It is also important to keep in mind that some types of roof also increase the possibility of electric discharges, such as metal roofs, which were very common in the communities visited. Poor technical designs and installations, cheap components and a lack of minimum safety and quality standards can also cause harm to the users. This is exemplified in the micro-hydroelectric whose operator fractured his finger due to the poor design of the system. Although no such cases were encountered, poorly designed systems can also cause short circuits.

2. Poor home construction constituted a problem, especially when homes were blown away by hurricanes or tropical storms along with their RE systems. It does not matter how well the internal electric installation is as it will also blow away.
3. Lack of attention to non-technical issues. When the context in which the systems are being installed is not taken into account, and the negative perceptions (whether true or not) are not attended to, the systems can create social tension or rejection. Examples seen in the evaluation include increasing inequality, social tension and rift among community members which leads to less functional governance structures, communication and unity (as noted previously, playing a role in the root causes and dynamic pressures of vulnerability).

Although cross-cutting issues are look at in more detail in Chapter 6, it is important to note here that governance at the national and communal levels, physical and geopolitical environments, and funding sources and implementation processes of projects are important to meeting renewable energy climate change adaptation goals. The hypotheses that systems' quality design and installation, sound governance structure, and attention to local context are necessary for the technologies to effectively reduce vulnerability are met and are explained in more detail in Chapter 6.

CHAPTER 4: RENEWABLE ENERGY AND CLIMATE CHANGE MITIGATION

4.1. Introduction

Renewable energy technologies (RET's), independent of their scale, can achieve greenhouse gas emissions reductions by displacing fossil-fuel based generation (Drennen, Erickson & Chapman 1996, Johansson 1994, CEPAL 2007, Acker, Kammen 1996, Islam, Ruhul Amln & Sadrul Islam 2006, Del Río 2007, Olsen 2007, Patel, Ragavan 2000, Purohit, Michaelowa 2008b, Sirohi 2007, Wohlgemuth, Missfeldt 2000, Uddin, Taplin & Yu 2007, Walker, Devine-Wright 2008), therefore they constitute an opportunity to participate in the regulated and non-regulated carbon markets. As described in more detail in Chapter 1, the Clean Development Mechanism (CDM), a regulated carbon market and one of the flexible development mechanisms of the UNFCCC's Kyoto protocol, was designed with two goals in mind: developed country compliance with quantifiable emissions reduction commitments and contribution to sustainable development goals as defined by the individual developing countries (United Nations 1998). The un-regulated, or voluntary carbon market, also creates emissions reductions with some of them aspiring to comply with sustainable development goals to a greater degree (Kollmuss 2007, Taiyab 2005, Brown, Corbera 2003). To this end the voluntary market has developed standards that seek to guarantee the additionality and sustainable development benefits of offset projects.

Because of this increased focus on sustainable development from some voluntary standards, especially the Gold Standard, together with the complicated nature of the CDM and its methodologies, rural development projects tend to sell credits into the voluntary market. This chapter focuses on the former by analyzing if the DRE projects included in this research indeed met their emissions reduction goals, independent of the project's primary goal.

Literature on the subject of emissions reductions has included the main barriers faced by projects, including renewable energy (Del Río 2007, del Río, Hernández 2007, Gilau, Van Buskirk & Small 2007, Michaelowa, Jotzo 2005, Noim Uddin, Taplin 2009, Schroeder 2009, Solis 2005, Uddin, Taplin & Yu 2010, Wang, Chen); and to a lesser degree, by rural scale electrification projects (Purohit, Michaelowa 2008a, Purohit, Michaelowa 2008c, Allal, Nogaret 2002, Benecke 2008, Dayal 2004) in obtaining CDM registration. Although the purpose of this chapter is not to analyze why the majority of the DRE projects included in the research were not selling carbon credits, nor the barriers that projects face in order to do so, some of the project developers and non-government organizations involved did discuss their thoughts, fears and skepticism of being involved in the carbon market during the interviews.

Extensive research has also been carried out on the CDM's calculation of emissions baselines and additionality. Especially for off-grid renewable energy projects, the calculation of real emissions reductions was difficult as the values obtained are only estimates due to the level of uncertainty in baseline calculations, and because it is

difficult to account for the number, length and frequency of blackouts that occur once the projects are functioning. (Pearson, Shao Loong 2003, Schneider 2007, Boyd et al. 2007, Paulson, Gezon 2005). Despite this, CDM approval may nevertheless still be possible, but the accounting process can become cumbersome.

I first describe the research and data analysis methodologies. The results are divided in sections, starting with the emissions reduction analysis of the carbon projects. Only three explicitly *carbon* projects were included in the research, two of which were originally conceived as development projects[96]. I then analyze the emissions reductions of all the DRE projects included in the fieldwork, except for those with the sole objective of climate disaster prevention, specifically the PV Early Warning Systems, and the communal projects in which the PV system was an integral part of an income generation project. Lastly, I describe the cross-cutting issues that have facilitated or hampered the projects' meeting their stated emissions reduction goals, although these are detailed in greater length in Chapter 6.

4.2. Research Questions

This chapter addresses whether renewable energy carbon projects, both CDM and the VCO, are meeting their stated emissions reduction goals. If not, it analyzes the reasons why. It also analyzes how effectively renewable energy projects generally meet emissions reduction goals.

[96] The sustainable development contribution of these carbon projects are evaluated in Chapter 5

The main **research questions** asked:

1. **Are renewable energy projects meeting their stated emissions reduction goals?**

2. **What factors influence renewable energy projects meeting their stated emissions reduction goals?**

4.3 Methodology and Data Analysis

Of the fifteen case studies evaluated, only three are, or are in the process of becoming, a CDM or VCO project. San Isidro, a small-scale hydroelectric plant in Guatemala, is the only project registered as under the CDM. Chel, a micro-hydroelectric also in Guatemala, was originally conceived as a development project but was able to sell credits on the voluntary market. Lastly, the mini-hydroelectric of El Bote in Nicaragua, also conceived initially as a development project, is seeking CDM registration. These three projects are detailed in Section 4 below.

Data gathering and analysis for each project changed depending on the type of project.

For the CDM project of San Isidro, I reviewed the Project Design Document (PDD), as well as the verification and monitoring reports[97]. As the project developer did not allow a

[97] http://cdm.unfccc.int/Projects/DB/AENOR1134580249.65/view, accessed on February 16th, 2010

site visit to the project, all the information used for this case study is based on publicly available reports and on interviews with members of the communities involved. For the projects of El Bote and Chel, I compared sources and uses of energy before and after the project based on information gathered in the interviews and, in the specific case of El Bote, from any available registry from the utility company. I had the original goal of comparing the energy matrices before and after the project, but this was not possible due to the lack of reliable information. For the El Bote project, which was seeking CDM registration at the time the field visit was carried out, I also analysed the Project Idea Note (PIN) and Project Design Document (PDD), electricity generation and consumption data obtained during my visit to the site and survey data. The analysis for the VCO project of Chel used the sparse documentation related to the sale of carbon credits under the un-regulated market. Electricity generation and consumption data, provided by the community, was also used.

In order to determine if the renewable energy projects were reducing their emissions, I had initially planned on analyzing the energy consumption patterns by forming clusters according to geographical location or project or program. When the communities were located within the same geographical area and followed a similar pattern of energy source use, I grouped them to obtain an average consumption per energy source. For those programs whose projects were located over a wider geographical area, the clusters were broken down to show the different energy consumption patterns as they differ by country regions. Analysis of consumption data by user type (domestic, productive or communal) was not possible as there was evidence of shift in user types

due to the arrival of the energy system. For example, in one of the communities, 60 households purchased refrigerators and started a business because of the micro-hydroelectric project; but the energy consumption data combines both domestic and productive applications as the businesses are in the homes. Therefore, it was not possible to disaggregate.

The creation of energy profiles prior to and after the projects was not possible due to the lack of reliable information. Not all users remembered the amount used of each different energy source before project inception. A subset of those who did, use different non-conventional measurements that can not be standardized or made uniform[98], while others gave unrealistic estimates for what they thought they used. In other households, the consumption was dependent on the crop cycle success when the families would have enough income. During years in which regions suffered from loss of crops due to climate variability, the consumption of candles and gas would decrease. For a few households I was able to obtain sufficient information to create energy profiles prior to the DRE project, although these pre-profiles were not enough to create a community energy profile.

4.4. Results

4.4.1 Reduction of CDM and VCO Stated GHG Emissions

[98]An example is the consumption of candles, which varies in price depending on a size that can not be quantified or easily measured. Another example is the use of fuelwood which varies depending on the amount that can fit within the width of the arms (as if hugging) or on the person's back.

I encountered difficulty in identifying carbon (both CDM and VCO) projects that met my selection criteria. Through the evaluations it became clear that there were few community-scale carbon projects because of the burden of cumbersome procedures and administrative hurdles that need to be followed to develop them for carbon credit. Developers of most projects that I visited considered the capacities of the DRE projects to be too small to sell carbon credits, even if they were bundled. Additionally, most projects would displace traditional energy sources and occasional diesel consumption, making the amount of CER's very small per project. Some developers were not familiar with the process, and those who were, considered it to be too long, complicated and costly and did not want to get involved. The result is that few community-scale renewable energy projects try to sell carbon credits, and as evidenced below, not all who try succeed.

Because of these barriers, and the different nature and origin of the three projects considered in this chapter, it is not possible to do a true comparison between them. Therefore, I first present the results of the three CDM and VCO projects separately. I then analyze emissions reductions by project, and lastly, I summarize the cross-cutting issues which affect projects reducing their stated GHG emissions. These cross-cutting issues are detailed in Chapter 6.

It is clear that DRE projects reduce emissions; however, in a similar case to energy efficiency projects, I found a 'rebound effect'. Energy demand has grown, especially but not exclusively, when the DRE system was a hydroelectric plant. Quality of life

indicators have improved, as described in Chapter 5, and with these new comforts and benefits, whenever the DRE systems suffer blackouts, some users would power their new appliances with a diesel generator, increasing emissions which would otherwise not exist.

4.4.1.1 Project Registered as CDM: San Isidro Small-Scale Hydro

In order to analyze whether this project reduced its stated emissions reduction goals, I reviewed the PDD, and monitoring and verification reports, which indicate that the project has reduced the emissions listed in Table 31 with negligible differences between the estimated and validated generation and emissions reductions indicating project success in meeting stated mitigation objectives.

Table 31. San Isidro emissions reductions for first crediting period[99]

San Isidro Hydroelectric Plant. First Crediting period.					
Year	**Estimated annual generation (MWh)**	**Annual validated generation (MWh)**	**Emission factor (ton CO2/MWh)**	**Estimated emissions reductions (metric ton CO2)**	**Validated Emissions reductions (metric ton CO2)**
2002	9,485	10,123	0.837	7,937	8,473
2003	16,513	17,631	0.837	13,818	14,757
2004	16,614	17,694	0.837	13,903	14,810
2005	16,000	15,703	0.837	13,389	13,143
2006	16,000		0.837	13,389	0
2007	16,000	15,272	0.837	13,389	12,783
2008	16,000	18,167	0.837	13,389	15,206
Total	**106,612**	**94,590**	**0.837**	**89,214**	**79,172**

[99] Totals are highlighted in red to indicate the difference between the estimated and the validated values.

This difference occurs because the plant was off line from the National Interconnected System between January 2006 and February 2007. The corresponding Monitoring Report cites problems with the powerhouse machines, although the Verification Reports indicated that not enough detail was given. Another problem encountered by the project was the need to develop a new version of the monitoring report due to problems with the accuracy of energy generation data including: 1) There is insufficient evidence for reported electricity generation prior to 2006. 2) Energy is measured without internal transportation and transformation losses. 3) The energy consumed by the plant for its own operation when it is not generating energy is not considered in the calculation of the net energy exported to the grid. 4) The commercial meter measures energy produced from two plants: Matanzas and San Isidrio; therefore, 'to obtain the net energy displaced from the grid, it is necessary to subtract the generation of Matanzas from the measurement of the commercial meter'[100]. These problems have been solved as reported in the 2008 Verification Report[101].

In 2008, an emergency 15.5 kW diesel generator was installed; however, as it has only operated for 54 hrs since its installation, its emissions are considered negligible and not included. This diesel generator is intended only for emergency purposes related to the hydroelectric facilities, not for generation to the grid.

[100] Periodic Verification of the Project Activity San Isidro Hidroelectric Plant, AENOR, Reference number: 2005/0002/CDM/04
[101] Periodic Verification of the Project Activity San Isidro Hidroelectric Plant, AENOR, Reference number: 2009/0002/CDM/02

In conclusion, the estimates of the PDD appear to have been accurate, except for the technical failure reported. San Isidro has contributed to meeting climate change mitigation efforts: during the project's first crediting period, an average of 62% of electric generation in Guatemala has come from fossil fuel sources, more than half from diesel as shown in Chapter 2 (Dirección General de Energía 2009), and this project has helped reduce this percentage, as was observed in the current and projected energy generation matrixes for Guatemala presented in Chapter 1.

The sustainable development benefits and commitments of this project are evaluated in Chapter 5.

4.4.1.2 Project Seeking CDM Registration: El Bote Mini-Hydro

This mini-hydroelectric plant, which is seeking CDM project registration in Nicaragua, has an installed capacity of 930 kW and has been operating since the third quarter of 2005. The project was developed by a local development NGO, ATDER-BL[102]. The mini-hydroelectric generates a maximum of approximately 600 kW[103]; however, the demand of the served communities is less than half of its maximum generation. The majority of the benefited communities used to use a combination of candles and gas lamps as their primary lighting energy source; and their current energy demand is still

[102] Govt. signs US$1.2mn loan to finance El Bote xpansion,, January 25, 2005. http://www.bnamericas.com/news/electricpower/Govt,_signs_US*1,2mn_loan_to_finance_El_Bote_expansion

[103] At the time field work took place, El Bote had not been generating to its maximum capacity and the PIN and PDD were filled out accounting for a generation of 930 kW.

quite low. El Cuá, the biggest urban center and capital of the municipality that benefits from the mini-hydroelectric is the largest consumer and its energy consumption profile differs considerably from the rest of the communities, with the exception of the municipality of San Juan de Bocay. Approximately 20 years ago, El Cuá used a mini-hydroelectric from the nearby community of La Chata. When the hydroelectric was destroyed by a hurricane, they opted for diesel generators from the country's utility, ENEL. Before the El Bote hydroelectric plant started operations, the national grid had been extended in order to interconnect El Bote with the national grid. The case of San José de Bocay is quite similar to this community. Now a separate municipality, it also had a mini-hydroelectric that was destroyed in a separate hurricane.

Even though the mini-hydroelectric has been in operation since 2005, the CDM validation process was still taking place in February 2009. Although ATDER-BL had been aware of the CDM, they had not applied for CDM revenues earlier as they did not have available funding to assist with the transaction costs.

In the summary of Nicaragua's energy sector in Chapter 2 we can observe the country's high dependence on fossil fuels and note the plan the Government of Nicaragua has to increase the participation of renewable energy within its energy matrix. The project of El Bote helps meet this goal. Considering the baseline used in the PDD corresponding to the energy matrix of the country in 2007, it is clear that this project is reducing emissions. This project can reduce up to 930 kW of fossil based fuel consumption, when the plant generates to its full installed capacity and reduces their number of

blackouts per months, which currently add up to 90 hrs/month. However, there are some considerations that need to be highlighted here.

The project is partially funded by a World Bank loan that has to be paid in full within 13 years. The low energy consumption of the beneficiary communities made it necessary for El Bote to interconnect to the national grid in order to sell their excess energy and generate more income to pay the loan. According to the administrator of ATDER-BL, who manages El Bote, their entire income is used to pay the World Bank loan; with hardly any income used to cover operating costs. As a consequence, El Bote does not have available funding to continue extending the grid to reach other unelectrified communities, or for social subsidies, such as for schools. Although this aspect is detailed further in Chapter 5, it is relevant as the loan payment may have hindered further emissions reductions goals. For example, many schools are not connected to the mini-hydroelectric because school parents can not afford it, with some (illegally) connecting to neighbors lines or bringing in a diesel generator. For example, a teacher said that *'Parents can't afford the connection. When we have an event at school, we connect to our neighbor's line and we just pay him for the day'*[104]. Household users that are not connected to the grid expressed that there should be some financing mechanism so they can get their connection: *'We are very poor, we can not afford to pay the connection fee at once, and they do not give us other options to pay'*[105]. Despite these setbacks within ATDER-BL's original development plan, without the sale of energy to the utility they would not be able to pay the loan. ATDER-BL's original

[104] Response from a school teacher from Sonora, Nicaragua
[105] Non-connected household in Peñas Blancas, Nicaragua

expectation had been to use the income generated from the sale of energy to continue extending their own grids and provide other social services. On the other hand, without the loan, they would not have been able to complete the mini-hydroelectric project, leaving El Cuá and the beneficiary communities still using the diesel generators and traditional energy sources.

There was discrepancy in some of the responses received from ATDER-BL and the Ministry of Energy and Mines regarding the World Bank loan and the CDM registration process. ATDER-BL stated that *'had the project not been interconnected with the national grid, El Bote may have qualified for a grant under World Bank rules'*[106]. This is an important consideration as the CDM registration process was initiated with the goal of providing additional income that would be used towards the loan payment. Without the connection to the grid, the baseline of the project would be considerably different as it would not be based on the grid's energy matrix. As noted in Chapter 2, only two of the benefiting municipalities, El Cuá and Bocay, used a combination of renewable energy and fossil fuels, while the other rural communities had an energy matrix dominated by gas for lamps, and to a lesser degree candles and torch pine. It is also important here to point out that *'without the El Bote project, the national grid would not have reached the other unelectrified communities'*[107] and *'We have electricity thanks to Rebeca (ATDER-BL), she fought for us and for this project to happen'.*[108]

[106] Response from an ATDER-BL official
[107] Response from an ATDER-BL official
[108] El Bote user from the municipality of El Cuá, Nicaragua

The connection with the grid has brought energy reliability problems: *'The utility's grid is old and decrepit, causing numerous blackouts as it can not carry the needed capacity'*[109]. This has created diverse problems, among them productive income losses as store owners in particular have complained that on occasion they lose meat and poultry to decay because of the blackouts that can be quite lengthy. According to interviewees, these losses are also due to the high energy cost, a sharp contrast from the cheaper energy cost they were promised at the beginning of the project: *'Why should we pay a high price if they have bad quality energy that provokes me to have economic losses?*'[110] Grid reliability has had an impact on the emissions reduction efforts as those wealthier community members own a diesel generator that they power when there are blackouts. ATDER-BL estimates that there is an average of 90 hours of blackouts per month. The interviews indicate that for a subset of these 90 hours there will be emissions from other energy sources: the richer families will use diesel generators while the poorer families will use candles and gas lamps to a greater degree. For example, one user said *'if the hydro plant is not working, I have to use candles to see at night*[111]*.*

One solution to reduce blackout hours, identified by the mini-hydroelectric developer, is to have another connection point with the national grid, entailing the construction of a new substation. Although this is a technically feasible solution, there is no available funding to carry this out.

[109] Response from an ATDER-BL official
[110] El Bote user from the community of Bocay, Nicaragua
[111] El Bote user from the community of Abisinia, Nicaragua

To conclude, the connection of El Bote with the grid has perhaps brought more disadvantages than advantages. Besides causing numerous blackouts, forcing the mini-hydroelectric to operate as an island[112] for approximately one year, the cost at which ADTER-BL purchases energy is approximately 4 times more than what the former Unión Fenosa pays them for the sale of energy.

The energy reliability problems that El Bote has been facing appear to be a big barrier to further emissions reduction efforts. As noted previously, many users are unhappy with the service they receive and in some cases, users do not have a good perception of the project. The interviewees from the community of Bocay claim they had better and cheaper energy through their own mini-hydroelectric: *'We hope our hydroelectric plant will be repaired soon so we won't have to depend on El Bote, we were better off with our hydro'*[113], *'The energy we have is terrible, we keep having blackouts and the people that come to my hotel are not happy. We pay too much'*[114], *and 'We miss our original hydro, we didn't have these problems and we paid less'*[115]. Currently, both mini-hydroelectric plants are interconnected, but the service disruptions caused by El Bote's connection destabilizes the entire network.

[112] As an off-grid generation plant
[113] El Bote user from the municipality of Bocay, Nicaragua
[114] El Bote user from the municipality of Bocay, Nicaragua
[115] El Bote user from the municipality of Bocay, Nicaragua

4.4.1.3 Project Registered as VCO: Chel Post-Civil War Micro-Hydro

Chel's 165 kW micro-hydroelectric plant is the only project visited that sold carbon credits on the voluntary market. Just like the majority of the communities receiving energy from El Bote; Chel, Las Flores and Xesaí families used to use traditional energy sources. While the families in Chel relied heavily on candles and, to a lesser degree, gas and torch pine, Nicaraguan families relied more on gas lamps. As in other communities, the richer families had a diesel generator that was mainly used for corn mills. In 2003, the Asociación Hidroeléctrica Chelense sold 2,147 ton CO_2 for a total of US$21,000 to EnerGreen and its sister company Green Empowerment, for use on the voluntary market[116]. At that point they had not started operation and were planning to sell more once the plant started generating electricity.

In 2003, the Association with the help of Fundación Solar, the local NGO supporting the project, also prepared a PDD seeking the project's CDM registration. By using the 'Simplified Modalities and Procedures for Small-Scale CDM Project Activities' the baseline was based on a small diesel plant in the range of 100 to 135 kW and a 50% load factor[117]. Over a period of 21 years, the project would avoid 4,284 CO_2. Just like with the case of El Bote, Chel did not have sufficient funding to complete the CDM

[116] During the fieldwork, I was unable to obtain further information from the three parties on the carbon standard used. The only information provided was the letter stating the purchase of the carbon credits.
[117] PDD Chel Micro-Hydro, Simplified Design Document, Fundación Solar-PCF Plus, 2003

registration process and opted to continue selling carbon offsets through the unregulated market.

The energy consumption of the three beneficiary communities, equivalent to approximately one third of the plant's installed capacity, is quite low and follows the same pattern: the main household loads are lights, cell phones, TV, DVD players, sound systems and refrigerator; and few homes have ovens and motors which are only used during certain hours every day. Chel's Hydroelectric Association is working on obtaining micro-credit schemes that will help families create other income generating activities to increase energy demand. The Association needs to increase its income as they currently do not have enough capital to deal with major repairs.

At the time of the fieldwork, they were generating less than a third of their maximum installed capacity and were not eligible to sell more carbon credits. The requirements of Green Empowerment indicated that in order to sell more carbon credits under the unregulated market, they had to generate at least two-thirds of their installed capacity.

The long-term expectation of Chel's Hydroelectric Association is to be self-sustaining, to have a larger number of users and to enable micro-financing schemes to promote income generating activities, which will be highly dependent on a reliable energy supply. The system currently can not handle large variations in energy demand so every time there are changes between peak and base loads, the plant shuts down: *'We do not have electricity every night from about 11 pm to 4 or 5 am*. *After so much time they still*

haven't fixed the problem'[118] and *'Every morning I have to go to where they have the diesel generator to grind corn because there is no electricity and we can't use our electric one'*[119]. This is mainly due to technical failures, and to a lesser degree to a lack of training of the operators as is suspected by the community members: *'Those operators should be trained better, they fall asleep and that's why we keep having blackouts'*[120] and *'Those operators are very lazy, we shouldn't be paying for this service'*[121].

In order to be able to generate more income, including through the sale of additional carbon offsets, ten additional communities were interconnected to the grid at the end of 2009. Although this has significantly helped them increase their demand, they are now lacking generation during the dry season, occasioning numerous blackouts during which users are reported to either use traditional energy sources or diesel generators. For example, a user expressed that *'Electricity is unreliable. We use diesel most mornings to grind corn'*[122]. The plant is only generating 95 kW out of its total installed capacity of 165 kW and will encounter this problem, which can worsen depending on amount of rain they receive, every dry season. One solution is to implement demand-side management strategies to control peak demand and maybe, through the Association, set specific times in which certain productive activities can be carried out to avoid the peak demand hours. Although this is an option, the Association is not sure if and how they can enforce it. The second alternative may have bigger consequences for the overall

[118] Chel user from the community of Chel, Guatemala
[119] Chel user from the community of Chel, Guatemala
[120] Chel user from the community of Xesaí, Guatemala
[121] Chel user from the community of Las Flores, Guatemala
[122] Chel user from the community of Chel, Guatemala

functioning of the micro-hydroelectric. Downstream, a 90 MW hydroelectric plant named Hydro Xacbal started operation. This plant is interconnected to the National Interconnected System and there has been discussion in the past about interconnecting the Chel micro-hydroelectric plant, effectively interconnecting it to the national grid. The upside of this option is that Chel can use Xacbal's energy as a back-up when their generation is lower than their demand. The downside is that they will be regulated under the rules of the National Electric Energy Commission (CNEE, for its acronym in Spanish), which imposes a different tariff structure than the one Chel currently has, voted for by the Association members. This is an option that the Association directives and members have to weigh.

These examples highlight a distinction that needs to be made with regards to DRE projects being grid connected or not. Emissions are reduced as service in remote places is decarbonised, however, with not-grid connected systems, although emissions reductions are negligible, electricity services increase.

The search for DRE carbon projects that met all the project selection criteria showed that within the CDM, there has been a high participation of countries with relatively high rates of economic growth but not countries like Guatemala and Nicaragua (Wara 2006). The only ones found in Guatemala and Nicaragua wev b re actually the ones included in this research. Additionally, most projects are large-scale as the transaction costs are higher relative to budgets for small-scale projects (Del Río 2007, Michaelowa, Jotzo 2005, Noim Uddin, Taplin 2009, Purohit, Michaelowa 2008a, Purohit, Michaelowa

2008c, Benecke 2008, Wara 2006). Rural electrification projects are at a clear disadvantage because the number of CER's obtained from these projects is small, especially if we consider that in most cases included in this research, the primary energy sources used for baseline calculations were traditional energy sources consisting of candles and kerosene and gas lamps, with the occasional use of diesel generators to grind corn. Several researchers have calculated the amount of metric tons of CO_2 that need to be reduced in order to obtain a reasonable transaction cost per ton of CO_2 (Del Río 2007, Purohit, Michaelowa 2008a, Benecke 2008), which is orders of magnitude higher than what can realistically be obtained by solar PV. Lokey (2009) indicates that there needs to be a minimum of 30,000 credits for a broker to be involved in a project (Lokey 2009). Purohit (2008) indicates that there are only two solar PV projects submitted to the CDM so far. He also highlighted that although the theoretical emissions reductions make household solar PV projects feasible, there are no incentives, political will or investment to enable it to happen (Purohit, Michaelowa 2008a), constituting another barrier for the participation of rural electrification projects in the CDM. In the past, this was the case for Guatemala and Nicaragua. Some case studies attest to the improvement in incentives and financial mechanisms as they were made possible by the political will and institutional building favoring community scale renewable energy.

4.4.2 Reduction of GHG Emissions of DRE Projects in general

DRE projects, independent of their primary goal, are reducing GHG emissions compared to baseline. However, with the data gathered, it was not possible to estimate the additionality and create energy use projections because the energy consumption data gathered does not follow a pattern that can be analysed by statistical methods. Energy consumption patterns were, to some degree, affected by blackouts created by the failure of the renewable energy systems. For example, a user stated that *'We used to use a solar panel, and candles when there wasn't any sun. We currently use some candles, but I don't remember how many, just when there is a blackout'*[123] while another said that *'We still use batteries when there's a blackout, some weeks we have more blackouts than other weeks'*[124]*.* These blackouts were most commonly tied to the quality of the design, materials or components used, or installation: poor technical designs and inadequate operation and maintenance procedures, as described in Chapter 6, cause the systems to break down often and can also cause harm to the operators and users. Therefore, when the systems need reactive maintenance and when users start getting negative perceptions of their DRE systems, use of traditional energy sources and diesel increases.

[123] Hydroelectric user in Abisinia, Nicaragua
[124] Hydroelectric user in El Bote, Guatemala

Prior to the implementation of most DRE projects, many communities used candles, gas or kerosene (or a combination of these[125]) in lamps, batteries for flashlights and on some occasions torch pine, which is also used for heating and cooking. The more prosperous community members would own a diesel generator to run a corn mill, for which other community members had to pay a fee to use, and very few had a PV panel. More than emissions reductions, the main environmental benefit of the introduction of the DRE systems to the users has been improved indoor air quality, primarily for women and children. Users identified seeing with clarity as the main advantage: *'We're very happy. We're studying and it's very useful'*[126] and *'We got used to the energy, we don't like darkness. Candles and gas are very expensive; with the solar PV system we didn't use anything else. After our system broke down, we use the same amount of candles and gas as before, but it's more expensive now'*[127]. The use of candles, gas, and kerosene has not been completely eliminated as these are still used on occasion, especially when there are blackouts in the case of hydroelectric projects; when the battery has a high depth of discharge in the case of the PV systems; and when people 7leave their homes after dark. Additionally, candles are still used widely for religious purposes. For example, a user indicated that *'We still buy candles for church and for our ceremonies'*[128].

GHG emission reductions varied widely depending on the type of DRE used and the type of source being displaced, among other factors that are discussed in Section 4.3. I

[125] The predominance of energy source (either candles or gas) is dependent upon geographical location.
[126] Solar PV user in Sta. Clara, Guatemala
[127] Solar PV user in El Carmen, Guatemala
[128] Hydroelectric user in Chel, Guatemala

found that when the previous energy source consisted of traditional fuels (as described in Chapter 1 as candles, gas or kerosene lamps, and torch pine), the emissions reductions were negligible, independently of the DRE used. In the cases where the previous energy source was fossil based, specifically through gas or diesel generators, the highest emissions reductions were obtained when the DRE were either biodiesel or hydroelectric plants. There were negligible emissions reductions when the DRE replacing the fossil source were photovoltaics or photovoltaic battery charging stations. This is because the PV systems could not replace most of the loads served by the generators, mainly consisting of corn mills or other power equipment. Finally, when the previous energy source was another DRE system, there was no difference in generated emissions. Table 32 summarizes these findings. These comparisons use an energy usage baseline; as such, they do not consider the increase in energy demand from new electricity applications.

Table 32. Amount of GHG emission reductions based on type of DRE used and type of energy source displaced

Previous Energy Source/Current Energy Source	**PV**	**Hydroelectric not grid connected**	**Hydroelectric grid connected**	**PVBCS**	**Biodiesel**
Traditional	Negligible	Negligible	Negligible	Negligible	Negligible
Fossil	NA	Highest	Highest	NA	Highest
DRE	NA	None	Emissions increase, amount depends upon matrix composition	NA	NA

It is important to mention again that it was not possible to quantify this table because of the difficulty in obtaining emissions reductions values. Despite this, the qualitative information obtained allows the following analysis to be generated.

Besides the type of energy source being replaced, I found qualitative evidence that the amount of emissions reduced also depended on the amount of energy demand growth; which is mostly linked to the current energy source. Energy demand growth was negligible in those communities in which the DRE system replaced traditional energy sources, especially for those projects in which the primary objective is sustainable development and poverty alleviation. The main benefit observed in these projects was the improvement in quality of energy: people could see clearer, better and brighter, as described in more detail in Chapter 5. Emissions reductions were greater when the DRE systems, most commonly mini or small-scale hydroelectric plants, replaced the national grid or diesel generators. This is due to the displacement of fossil based fuels and the higher energy consumption that exists with electricity, as opposed to with traditional energy sources. When users have access to electricity, their energy consumption profile changes as the per capita energy intensity increases from the use of appliances they would otherwise not be able to power. For example, a user indicated that *'With the micro-hydroelectric and biodiesel plants we are now able to power more equipment and it's cheaper. We use the electricity to take the shells off the macadamias, to power the UV ray machine for purified water, in the delivery truck of the purified water, to give heat to the chickens*[129]*, for illumination and use of blenders in te*

[129] This project had finished by the time the fieldwork was carried out.

hotel and to power our computers in the offices'[130]*.* Another user explained the new appliances that exist in the community: *'We used to use the PV, but it's not worth to keep the system up now that we have the hydroelectricity. Between 5 and 8 families still have solar systems. The problem is that when there is no sun, the panel doesn't charge. The panel just gave us light, nothing else. Now that we have the hydro plant we can do more things. More than 30 houses have a refrigerator. We have also been able to get nice roads built and may be able to get more appliances because of that'*[131]. The same was evidenced when the previous energy source had been another DRE system. The cases observed in the field were new mini-hydroelectric plants being built because additional capacity was required or because the previous mini-hydroelectrics had been destroyed by an extreme weather event. In the two cases evaluated under this category, users relied on diesel generators during the construction of the DRE system to cover the increased demand: *'We used to use energy from La Chata mini-hydroelectric plant, but it was destroyed in a hurricane and ENEL provided us with diesel generators and they were very expensive and we had blackouts. Right now we are using the hydro plant o El Bote'*[132] and *'We preferred our old hydro, before it was destroyed. I hope it will be repaired soon so we can stop using the electricity from El Bote'*[133]*.* As always, there were a few exceptions as the lower income households would go back to using traditional energy sources as they could not afford the cost of the fossil fuel. Some households did not perceive any change as they could not afford the connection fees and continue to use their same energy source. For example, a

[130] Hydroelectric and biodiesel user in Nueva Alianza, Guatemala
[131] Hydroelectric user in Chel, Guatemala
[132] Hydroelectric user in El Cuá, Nicaragua
[133] Hydroelectric user in San Juan de Bocay, Nicaragua

respondent said that *'The project does not benefit us. We can't afford the connection fee, and the public lighting is bad so we are just the same with or without the project'*[134]

Projects in which the DRE source was a PV system, whether for home lighting systems or battery charging stations, saw less growth in energy demand than in hydroelectric or biodiesel projects as PV is mainly used for illumination and perhaps a radio or a small TV. Therefore, when the PV systems were not being used, users would go back to traditional energy sources and there was no evidence of fossil fuel consumption. A user indicated that *'We're poor, If the battery discharges we use candles and hope we have sun so the panel can recharge the battery'*[135] while another said that *'If I can't afford to recharge my battery at the charging station, I just use a candle until I can afford a recharge'*[136]. These findings are summarized in Table 33.

[134] Respondent in Xesaí, Guatemala
[135] Solar PV user in Amajchel, Guatemala
[136] PVBCS user in Francia Sirpi, Nicaragua

Table 33. Evidence-based differences in energy demand growth based on type of DRE used and type of energy source displaced.

Previous Energy Source/Current Energy Source	PV	Hydroelectric not grid connected	Hydroelectric grid connected	PVBCS	Biodiesel
Traditional	Low	High	High	Low	High
Fossil	NA	Same, although growth is dependant upon cost and reliability	Same, although growth is dependant upon cost and reliability	NA	Same, although growth is dependant upon cost and reliability
DRE	NA	Same	Same, although growth is dependant upon cost and reliability	NA	High

As with the case of Table 32, Table 33 was constructed with quantitative data as more than 50% of respondents did not provide qualitative information, either by unit or by amount of money spent, of their previous energy expenses.

All communities showed a reduction in candle use. During interviews, I asked for the consumption for the first year of use of the DRE. With PV systems, the use of candles increased as the life of the battery shortened. For example, a user stated that *'I don't remember how many candles I used. The first year we had the panel, we used less candles than now, the battery does not hold so much energy anymore'*[137]. Another user complained that *'My panel only gives me two hours of light every night so I have to use*

[137] Solar PV user in Sta. Clara, Guatemala

candles almost daily. I used to use less candles. I wish someone would donate me a new battery'[138].

In the case of the hydroelectric plants, it was not possible either to obtain reliable data on the number, length and frequency of blackouts for all the hydroelectric plants researched. Some users expressed frustration with these blackouts: *'We get blackouts more often now than when the hydro first started operating, I think they need to train the operators better'*[139] and *'Our previous hydroelectric plant was more reliable, some blackouts last very long and we lose meat because they rot'*[140].

The lower percentage of reduction in candle use of the PVBCS as compared with the PV systems in Guatemala is explained by the working principle of the PVBCS. In a stand-alone PV system, batteries are charged every day as long as there is insolation. This is not the case of the PVBCS in which batteries are only charged when the user takes the battery to the charging station, which for most users was highly dependant on when they could afford to charge the battery instead of when it was appropriate for the battery's health. For example, a respondent said that *'If I don't have money I can't recharge my battery and I use candles again'*[141] while another one reported that *'The battery discharges really fast and I can't recharge it as often as needed so I end up using candles more often than I had expected to'*[142]. As a consequence, if the batteries discharged before the users could recharge them, they would buy candles as in the

[138] Solar PV user in Bocancha, Guatemala
[139] Hydroelectric user in Chel, Guatemala
[140] Hydroelectric user in El Cuá, Nicaragua
[141] PVBCS user in Francia Sirpi, Nicaragua
[142] PVBCS user in Francia Sirpi, Nicaragua

poorest communities there is not a savings culture. What was reported in most homes, and exemplified above, was that each night they would use a combination of light bulbs and candles, especially as the age of the battery increased. This was also reported with some of the PV users in Guatemala, although to a lesser degree.

As mentioned above, one of the biggest problems encountered while doing fieldwork and data analysis was the lack of complete and reliable data to create energy use profiles. This is particularly true for those users who, before the arrival of the DRE projects, relied on traditional energy sources and whose consumption varied mostly according to harvest season: when they had more income, they were able to purchase more candles, gas and/or kerosene and have more illumination at home. While some families did not remember their previous consumption, other cases showed the DRE projects had numerous blackouts that led the users to use either diesel generators or traditional energy sources as described above. These reasons make it difficult to calculate the real amount of emissions reduced and, at best, to only obtain an estimate. Schneider (2007) states that it is necessary to develop improved tools to calculate baselines (Schneider 2007) because of the different types of baselines that can be used. El Bote and Chel used hypothetical baselines, as described in Section 4, which, according to Wara (2006) can create a problem because in many cases it is not possible to assume what would have happened without the CDM project (Wara 2006). This is especially true for rural electrification projects: most of the users of the systems visited declared that they would still be using traditional energy sources had their DRE project not been implemented: *'If it wasn't for this hydroelectric project, we wouldn't*

have known clarity, we can see better and we are happy'[143] and *'We are very poor, if it wasn't for this project, we would still be using candles, living in darkness'*[144]. Del Rio (2007) proposes the elimination of the additionality requirement for small-scale renewable energy projects and the provision of generous baselines to increase the volume of CER's that would then reduce the transaction costs because of the practical difficulties of their assessment (Del Río 2007). Given the difficulty that already exists in obtaining the number of real emissions reductions, I consider this process would further lessen the prospects of knowing what the real emissions reductions are as the amount of emissions reductions calculated would be fictitious. However, there are other approaches for these small-scale projects other than project-based carbon offsetting. It may be feasible to use sectoral approaches or Nationally Appropriate Mitigation Actions (NAMA's), in which mitigation is induced, but not as a main goal and reductions must not be calculated with the same level of correctness. Under the NAMA's, developing countries carry out mitigation actions that are tailored to each country's circumstances and respond to their respective sustainable development strategy. These actions, and the support provided by developed countries, will be measurable, reportable and verifiable. For example, in Latin America, Panama, Paraguay and El Salvador have aggregated mitigation policies and programs at the different government levels (Sterk, 2009).

Purohit (2008) indicates that creating a baseline under these conditions is also difficult because of the difference in quality of service: for example, the lumens that a candle or

[143] Hydroelectric user in Chel, Guatemala
[144] Hydroelectric user in Sonora, Nicaragua

gas lamp give compared to a compact fluorescent light (Purohit, Michaelowa 2008b). Case studies show that with the arrival of electricity, energy consumption patterns changed as users are now able to use other appliances that could not be enabled by traditional energy sources or would have been too costly with diesel generators. For example, users said that *'With the arrival of electricity I bought a refrigerator and a color TV. I can now use a blender in my kitchen, I couldn't do all this before'*[145] This is further detailed in Chapter 5.

4.4.3 Cross-Cutting Issues in mitigation

My discussions of cross-cutting issues seek to answer the question of how DRE systems can simultaneously meet the triple objective of mitigation, adaptation and poverty alleviation. Although discussed in greater detail in Chapter 5, there are some key findings as they relate to climate change mitigation goals that are described below.

1. Equity. Emission reduction efforts may not be as great as hoped when the poorer segments of the populations can not afford to connect to the DRE system and therefore continue using traditional energy sources and, on occasion, diesel generators, mainly to grind corn. Although the emissions reductions from users who use traditional energy sources is very low, as observed in Table 2, lack of access to the DRE systems may cause 1) diesel consumption to continue, even when the DRE systems are working, and 2) a higher DRE electricity generation than consumption (especially in the case of the small-scale hydroelectric plants) which lead to losses.

[145] Hydroelectric user in Chel, Guatemala

Before the micro-hydroelectric of Chel interconnected ten additional communities, they had to dump their excess generation into a phantom (passive) load. This option, although highly inefficient as it constitutes dissipated (wasted) energy, is necessary for the correct functioning of micro-hydroelectric plants when the electricity consumption, as compared to its total generating capacity, is very low. Developers and users have yet to find a productive use that benefits from this ‘excess’ energy.

Equity issues also arose in Nicaragua because of the energy sector laws and regulations that differ between the concession area of the utility Unión Fenosa and the non-concession zone of all other energy concessionaries (distributors), as explained in greater detail in Chapter 1. Unión Fenosa customers receive cross subsidies that help the lower income users and have an overall lower cost per kWh. Customers within the non-concession zone, where the greatest number of unelectrified population resides, do not receive these cross-subsidies and they pay a higher cost per kWh. In order to improve the equity between the two types of customers, a new regulation is needed that provides the same types of benefits to all customers country-wide independently of who their distributor is. In conclusion, the consequence of the current tariff inequity is affecting the poorest segment of the Nicaraguan population. Although the unelectrified populations are receiving electricity, they pay considerably more than those in the concession zone, who in general have higher incomes.

2. Energy demand growth exceeding supply. Mitigation efforts may be hampered when there is a growth in energy demand as users change their lifestyles, thereby changing their energy consumption patterns such as by acquiring more appliances and having to use fossil fuels when there are problems with the DRE systems. On occasion, the DRE system can not increase capacity at the same rate as the demand and additional loads have to be powered by fossil fuels. One project exemplifies this phenomenon. Nueva Alianza is using two DRE systems to power their productive projects, such as purified water, coffee and macadamia processing; however, due to their continued development in households and productive applications, they now need more energy than what their DRE projects can provide. Besides increasing the capacities of their DRE systems, they are also considering to increase their diesel consumption and interconnecting to the national grid. One of the community leaders indicated that *'Although we are committed to the use of clean energy, a lot of people in the community want to use more appliances and we currently don't have enough capacity with our renewable energy plants, so the only other alternative we have is to grid connect'*[146].. In the long term they want to produce their own biodiesel, for which they have partnered with a local university to study the most viable crops for that region. The expectation for this community is that they can supply all of their demand with DRE, with either a more efficient micro-hydro or one of a bigger capacity and locally produced biodiesel. Until that happens, they will most probably be consuming diesel.

[146] Biodiesel and hydroelectric user in Nueva Alianza, Guatemala

3. Market price fluctuation. The price of electricity generation is a driving force in the choice of generation options. In the case of biodiesel generation, communities who do not produce their own prime materials are subject to the price volatility of such materials, including recycled cooking oil and other crops. This is a problem encountered by the community of Nueva Alianza who started producing biodiesel in order to reduce its diesel consumption, and therefore, its costs. Their biodiesel production started with the purchase of used cooking oil, but when the cost of used oil increased to the point that diesel was cheaper than producing biodiesel, they considered purchasing diesel. Although the community leaders were committed to, and believe in the use of DRE, they could not have afforded the escalating costs of the oil. Restaurant owners, aware of the biodiesel production, have been steadily increasing their prices to the point where biodiesel production is not economically feasible. For example, a community member said that *'The restaurant owner took advantage when they found out we were buying the oil to produce biodiesel. They kept increasing the price and we can't afford it anymore'*[147].

4. Technical quality. System reliability prevents mitigation opportunities from being achieved. Substandard technical quality within system design and installation, lack of codes and standards and/or their enforcement, inadequate operation and maintenance protocols, and untrained operators and electricians can cause the DRE systems to stop working, whether it be for short periods or longer blackouts. As exemplified in the two previous points and throughout the case studies, users may supply all their (increased) energy demand with fossil fuels.

[147] Biodiesel and hydroelectric user in Nueva Alianza, Guatemala

5. Institutional issues and decision-making. Mathematical and engineering models are generally used to optimize water usage within a watershed, including when a number of hydroelectric plants (independent of their capacity) are put in series within the same river. Fieldwork evaluations showed that results of such modeling are not always considered and that upper watershed users, not limited to hydroelectric plants, decide the water usage for the rest of the watershed, depending on their priorities. None of the upstream hydroelectric plants visited released water based on the needs of downstream users. In the case study of the San Jerónimo watershed, there are three hydroelectric plants (two private ones of the same utility and a municipal one) in series and an irrigation canal in the lower watershed that uses the water after it has gone through the three hydroelectric plants. GHG emission mitigation efforts are impeded when the hydroelectric in the upper watershed does not release water in its dams to allow the electricity generation of the other two hydroelectric plants. This problem has been more evident for the municipal plant as there are occasions in which they can not generate. I was told that *'We can't always generate as we are subject to the water usage of the hydroelectric plants upstream, so sometimes we generate losses'*[148]*. When* the hydroelectric plants do not generate, thermal plants tend to supply electricity to the grid. Besides the emissions reduction concerns, environmental problems are also created. The first hydroelectric stores the water in its dam to generate hydroelectricity during peak hours. The other two hydroelectric plants do the same when they have enough water to do so, putting the users of the irrigation canal at risk as they do not always have sufficient water for

[148] Municipal hydroelectric operator

their crops. The irrigation users have complained in the past, and although the situation has improved, it is far from desirable; *'When the hydros started operating, we would be left without water for days at a time, but it's better now'*[149]. Furthermore, and not related to GHG emissions reduction efforts, the operation of the hydroelectric plants have also affected water quality when these decide to clean their dams and all the accumulated silt travels down the river and into the irrigation canal. Although there is an agreement between AURSA and the utility, the situation has not been alleviated and still creates conflicts and social tension.

6. Governance. From the responses received, I found that users' ability to participate and be part of the project (defined by them as knowledge of the project and/or ability to make decisions) is important for the proper long-term functioning of the projects. Poor governance structures and poor community participation can lead to users preferring not to use the DRE systems or to not take proper care of them, also hindering mitigation efforts. In one instance, users of a mini-hydroelectric plant compared the local utility of the DRE system to the unpopular national utility company. This perception has caused some discontent within the beneficiary communities. In general, the level of community participation appeared to be linked to the projects' funding source, as described below.

7. Funding sources. I found that the funding source is an important factor within the implementation process of the project and the cost of energy (CoE). The development and implementation processes of the projects are dependent upon the

[149] AURSA member and user of irrigation canal

funding entities. This was especially true for those projects funded by private companies and multi-lateral development organizations. Although there is no evidence generalizing all projects funded by these groups, the projects included in the research funded by them had a generally low participation from users and a lot of generated discontent. This aspect is discussed further in Chapter 5. Lack of participation may influence the lack of consistency between users' expectations and donor/developer objectives which may be the root cause of the social problems encountered, as described in more detail in the case studies in Chapter 6. An example of the lack of consistency between expectations occurs in the PVBCS project in Nicaragua. Users are not taking proper care of their illumination kits have been expecting individual PV home lighting systems, leading them to rely on other energy sources that create GHG in the interim, as indicated by a user's response: *'We are still waiting for a donor to deliver the individual PV systems we were promised, this* (the PVBCS) *is not what we were promised. If it breaks down, maybe we'll get the other systems faster'*[150].

The funding schemes set in place by these donors also influence the cost of energy, which was unaffordable for the poorest segments of the population. In one example, users did not notice any difference between energy from the mini-hydroelectric and energy from the grid as the quality remained the same (same number of blackouts) as well as their utility bills, contrary to what they were promised. Nicaragua shows the starkest contrast in terms of funding source, although all these projects are implemented through the same agency, the Ministry of Energy and Mines. The mini-

[150] PVBCS user in Francia Sirpi, Nicaragua

hydroelectric plant of Río Bravo was funded through a grant by numerous entities, mainly the Swedish Government and the UNDP and has a cost of energy reported as affordable by its users. The mini-hydroelectric plant of El Bote was made possible through a loan from the World Bank. In order to pay the loan back, the cost of energy was increased, with the consequences that a subset of the population can not afford a connection and those who can, complain it is too expensive for the quality they are receiving. Communal places, such as schools, remain off-grid because school parents are too poor to pay for the connection fee and monthly bills. This example highlights the inequities derived from the funding sources even though the projects are implemented by the same entity and the socioeconomic studies of the populations indicate similar levels of poverty and income sources.

4.5. Summary

Very few projects were identified that meet the project selection criteria set forth for this research. Although the original intent was to include the same number of carbon as development projects, this was not possible due to the lack of community scale (mainly pico, micro and mini-scale) renewable energy systems that sell carbon credits under the regulated and unregulated markets. The CDM renewable energy projects categorized as ‘small’ in both countries are greater than community scale, the smallest having more than 1 MW capacity, and not community owned, creating an unequal comparison between CDM and VCO projects. Therefore, it was only possible to include one CDM project, the small-scale hydro of San Isidro in Guatemala, even though it did not meet

all the project selection criteria as it is interconnected to the national grid. To date, there are no CDM projects in Central America that meet all the project selection criteria of this research,[151] and community-scale rural electrification projects rarely sell carbon credits on the voluntary market. The majority of projects selling carbon credits are of reforestation and efficient stoves.[152] Results indicate that the administrative hurdles to developing carbon projects are so great that few projects try, and even fewer succeed, to be carbon offset projects. Since there are many obstacles projects must face in order for them to be registered, I did not use project registration in either market as an indicator of whether the DRE projects are reducing their stated emissions reductions as the case studies show that DRE projects are indeed reducing emissions.

The case studies visited shed light on some of the problems faced for baseline and additionality calculations discussed above. The baseline created for the project of El Bote is based on an average grid emission factor for the country, which includes the fuel generation sources that serve the electrified population, including fossil fuels. The actual fuels displaced, though, are candles and biomass with a low emission factor in eighteen of the twenty beneficiary communities; leading to false emission reductions. However, the use of this baseline facilitated a larger amount of emissions reductions, and consequently, a lower transaction cost per ton CO_2. In contrast, Chel provides us with an example of an off-grid micro-hydroelectric which, during project planning and implementation, never considered the connection to the grid. The operation of a nearby large-scale hydroelectric, Hydro Xacbal, which is interconnected to the grid will enable

[151] UNEP RISOE CDM/JI Pipeline, 1 March 2010
[152] www.cdmgoldstandard.org and http://www.v-c-s.org/

them to be interconnected to the national grid if they accept to be interconnected through Hydro Xacbal. This connection will cause a difference in emissions reductions as Chel will be consuming electricity from the grid when their micro-hydroelectric can not generate enough electricity to meet the demand of their customers. As described in Chapter 1, electricity generated with coal will increase the emissions of the current energy matrix in Guatemala, suggesting that emissions reductions would be further overstated.

Perhaps, and as discussed in Chapter 5, there needs to be a realization that projects like the ones included in this research, with the exception of San Isidro and El Bote, should be considered mainly because of their sustainable development goals. There is a relationship between energy consumption and poverty levels. While the quality of life has improved and their energy consumptions have increased, emissions are still considerably low, leading to the creation of a small amount of emissions reductions.

The lack of proper tools to calculate emissions baselines only hampers efforts to know exactly what the real emission reductions are: in the DRE projects analyzed, emissions reductions clearly occurred, although it was not possible to obtain a value. There are a number of cross-cutting factors that can act as barriers to emissions reductions and these were observed in the case studies. Governance has been mentioned as an important factor for project sustainability and for ensuring emission reductions (Benecke 2008, Bumpus, Liverman 2008). Benecke (2008) indicates that ‘governance matters and determines how, and to what extent and with what impacts energy supply options

are implemented' (Benecke 2008). As was seen in some of the case studies, and detailed in Chapter 6, the lack of robust governance structures has led to the technical failure of the DRE systems or to the creation of social tension among the users that subsequently leads to poorly managed projects. Institutional and policy support (Benecke 2008), technical risks and failures (Del Río 2007), and diesel price and interest rate volatility (Gilau, Van Buskirk & Small 2007) are all factors that can hamper emissions reductions and can alter emission baselines, and are detailed in Chapter 6.

To conclude, the data gathered was useful and reliable to identify general energy and emissions trends. Although I did find that the use of traditional energy sources has decreased since the arrival of the DRE systems, it is not possible to quantify the exact amount by which it has decreased. DRE projects are reducing emissions, although they might not always achieve their stated emission reductions. The different cross-cutting issues play an important role in guaranteeing optimum emissions reductions, project sustainability, and the DRE projects meeting the triple objective.

CHAPTER 5: RENEWABLE ENERGY AND SUSTAINABLE DEVELOPMENT

5.1. Introduction

The 1987 Brundtland report contained the first, albeit vague, definition of sustainable development (Brundtland 1987). A number of researchers and institutions have also defined sustainable development, some of which follow below. Bruntland refers to sustainable development as (Huq 2003) follows:

> *'a balance between people and the planet, a balance that addresses the great challenges of today, while protecting the interests of future generations'*

Wilbanks (2007) provides more details to what constitutes sustainable development:

> *'development that meets the social and economic needs of the world's population, current and future, without endangering the viability of environmental systems important to meeting those needs'.*

The Food and Agriculture Organization of the United Nations (FAO) refers to natural resources management and conservation, and the use of technology that is appropriate, economically viable and socially acceptable in defining sustainable development (Food and Agriculture Organization of the United Nations. Conference 1989):

'Management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations'

The social and economic needs of the world's population differ according to site specific contexts, among other factors; and can include meeting basic needs such as potable water provision and access to modern energy services. Meeting social and economic needs of rural communities in developing countries can contribute to poverty alleviation and shift focus towards development rather than solely on survival.

According to the definition of FAO, achieving sustainable development would imply the use of appropriate technology for the preservation of environmental resources when meeting development needs (Elliott 1994). In poverty-stricken areas, the dependence upon natural resources tends to be higher; therefore, technological solutions must also include environmental responsibility. By working on the three pillars of sustainable development (environmental responsibility, social acceptance and economic feasibility), alleviating poverty can put these populations on a path towards development. Achieving rural sustainable development includes putting people first, building on their capabilities rather than their needs, and involving them in the decision-making process. For DRE to contribute to sustainable development, the development process must include social and economic aspects together with technological and environmental

criteria. To achieve this, I use the sustainable livelihoods framework (SLF) (Elliott 1994, Chambers 1987, Chambers 1988, Chambers, Conway 1992, Scoones 1998), since it provides a means of thinking about development and has been widely used by development professionals.

The UK Department for International Development (DfID) defines livelihoods as follows (Great Britain. Dept. for International Development 2000):

> *'comprising the capabilities, assets (human, natural, financial, social and physical capitals) and activities required for a means of living'*

A sustainable livelihood is one that meets these criteria (Great Britain. Dept. for International Development 2000):

> *'can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base'*

Renewable energy technologies are oftentimes the only available energy option for communities that are isolated from the electric grid (Chaturvedi 2004, Ezzati et al. 2004, Islam, Ruhul Amln & Sadrul Islam 2006, Yu, Taplin 1998, Carmody, Sarkar 1997). National electric grids are unlikely to reach rural populations living in difficult terrain, such as mountainous regions, in the foreseeable future. Thus DRE systems are an

alternative for these people to obtain modern energy sources that can support a range of domestic, productive, and communal applications (Cabraal, Barnes & Agarwal 2005), helping them meet sustainable development goals and achieve Millennium Development Goals (MDG) (Islam, Islam & Amin 2005, Katti, Khedkar 2005). Most of the projects visited benefit communities with these characteristics: isolated from the electric grid, located in areas with difficult terrain, and with backgrounds that included social and military conflict. The deep roots of poverty, the physical characteristics of the locations, and the specific context of the communities visited are explored in Chapter 6. Chapter 1 provides an overview of the energy sector context of both countries.

Following the same structure as the two previous chapters, this chapter analyses whether DRE projects met poverty alleviation goals and how primarily development projects compare with emissions reductions and climate change projects in terms of meeting such goals

Because ‘sustainable development’ is a broad term and some factors leading towards sustainable development are discussed in Chapters 2, 3 and 6, I focus solely on poverty alleviation and improved livelihoods indicators. The environmental component of sustainable development is not analysed in this chapter as it has been discussed broadly in Chapters 3 and 4.

This chapter starts (Section 2) with my research questions and then describes (Section 3) the Sustainable Rural Livelihoods (SRL) approach. Section 4 explains my data

analysis while Section 5 presents the results divided in four parts: quality of life, social acceptance, environmental responsibility, and a series of case studies comparing projects with primarily development-related goals with those focusing on mitigation and adaptation.

5.2. Research Questions

This chapter addresses whether renewable energy development projects are meeting their stated goals and analyses why they are or are not meeting them. It also analyses how effectively carbon projects and climate change adaptation renewable energy projects meet development goals.

The main **research questions** are these:

1. **Are renewable energy development projects meeting their stated poverty alleviation goals?**

1. Are the projects improving the quality of life of the beneficiaries?
2. Have the projects reduced the cost of energy?
3. Are the projects socially acceptable?

2. **Are renewable energy carbon and adaptation projects meeting poverty alleviation goals?**

1. Does the primary objective of a project make a difference in it meeting poverty alleviation goals?

5.3 Sustainable Rural Livelihoods Approach

In this chapter I use the Sustainable Rural Livelihoods (SRL) framework to analyse if projects are meeting poverty alleviation and improved livelihoods goals. The SRL allows an analysis of the livelihoods of households and communities, which includes their capabilities, assets, activities and strategies (Chambers 1987). The results of this chapter will focus on the five components of livelihood assets (human, natural, social, physical and financial capitals) as they allow a detailed analysis of the social, economic, and environmental needs of the communities and of the impacts DRE systems can have on each. For the purposes of this chapter and dissertation, the other elements of the SRL will not be analysed.

Figure 10 shows the Sustainable Livelihood Framework (SLF).

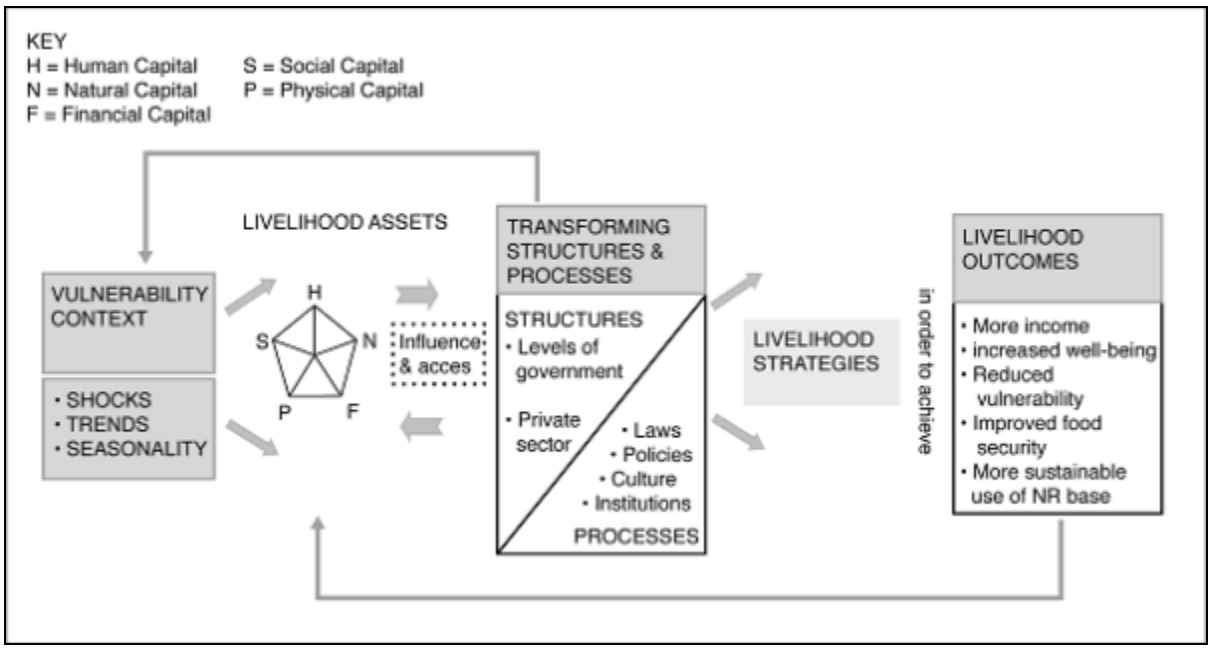


Figure 10. Sustainable Rural Livelihoods Framework

(Chambers 1987)

I analyse how DRE systems can have an impact on the five assets, thereby improving the overall livelihoods that will make populations less vulnerable to external shocks. DRE systems have been linked to improved quality of life and as a means to a sustainable livelihood in diverse studies. Chaturvedi (2004) claims that renewable energies are a *prerequisite* for sustainable livelihoods (Chaturvedi 2004), while Ezzati, et.al. (2004) goes further in saying that modern energy technologies 'have a central role in social and economic development at all scales' (Ezzati et al. 2004). A number of country case studies have been developed reflecting the experiences, or expected outcomes, of the use of DRE systems in rural areas and their specific relationship to improved quality of life and rural economic growth, highlighting impacts in health,

education, information technologies, and other areas (Yu, Taplin 1998, Li et al. 2005, Kammen, Hankins 2000, Kammen, Lankford 1990). The contribution of DRE for the improvement of these sectors can lead to an improvement in the five assets of the SRL. Consequently, DRE systems could simultaneously meet poverty alleviation, climate change mitigation, and climate change adaptation goals. The roles that DRE can play to improve the five capital assets follow:

1. Human capital focuses on health, nutrition, education, knowledge and skills, and capacity to work (Great Britain. Dept. for International Development 2000). DRE systems can provide illumination within health centers and schools, improving service quality for those locations currently using traditional energy sources, and reduce energy costs for those using fossil fuel generators. DRE systems can additionally enable other income generating activities by providing new skills and jobs. The implemented hardware can also be used for income generation, for example, vaccine refrigerators can also be used to sell ice cream.
2. Natural capital includes environmental services, lands and produce, trees and forest products, and other environmental topics (Great Britain. Dept. for International Development 2000). DRE can improve natural capital by providing alternate income sources, diminishing impacts on the natural resource base. Integrated watershed management and environmental services plans may be developed in support of hydroelectric projects, providing an indirect benefit of DRE on natural capital assets.

3. Social capital is defined as the existence and strength of networks, trust, mutual support, common rules and sanctions, decision-making and leadership (Great Britain. Dept. for International Development 2000). Governance and maintenance of communal DRE can strengthen these. The process of planning and implementing projects may enable trust building.
4. Physical capital such as infrastructure can be built or strengthened by DRE projects. The implementation of DRE systems may bring needed or improved roads and other infrastructure to the communities and can enable new technologies, as described in Chapter 3 (Great Britain. Dept. for International Development 2000).
5. Financial capital is comprised of the savings, credit, remittances, pensions and wages of the communities (Great Britain. Dept. for International Development 2000). DRE systems can impact financial capital in two ways: energy cost savings and creation of new jobs which lead to additional income.

These capitals are analyzed using quality of life, energy cost savings, and social acceptance indicators:

1. *Quality of life* indicators are used to evaluate human, physical and financial capital
2. *Energy cost savings* indicators will evaluate financial capital
3. *Social acceptance* indicators will evaluate human and social capital.

Natural capital is evaluated directly through specific hydroelectric projects and indirectly through quality of life indicators by assessing income diversification opportunities and consequently, a decreased impact on local natural resources. As indicated previously, this was analysed in Chapters 3 and 4.

5.4. Data Analysis

Eleven of the fifteen projects included in this research had primarily development objectives. The contributions that these DRE systems have made on poverty alleviation and improvement of livelihoods are discussed in this chapter.

Two different indicators were used to measure poverty alleviation:

1. Improvement in *quality of life* through the improvement of services, such as lighting, health and education and through income diversification.
2. *Energy cost savings* by calculating the current cost of energy compared to the cost of previous energy sources, or the percentage of income spent on energy. This value was also compared to the differences in quality of energy received. For example, the lighting quality of a candle is inferior to the lighting quality of a compact fluorescent bulb. In similar cases to that explained in Chapter 4, it was not always possible to obtain an energy savings figure for each project or community due to a lack of reliable data. The majority of respondents did not remember their exact savings, but they indicated there have been cost savings since the arrival of their

DRE system: *'we spend less money on energy now, but I don't remember how much'*[153] or *'in general, we do spend less, but the cost also depends on how many blackouts we have. We use candles when we have blackouts and some weeks we have more than others'*[154]

Three indicators of social acceptance were analysed, as discussed in detail in Chapter 6: consistency with local culture and religion, consistency between project's goals and user's expectations, and conflict resolution. In Chapter 6, these indicators are analyzed under broader categories: site-specific contexts, such as historical and environmental background; implementation process of project and funding sources; and existence and types of governance structure, respectively. Therefore, in this chapter, the discussion of these indicators focuses on how they enabled or disabled the projects to meet poverty alleviation goals. Additionally, I analyse the sufficiency of funding available for the communal creation and upkeep of an *operation and maintenance fund* that would allow long-term functioning of the DRE system. This indicator is closely related to the *energy cost savings* indicator as, in some cases, users were able to afford paying a maintenance fee because they were saving cost as compared to their previous system. This indicator is also related to one of the cross-cutting issues discussed in Chapter 6: community governance structures for the DRE system's upkeep and management. In the projects researched, the existence of a governance structure always implied the existence of a tariff structure. Importantly, the existence of a governance structure did not always ensure the effective enforcement of a tariff structure, as explained in Chapter

[153] Hydroelectric user in Chel, Guatemala
[154] Hydroelectric user in El Cuá, Nicaragua

6. In this chapter I only discuss the implications of an *operation and maintenance fund* on poverty alleviation and improved livelihoods goals.

Their relevance and impact on emissions reductions and climate change adaptation are detailed in the next chapter.

The main survey questions used to obtain this information are in Table 34.

Table 34. Main survey questions for poverty alleviation indicators and social acceptance indicators

Quality of life	Domestic uses	How do you use the energy in your house?
		Are you happy with your energy?
		Is there anything else you would like to do with your energy?
		Why do you have to complement your renewable energy source?
	Productive uses	Has the DRE project helped you increase your income?
		Has the DRE project helped other community members increase their income?
		Has the DRE project contributed to you or other community members to lose income?
	Communal uses	Does the DRE project provide electricity to communal places?
		Have you noticed a change in the quality of service?
		Have you benefitted from having electricity in communal places?
Energy cost savings		Have you saved money as compared to your last energy source? If not, why?
		If you need to complement your DRE electricity with another energy source, do you still save money?
		Are you able to pay the costs associated with having the DRE system?

Social acceptance	Consistency with local culture and religion	Was your opinion taken into account when the project was being developed?
		Was the project developer/planner sensitive to the background of your community?
		Has the project helped meet your needs?
	System upkeep and management	What do you do when the system stops working?
		Do you think you received sufficient training to be able to care for your system?
		Is there a governance structure to help manage the system?
		Is this structure effective?
		Do you trust the members of this structure?
		Are you able to participate in all matters related to the system? Are other community members able to participate freely?
		Have there been any conflicts related to the system?
		Have you been able to solve the conflicts satisfactorily?

All the projects were analysed using the indicators described above, except for four projects:

1. The small-scale CDM hydroelectric project of San Isidro is excluded because its development component has focused more on sustainable water management and not on energy provision, as described in further detail in the case studies in Section 5.4.2.
2. The PVEWS systems in Guatemala and Nicaragua are excluded as only one household per community/sector has a system and its main purpose is for disaster

prevention rather than poverty alleviation. These projects could indirectly meet poverty alleviation goals as they will help people prepare in the case of a climate hazard and hopefully, they will lose less income than they would otherwise. However, as their main objective is not poverty alleviation I did not analyse them following the indicators described above. The linkages of these PVEWS projects have been analysed in Chapter 3.

3. The disaster reconstruction project of Hurricane Mitch in Cahabón, Guatemala was also excluded. Although this project has a poverty alleviation component, its main purpose was reconstruction. I also include a brief case study of this project in Section 5.4.3.

The project-level analysis showed different results between technologies, therefore, the results shown in the next section are a comparison between technologies rather than projects. I hypothesize that the main reasons for this are the differences in system capacity and current output between solar PV and hydroelectric plants. While solar PV systems have a direct current output, requiring an inverter for use of most appliances, hydroelectric energy output is alternate current output, allowing the use of more appliances.

5.5. Results

I first analyse whether DRE projects have contributed to poverty alleviation goals and then I discuss their social acceptance. Environmental responsibility is not discussed in great detail in this chapter as it was discussed in Chapter 3 and emissions reduction

were discussed in Chapter 4. For this chapter, environmental responsibility is limited to the analysis of the disposal of batteries used in solar photovoltaic systems. The additional benefits of hydroelectric plants, such as reforestation, were discussed in Chapter 4.

5.5.1 Poverty Alleviation

5.5.1.1 Quality of Life

Respondents had a generally positive perception of renewable energy improving their quality of life. Domestic users state the following as primary reasons: having electric lighting, ability to better see each other's faces, need to pay less for energy every month, ease of turning a switch on, reduction of need to breathe the fumes from gas lanterns, ability to cook without candle-light. For example, users indicated that *'Illumination is better, it was very hard to see with candles'*[155], *'I'd rather leave my wife than give up having light'*[156], *'We are happy because we pay less every month and can see better'*[157], and *'We don't need to suffer at night cooking and eating with candles'*[158]. Productive applications users indicated their main benefit was the ability to work longer hours and increase their income without the need for candles and gas/kerosene lamps. Users indicated that *'People can come at night hours to shop here and charge their cell phones'*[159], *'We save money as we don't have to pay for gas anymore. We save approximately 35% of costs which we reinvest in community projects'*[160], *'We can now*

[155] Solar PV user in Los Horcones, Guatemala
[156] Solar PV user in La Bolsa, Guatemala
[157] Hydroelectric user in Nueva Alianza, Guatemala
[158] Hydroelectyric user in La Pitilla, Nicaragua
[159] Solar PV store owner in Bocancha, Guatemala
[160] Hydroelectric and biodiesel user in Nueva Alianza, Guatemala

get bread in the community, whatever people hunt, we can carve it up and sell at night'[161], and *'I'm happy since the hydro started working, we have stores, dining rooms, bars, and other businesses that we used to not have'*[162]. Finally, community applications beneficiaries indicated that health and education services had improved, there was more safety with public lighting and that religious services were *'happier because now we can sing, we have sound equipment and bright light and we can see better than with candles'*[163]. All users, independently of the specific uses they give to their DRE systems, indicated the light had changed their lives.

Domestic applications

In all projects, independently of the renewable energy technology used, 100% of the beneficiaries had compact fluorescent lamps. Households with stand-alone solar PV systems often had use of a radio or a small black and white TV. Except for the PVBCS, more than 85% of beneficiaries of the other projects had a radio and a cell phone charger. In the case of small-scale hydroelectric beneficiaries, most households also had TV's, DVD players or sound equipment[164]. Other applications found in Guatemala (Nueva Alianza and Chel) and in Nicaragua (municipality heads of El Cuá, San José de Bocay and Río Bravo, who, as explained previously, already had electricity) include refrigerators, blenders, and computers. Consequently, their per capita energy intensity

[161] PVBCS user in Awastingni, Nicaragua
[162] Hydroelectric user in Puerto Viejo, Nicaragua
[163] Hydroelectric user of Chel, Guatemala
[164] The exception are the poorer families who could barely afford the service they currently have

is higher than in other communities who used to rely on traditional energy sources, making it impossible to carry out a level comparison by project.

Despite the benefits users enjoy with their DRE systems, some users indicated they were not happy with the energy they are receiving. As explained in Chapter 3, these responses were highly dependent on users' perceptions and expectations of the DRE systems. In both countries, the most common complaint against solar PV systems is that after a number of cloudy days, the battery discharges and they can not use their solar panel. Additionally, users prefer the grid as they would like to use more appliances that cannot be run with the PV panels they currently have. User statements include *'I do not know what the problem is, I can only use my bulbs for one hour every night'*[165], *'When it rains the most, when we most need the light, the panel doesn't charge and we don't have light and have to suffer with the candles again'*[166], *'I'd be happier with the grid, I want to use more appliances, but the panel cannot cope*[167][168], and *'I have to recharge my battery very often, it's heavy to carry and it's expensive to keep recharging'*[169]. The primary complaint among hydroelectric users in both countries is quality of service, which needs to be improved in order to reduce blackouts. Although all systems presented some problems, users' answers again depended considerably on their perception: some users were happy to have the service. For example, users stated that *'everything is happier with light, even if it is for a few hours; I do not want to go back*

[165] Solar PV user in Nueva Amajchel, Guatemala
[166] Solar PV user in Nueva Amajchel, Guatemala
[167] The panel can't handle the additional capacity of other appliances
[168] Solar PV user in El Zapotal, Guatemala
[169] PVBCS user in Francia Sirpi, Nicaragua

to use candles'[170] and *'We are happy because we have light and pay less for energy every month'*[171]; while others indicated their tariff was too expensive for the service they were receiving: *'the light keeps going out and they charge us a lot; they should improve their service and fix the problems'*[172], *'there are a lot of blackouts and we still have to pay a high tariff; we had less blackouts with the diesel generator'*[173] I also found that users' expectations and perceptions depended on their previous energy source, especially for those who currently use hydroelectric energy. For instance, the first quote was from a user who used to use candles as the main energy source, while the second respondent received diesel-generated electricity previously.

Finally, domestic energy users stated they would like to be able to use more appliances. In Guatemala, 100% of users would like to use more kitchen appliances (blenders, refrigerators, microwave, etc.), and to a lesser degree, have access to computers, the internet, and more lights in the households. In Nicaragua, domestic users expressed they would like to open businesses at home once they are able to have more appliances. As expected, the percentage of users wanting more appliances is lower in Nicaragua. Because of the existence of the large electrified urban centers, most users already have these. The increase in the use of appliances begs the new question on whether poorer households are able to afford the increased costs of new loads: users of PV systems would need additional panels and a larger battery bank; hydroelectric system users would be pay higher electricity tariffs.

[170] Hydroelectric user in Xesaí, Guatemala
[171] Hydroelectric user in Nueva Alianza, Guatemala
[172] Hydroelectric user in El Cuá, Nicaragua
[173] Hydroelectric user in El Cuá, Nicaragua

Productive applications

Among the benefits that are attributed to DRE systems is the increase in income that users might perceive, and this is confirmed through the case studies. My research supports the hypothesis that income generating activities are important for the long-term sustainability of the systems (Chaturvedi 2004, Ezzati et al. 2004). A greater number of solar PV systems were functioning when associated with a store than when the systems were being used solely for domestic applications: in Guatemala, five solar PV users had some kind of income generation because of their system and these were still functioning; while in Nicaragua three of the photovoltaic battery charging station users had income generation resulting from their systems, although system capacities were not always appropriate to demand, as has been explained in other chapters. Solar PV users that started a business shared *'we now charge people to charge their cell phones'*[174], and *'we open until late and when people have a party, they can come with us and buy until midnight; we all benefit'*[175]. As predicted, beneficiaries of hydroelectric projects were able to capitalize on productive use applications to a greater degree. Those who do not have businesses constitute poorer families who could only afford basic illumination in their homes and could not afford to start shops or other business, despite their interests. The types of businesses that flourished with the DRE projects vary: in Nicaragua, bars and slot machines were predominant, while in Guatemala households purchased refrigerators to sell popsicles and cold drinks. Other businesses

[174] Solar PV user in Sta. Clara, Guatemala
[175] Solar PV user in Col. Agrícola San Juan, Guatemala

created include carpentry shops, grain mills, bakeries, car mechanics, tire repair workshops, and others. A user in Nicaragua said that *'With the energy I installed a billiard parlor; I can use the light at night, and it allowed me to have a refrigerator for the sale of cold products, and I can sell until late at night'*[176]. In Guatemala, a user stated that *'I have always been a carpenter; the energy facilitates my work and gives more formality as I can now power my tools'*[177].

The most common productive use application in both countries was refrigeration. Most users purchased a refrigerator and other kitchen appliances with the arrival of the electricity. *'We now use a refrigerator and sell ice-cream and cold water. We sell a lot of ice-cream'*[178] indicated a store owner who recently purchased a refrigerator. Some users that were able to purchase TV's and DVD players, used their homes as movie theaters. This was also seen in the PVBCS projects in Nicaragua, although the system was not designed for this application: *'We now show movies in the house, and people come to see it and we also sell cold drinks, it's very rewarding'*[179]. Although the majority of solar PV users did not use their systems for income generation, some who could afford it opened small business such as shops in their homes: the ability to open extra hours and have electric light was enough to attract more customers even in the absence of refrigeration. Most store owners with solar PV panels expressed the desire to expand their systems and acquire refrigerators to sell cold drinks and meats.

[176] Hydroelectric user in Puerto Viejo, Nicaragua
[177] Hydroelectric user in Chel, Guatemala
[178] Hydroelectric user in Chel, Guatemala
[179] PVBCS user in Francia Sirpi, Nicaragua

To summarize, DRE systems have allowed increases in income because of reductions in electricity-related costs, improved communications and the creation of businesses that previously existed only in larger municipalities.

Those who already had businesses prior to the arrival of the DRE system noticed a cost reduction in energy expenses as the system displaced use of candles, gas/kerosene lamps and diesel generators. Some users with carpentry or weaving workshops said that the electricity had helped their processes become more efficient, as opposed to not having electricity to power equipment and do everything manually, or with candle light, therefore increasing productivity. Especially in Guatemala, the use of cell phones and cell phone charging has enabled users to communicate and exchange with other markets, thus increasing sales. Increased and improved communications have had a considerable impact on quality of life, energy cost savings and social acceptance indicators. Communications within families and among neighboring homes have improved, as well as between communities, who can now engage in a broader market base for the sale of local products.

Some system users also indicated the DRE system had not only failed to increase income but had caused them to lose income. Especially in Nicaragua, the electricity costs are too high and the benefit of a renewable source of electricity has not been able to offset the high tariffs they have to pay[180]. Frequent system breakdowns were also detrimental to businesses in both countries. For example, a baker said that *'We sell bread. The bread needs 5 hours to rise before baking. After that the bread gets*

[180] Chapter 1 explains the Nicaraguan electricity market and the tariff structures.

damaged so when there is no light, I lose 600 Quetzales.'[181] Users that purchased refrigerators and freezers reported losing meat products because of extended blackouts. In addition to paying high monthly electricity tariffs, they now incur expenses due to loss of products and burnt appliances: *'With all the blackouts, I've lost count of how many TV's and bulbs have been burnt and I have to keep spending money to replace them.'*[182] Lastly, those who sold candles, gas and kerosene have seen a drop in sales as those products are not purchased as often. As discussed in Chapter 4, candles are still used for religious purposes and during blackouts, but the bulk of sales have decreased. A user said that *'We have less income from the candles, but we are starting to have more income from the sale of other products, such as popsicles.'*[183] Of course, new businesses that take advantage of the increased benefits of electricity have flourished.

Interestingly, beneficiaries of PV projects installed for the sole purpose of income generation did not report that their systems provided them with much additional income. Examples of this include the women's weaving cooperative of Chapín Abajo, Guatemala; the visitor's center of the archaeological site in Cancuén, Guatemala; and the PV water pumping system of El Trapiche, Nicaragua. Although the systems have enabled longer work hours and the provision of better service to visitors, there has not been a significant difference in generated income, as explained briefly in Section 5 of this chapter and in the cross-cutting issues of Chapter 6. The women's weaving cooperative of Chapín Abajo, Guatemala does provide lighting to enable longer working

[181] Hydroelectric user in Chel, Guatemala
[182] Hydroelectric user in El Cuá, Nicaragua
[183] Hydroelectric and biodiesel user in Nueva Alianza, Guatemala

hours, however, the longer working hours add to the daily burden of the women who still have to complete their tasks at home. Some women indicated that *'our work hours are much longer as we still have to do all our daily activities at home'*[184] and *'although we have light to work more, we haven't been able to sell that much more since we got the panel.'*[185] The eco-tourist site of Mucbhil'ha and the archaeological ruins of Cancuén, both in Guatemala, face similar dilemmas as the number of tourists has not significantly increased: *'We use the PV panels for lighting in rooms and bathrooms…, but the number of tourists hasn't changed. We can provide a better service, but we would like to see more tourists so we can sustain this project'*[186].

Community applications

Community applications include uses of electricity in places that benefit the community in general, such as in schools, health centers, churches, community centers and public lighting. Most of these places lacked modern energy services and the benefits they provide, prior to the installation of the DRE. For example, and especially for middle school education, students from smaller communities would have to walk long distances to the bigger population centers: *'I want to send my son to study middle school, but he has to walk to Chel, which is about 8 hrs by foot and I don't have enough money for him to live there during weekdays.'*[187] Pregnant women and sick people from smaller, more isolated communities would have to travel long distances by foot to reach fully-staffed

[184] Solar PV user in Chapín Abajo, Guatemala
[185] Solar PV user in Chapín Abajo, Guatemala
[186] Solar PV user in Mucbil'ha, Guatemala
[187] Respondent in Sta. Clara, Guatemala

and –equipped health centers: *'We have a health center, but it's ill-equipped and we have to walk to the muni* (municipality head) *to get better service.'*[188]Community services have benefitted from DRE on multiple levels. For example, users specified the difference between better quality lighting in schools and having electricity for distance education delivery through televisions and VCR's or DVD's. In the case of health centers, high-quality illumination aided in the provision of health services and having electricity to power refrigerators for vaccines or nebulizers for asthma patients was equally significant.

There is however an exception in Nicaraguan schools and health centers. Only schools located in the municipality heads have their electricity paid for by the central government. Rural schools are not included in this program and have to pay for the electricity themselves, with help from parents, or go without. As discussed previously, the poorer families can not afford connections in their own homes, much less in schools; therefore, these remain unelectrified and lack the benefit of a better quality education that other schools are enjoying. A parent said that *'We were excited that the school would have illumination with the hydroelectric project, and if we can't afford electricity in our homes, and we can't afford it either in the school. The school buys electricity from a neighbor when they have a festival.'*[189] In the communities served by the small-scale hydroelectric of El Bote, the managing company indicates that they do not have the necessary budget to help schools cover these expenses.[190] Most of the rural health

[188] Respondent in El Cedro, Nicaragua
[189] Respondent in Sonora, Nicaragua
[190] As explained in Chapters 2 and 6, this Project was financed by a World Bank loan which must be paid. All the income the hydroelectric is generating is used for the payment of the loan and for staff salaries.

centers visited were powered by solar PV panels which were part of a project not included in my research.

The benefits brought by DRE systems to the communities in which they are located varied by technology, except in the case of education. Solar PV users have mainly benefited from having light in community centers, churches, schools and health centers, while hydroelectric users have additionally enjoyed public lighting and a *better economy*, defined in Guatemala as the ability to do business and interact more with neighbors after dark: *'When I have my store open at night, I can sell more things, but neighbors also gather and we all communicate much better now, it's good for the community'*[191]. Although the hydroelectric plants provide public lighting, some communities consider the lighting insufficient. In fact, they complained that the posts are too far apart, blow out often (or are subject to vandalism) and are not replaced. Users said that *'My bill includes a payment for public lighting, but there isn't any lamp near my house'*[192] and *'The lamp closest to my home has been broken two times, people throw rocks at it, it was replaced, but it was destroyed again shortly after that. I'm afraid of growing vandalism here'*[193]. Electricity in churches was also important as churchgoers are able to bring sound equipment and sing and hear music: *'We can now power music instrument in the church and we're all very happy'*[194].

[191] Hydroelectric user in Chel, Guatemala
[192] Hydroelectric user in La Chata, Nicaragua
[193] Hydroelectric user in Xesaí, Guatemala
[194] Hydroelectric user in Chel, Guatemala

In Nueva Alianza, a respondent summarized the communal benefits: *'people are more comfortable, there are teachers working at night. The clinic can take care of more people. There has been an improvement in the education and health of the community. We can take care of medical emergencies at night and there's better performance of students. Now we teach English, computing and typing'*[195]. Another user said that *'the children go to school, the family goes to church and they can sing because there are speakers and a keyboard, and we can all use the health center at night'*[196]. Chel respondents also pointed out the benefits they have received: *'We have improved education and health. We take advantage of the time we have. We have night school, children have improved performance because of the light. In the health centers, energy helps keep vaccines refrigerated. When a baby is born we can take him for shots immediately, before we couldn't do that'*[197], *'Quality of education and health has improved. Before we had a PV panel in the health center, but the medicine would expire faster because it's hot. In schools, we have a morning and a night schedule. We have computers in the professor's house and two or three times per month students go to his house to use the computer'*[198], *'The biggest impact has been a social one. We have never seen energy here, the whole community got organized for a long time, and we saw the results. In schools, there were no TV's and computers, children learn from these now, they can watch videos (educational videos) and they can think something*

[195] Hydroelectric user in Nueva Alianza, Guatemala
[196] Hydroelectric user in Nueva Alianza, Guatemala
[197] Hydroelectric user in Chel, Guatemala
[198] Hydroelectric user in Chel, Guatemala

new. Through the light they can transmit via satellite, the learning levels will improve. Donors can provide equipment that teachers can use'[199].

The projects in Nicaragua were no different as are exemplified by responses received by users: *'Before we couldn't do a study circle at night, since last year, we do it. When something is not understood, we do a study group among students and the teachers helps the students. There is a better development of topics. Without light there are a lot of appliances that can't be watched or used, like movies. We are trying to have more movies this year as we didn't have the conditions to do it before. When we do school festivities, we needed a battery or a genset, and right now we don't have those expenses. With light there is a higher amount of students in the school than working, people of other communities come for secondary school'*[200], *'We can take care of patients at night, they nebulize children, take care of injured and pregnant women'*[201], *'There is more security among the population. In the dark, anything can happen and nobody knows, right now that doesn't happen'*[202], *'In the health center, if there is a very sick patient, the light is useful. In the church we have mass and celebrate. In the school, we can have activities or give class at night. That is not done yet, but we are thinking of giving education to adults'*[203], *'There are more children registered in school. People suggest there could be a night school, to provide another modality or option for education; there are people who can't study during the day because they work. There are better grades: last term, this school had the best students at the department level in*

[199] Hydroelectric user in Chel, Guatemala
[200] Hydroelectric user in Puerto Viejo, Nicaragua
[201] Hydroelectric user in Puerto Viejo, Nicaragua
[202] Hydroelectric user in Puerto Viejo, Nicaragua
[203] Hydroelectric user in El Bote, Nicaragua

the areas of Spanish and math. We did well in other disciplines, like sports and folklore. The light facilitates rehearsing at night. It allows help and lets us give special attention to kids who wish to improve'[204]*, 'There are ideas of self-improvement, people are opening institutes, each community has emergency brigades and use radios to call El Cuá to help at different shelters'*[205]

I also found that under some circumstances, DRE systems did not bring the expected benefits. For hydroelectric system users, the main complaint is that although there is electricity, schools and health centers do not open at night: there is no evening/night school scheduled and health professionals are only present during the daytime, defeating one of the main purposes of electricity provision and one of the benefits about which many users were told initially.

The primary negative responses received are the same as those given by the domestic and productive use beneficiaries described previously: for solar PV projects, batteries are not replaced at the ends of their lifecycles; for hydroelectric projects, technical failures lead to frequent blackouts.

Public lighting was perceived both positive and negatively. While some locations report a decrease in crime rates, mainly theft, since the arrival of electricity, others *perceived*[206] an increase in crime as more people gather out late at night.

[204] Hydroelectric user in El Cuá, Nicaragua
[205] Hydroelectric user in El Cuá, Nicaragua
[206] These are only perceptions as existing police stations, where they exist, have not reported an increase in crime.

Although we can conclude that the DRE systems have improved life quality, whether they are domestic, productive, or communal applications or a combination of these; responses from those who do not benefit from electricity might indicate that the provision of renewable energy may create or increase inequality in the communities. This was evidenced within communities and municipalities, as the most prosperous families are able to increase their income by starting productive enterprises which the poorer families cannot afford. Furthermore, the few micro-financing schemes available are not accessible for the poorer segments of the population, further highlighting this inequality.

At the household level, and especially in the case of hydroelectric plants, lower income families could not afford to connect to the grid as the upfront cost is high so they continue to use candles, gas, kerosene, and torch pine. Even though their current energy expenses represent a higher percentage of their income, they do not have any other alternative as the financing schemes announced by the hydroelectric companies or associations are not implemented: *'I've asked about paying in installments, and they say yes, but then they do not come'*[207], and *'I asked for a payment plan, but the company says they currently do not have funds and can not help me'*[208]. Primarily in Nicaragua, some users also indicated that if they could afford paying the connection fee they would not be able to afford the monthly tariff as it is very high. As explained in Chapter 1, the electricity tariff structures in Nicaragua differ between the concession

[207] Hydroelectric user in Puerto Viejo, Nicaragua
[208] Hydroelectric user in Abisinia, Nicaragua

zones of the monopolistic utility and those that do not belong to the utility, putting those companies and communities outside the concession zone at a disadvantage.

Although these lower income families do not benefit with household connections, they do benefit from the communal energy services, such as public lighting and illumination in stores. During the interviews, these families asked if they would get a donated solar panel, battery or any other renewable source of energy, which opens a new question. These communities are already considered to be electrified. Will national or international aid reach the unelectrified homes within these communities? Since many rural renewable energy donors tend to work in communities that are completely unelectrified, have the hydroelectric projects closed the door for these poorer homes to obtain some kind of assistance in obtaining a modern energy source?

In El Bote, half of those interviewed who are not connected to the mini-hydroelectric project stated that the connection costs and monthly tariffs were prohibitively high. The remaining respondents stated they had 'no money': independently of the connection costs and monthly tariff, they cannot afford electric power. These families manage their budget day by day and their expenditures on energy sources change according to the season. Two respondents said that land tenure problems were the main reason they did not connect to the project. For example, a woman said *'my boss owns this land and lets us live here, but he did not pay our connection. What will we do the day we move to our own land'?*[209]

[209] Non user from Sonora, Nicaragua

The case study of Chel is somewhat different. Sixteen respondents are not connected to the hydroelectric system because of high connection costs and monthly tariffs, and they lacked cash. An additional fifteen families stated that they could not afford service due to illness. As explained previously, all or part of connection costs could be offset by providing labor during the construction phase, but these respondents were ill at the time or did not believe in the project: *'my husband was sick and could not work'*[210] or *'I am a widow and only have five daughters, I wish I had a son who could have worked for the family, but with only females, it is not possible'*[211]. Although the Hydroelectric Association of Chel has a payment plan for those who can not afford paying the entire fee at once, it is rarely used. Those wanting to connect cannot afford the fee even with a payment scheme.

In communities benefiting from solar PV panels, the responses were very similar among different projects: sixteen families without the service said it was because their system broke down while another sixteen indicated they had sold the system. Robberies were not very common, but were reported in four homes, while an additional four stated they could not replace the battery, mainly because of cost issues. The only difference in responses corresponds to the disaster reconstruction project of Cahabón, in which more than 60% of the systems were sold within a year of their installation.

The majority of the respondents were former users of systems. Except for those in Cahabón, most of them still had the systems in their possession but were not in use,

[210] Respondent in Chel, Guatemala
[211] Respondent in Chel, Guatemala

which was traced to several factors: lack of appropriate training and information, lack of adequate system maintenance, lack of funding to replace parts[212], long distances to population centers that would have the parts, and theft.

These responses are explained in greater detail through the cross-cutting issues presented in Chapter 6 and are only briefly analyzed here.

Results highlight the impact of DRE on the human, physical and financial capitals of the SRL framework. Although there are still areas that require improvement, such as having sufficient education and health professionals, the DRE systems have brought much-needed basic infrastructure that would otherwise not exist. The results I found in Guatemala and Nicaragua are consistent with case studies from other parts of the world that stress the importance of having modern energy access, specifically through renewable energy systems for a variety of domestic, productive and communal applications (Islam, Ruhul Amln & Sadrul Islam 2006, Islam, Islam & Amin 2005, Acker, Kammen 1996, Ley et al. 2006a, Ley et al. 2006b). Although not specifically included as an asset, happiness was a major factor for the success of DRE systems. When asked the main benefit of the DRE systems, many responses were related to their level of happiness, confirming the finding of Uddin, et.al. (2007) who developed a case study of Bhutan's approach to renewable energy use through the Gross National Happiness (GNH). This study states the GNH as 'a tool to balance poverty alleviation, environmental conservation and development' (Uddin, Taplin & Yu 2007).

[212] This is especially true for batteries, which have a shorter life when the charge controller is bypassed. I found this to be a common problem.

The range of benefits derived from the use of DRE systems was not equal among users as the middle and upper classes among the rural poor were able to better take advantage of the productive uses and alternate income generation sources that were enabled. Although DRE systems are in many cases the only alternative for isolated communities to obtain modern energy services, the rural lower class is not always able to afford the start-up of or upkeep of these services. These findings are not exclusive to the two countries studied in this dissertation. Jacobson's (2007) study of Kenya's unsubsidized solar photovoltaic market had similar findings to the ones presented in this chapter, especially those related to the potential increase of the rural inequality gap with the arrival of DRE (Jacobson 2007). Additionally, Jacobson found that the solar energy mainly enabled connectivity through the use of TV's, radios, and cell phones, a trend that has been increasing exponentially in Guatemala and Nicaragua with the arrival of the renewable energy systems, also confirming the findings of Hanley, et.al (2002) (Hanley et al. 2002). As observed, increased use of cell phones, cell phone charging, radios, TV's and in some cases internet, has enabled connection to urban centers and other markets to which rural merchants can sell their products.

5.5.1.2 Energy Savings

Different percentages of energy cost savings were evidenced in all the projects. Similar to the emissions reductions calculations presented in Chapter 4, it is not possible to make a level comparison between all the projects due to their different circumstances, contexts and backgrounds. Most importantly, there is not enough information to make a

quantitative analysis or to create the energy cost profiles originally planned. Most of the energy costs obtained, especially from energy sources prior to the DRE system, were guesses by the users. Users indicated that their expenditures on energy sources varied during the year as their available income is highly dependant upon the harvest season. However, I was able to infer a trend in energy cost savings based on the type of DRE used and the type of energy source displaced. The results are shown in Table 35 and do not take into consideration the difference in energy quality.

Table 35. Amount of energy cost savings based on type of DRE used and type of energy source displaced

Previous Energy Source/Current Energy Source	**PV**	**Hydroelectricnot grid connected**	**Hydroelectric grid connected**	**PVBCS**	**Biodiesel**
Traditional	High	Average to high	High	Low to average	High
Fossil	NA	Average to high	Depends on the grid mix, and country interconnection laws and tariffs	NA	Average to high
DRE	NA	Average to high	Depends on the grid mix, and country interconnection laws and tariffs	NA	NA

Note: The cost savings of grid connected RE systems can be contentious, especially in Nicaragua because of the form the concession and non-concession zone tariffs operate.

Solar PV users have high energy cost savings as the monthly tariff they have to pay, or the money they spend on doing their own maintenance, is generally lower than their

previous expenses on candles, gas and kerosene. Although families still purchase batteries for flashlights when they need to go out, their expenses have decreased. Hydroelectric users, independently of their previous energy source, report average to high energy cost savings. The amount of cost savings depend predominantly on the number of blackouts and the number of new appliances or equipment that have been purchased since the installation of the DRE system and which run on fossil fuels for the duration of the blackout. The energy cost savings of the PVBCS are low to average, mainly because some beneficiaries use their batteries improperly. Families that use the batteries for the specified applications, such as the CFL's and a small radio or black and white TV, do enjoy energy savings. Families that use the batteries for TV's, DVD players, and refrigerators, wear the battery out faster and need to recharge it and pay more often. The life of the battery is drastically cut short when it is *abused*, and these families cannot afford a replacement; therefore, towards the end of the life of the battery, users pay for the service to recharge their batteries in addition to their previous energy source. Finally, the biodiesel project has great potential to provide more energy savings; however, it is dependant upon the cost of the raw material from which the biodiesel will be produced. In this case, the community purchases recycled oil and the price has been increasing to the point that the biodiesel production cost is almost equal to that of diesel. A community leader said that *'we strongly believe in renewable energy, we don't want to use fossil fuels, but we can't afford the restaurant's costs for recycled oil. As soon as they found out we produce biodiesel they kept increasing and increasing the cost. We want to do our own jatropha plantations so in the future we can*

produce our own raw material and not depend on the restaurant or on anyone else anymore[213].

Table 36 summarizes the energy cost savings by case study.

Table 36. Summary of energy cost savings by project.

Project		Cost Savings	Comments
Guatemala	Nueva Alianza	X	Nueva Alianza has managed to almost eliminate all their fossil fuel consumption with their DRE systems. Although diesel is still consumed, its use is minimal and they have reported significant cost savigns.
	San Jerónimo	Grid connected	As the surrounding communities are grid connected, they are subject to the dispatch and tariff of the country. They pay the tariff and receive the same quality electricity, therefore, they don't report any savings from the hydroelectric plant.
	Chel	X	Although they still consume fossil fuels and other traditional energy sources during blackouts, they have overall been able to report considerable cost savings.
	Cahabón	The majority of the systems do not work anymore	Most users don't have their PV systems anymore, either because they stopped working or were sold, and have returned to using traditional energy sources. During the time the PV systems were working there were cost savings, but that was short lived.
	ADIM PV	X	Unlike the PV project of Cahabón, a higher number of systems under this program are still working and users do enjoy cost savings. The only energy source they still have to purchase separately are batteries for flashlights for when they go out at night.
	Cancuén	Project exists because of RE system	The visitor center for this archaeological site exists because of the DRE system.
	Chapín Abajo	FDN maintains system	The women's group that benefits from the solar panel does not see cost savings as they do not maintain the system. The environmental NGO that brought the system to them has been responsible for its upkeep.
	MEM PV	X	A high number of systems under this program are still working and users do enjoy cost savings. The only energy source they still have to purchase separately are batteries for flashlights for when they go out at night.
Nicaragua	PVBCS	Based on how users use the charging stations and the frequency with which batteries are charged	The energy cost savings in this case study varies considerably among users. Those who use more appliances, discharge the battery faster and therefore spend more money recharging it.
	El Trapiche	Donor maintains system	Users do not perceive any savings as the donor is in charge of all the operation and maintenance.
	Río Bravo	Cost of energy higher than national utility, but lower than diesel generators or traditional biomass	As explained in Chapter 1, users outside of the concession zone of the utility pay a higher tariff for electricity. As compared to diesel generators or traditional biomass sources, users do perceive savings. Those who do not is because they purchase diesel to run their generators when the DRE system is offline.
	El Bote	Cost of energy higher than national utility, but lower than diesel generators or traditional biomass	As explained in Chapter 1, users outside of the concession zone of the utility pay a higher tariff for electricity. As compared to diesel generators or traditional biomass sources, users do perceive savings. Those who do not is because they purchase diesel to run their generators when the DRE system is offline.
	Women's solar center	Project exists because of RE system	The visitor center for this archaeological site exists because of the DRE system.

To summarize, greater energy cost savings were hampered by the high number of blackouts. Families that can afford it run their operations with diesel generators while the poorer families revert to using candles, flashlights and gas or kerosene. For the

[213] Respondent from Nueva Alianza, Guatemala

former, it implies higher expenses on fossil fuels, which is already more expensive in rural areas; while for the latter, it represents a problem as they are paying for more than one energy source and can not always afford it.

In most cases, paying (or saving) a monthly fee, whether it be for battery replacement, the monthly tariff or any other required maintenance was cheaper than their previous energy source. Although this was recognized by some non-users, they admit it is difficult for them to save a monthly amount as oftentimes there are more pressing needs, such as when they lose a crop or a child gets sick and the money they save is used otherwise. Chapter 6 explains the difference in savings culture between countries and regions of the countries, specifically populations with cash flow versus those without cash flow, which I found to be key for DRE system sustainability.

Finally, the use of pirate equipment hampers energy cost savings. Although some of the projects followed technical and quality norms and standards, some systems were substandard. Initially cheaper and representing lower up-front costs, they break down faster requiring more frequent replacements than can be afforded. Like in the previous cases, when the DRE system stops working, users go back to using their previous energy source.

5.2 Social Acceptance

The indicators used to measure social acceptance, described in Section 4 of this chapter, constitute a subset of the project success drivers discussed in Chapter 6. In

this section I briefly discuss the implications of these indicators on the projects' meeting poverty alleviation and improved livelihoods goals.

Sufficient and appropriate training is one of the indicators used. A project can be deemed socially acceptable if the training is seen by the community to be sufficient and enables them to properly care for their systems. Results demonstrated that when there was a lack of appropriate or sufficient training, users would not be able to solve the problems that arose with the DRE systems, causing users and non-user neighbors to lose confidence, and consequently, acceptance of the technologies.

Lack of sufficient training became more evident with solar PV users when they did not give the appropriate maintenance to their batteries. For example, a user said *'I went to buy distilled water but the man at the gas station sold me battery electrolyte and that is what I'm using, but it is very expensive'*[214]. In reality, the so-called *battery electrolyte* does not extend the life of the battery and the gas station was trying to make more money out of solar PV system owners who they knew were not properly trained on the care of the equipment or who were themselves unaware of appropriate battery maintenance. Although this topic is discussed further in Chapter 6, the inappropriate handling of batteries can cause environmental, health and safety hazards as they are made of toxic material, mainly acid, that can explode and cause burns and other injuries to its users.

[214] Solar PV user in La Bolsa, Guatemala

The longstanding recommendation within the DRE practitioner community of having governance structures[215] in place to ensure long-term sustainability of DRE systems did not always prove to be true. This especially occurred in the case of stand-alone photovoltaic systems where governance structures were implemented, but did not always bring the expected results. In these cases, families preferred to handle their own monthly savings rather than pay tariffs to elected community representatives. Oftentimes, this method of self-savings was successful in ensuring functional systems. In war stricken areas, one explanation for this occurrence might be the lack of trust, explaining why self-saving methods were successful. One unusual case is based in a Guatemalan community in northern Quiché. The community pays a monthly tariff to their elected treasurer; however, they are not aware of the benefits that they are entitled to, such as battery replacement and technical assistance from the community's trained technicians should they require it. Additionally, the same community has encountered other trust problems with the treasurer: *'The guy that we had as a treasurer took all our money and wanted to go como mojado[216] to the U.S.'*[217] Results in hydroelectric projects were different because the role of a governance structure, whether a company, association, or committee, is relevant for the overall management and functioning of the plant. The same can be said for the lone biodiesel project included in this study. We

[215] Jeff Haeni and Debora Ley, 'Using Renewable Energy to Promote Ecotourism', USAID Case Study (2004), published on the Internet at www.usaid.gov/our_work/economic_growth_and_trade/energy/publications/success_stories/guatemala_ecotourism.pdf (last accessed on 7 April 2010); Brian Smith, 'Informe General Sobre Capacitaión Lavadero Communal, Sepalau y Sepoc II, Chisec, A. V.', USAID (2005), unpublished document; Brian G. Smith and Debora Ley, 'Sustainable Tourism and Clean Water Project for two Guatemalan Communities: A Case Study', 248 *Desalination* (2009), 225-232; Jeff Haeni, Debora Ley and Iván Azurdia, 'Promoting Tourism, Protecting Human and Environmental Health', USAID Case Study (2005), published on the Internet at www.usaid.gov/our_work/economic_growth_and_trade/energy/publications/success_stories/guatemala_tourism.pdf (last accessed on 7 April 2010); Fundacion Solar 'Micro Central Hidroeléctrica Chel', 2005; Asociación Hidroeléctrica Chelense 'Memoria de Labores', 2001-2002, unpublished document

[216] Wanted to cross illegally into the United States. Literally "went as one who was wet."

[217] Solar PV user in Sta. Clara, Guatemala

can then conclude that one of the differentiating factors is the centralized or decentralized nature of the infrastructure itself: stand-alone PV systems can be cared for at the household level, which does not hold true for the biodiesel or hydroelectric plants included in this study because of their scale. In conclusion, the relevance of the governance structure for system success varied between locations and the renewable energy technology being used, but I did confirm the finding of Kammen (1999) that DRE systems can bring great benefits to users if the 'right institutional framework' is applied (Kammen 1999).

Community participation remained an important factor for the functioning of the systems throughout the interviews, and in a similar case to the definition of *governance structure,* community participation meant different things to different communities. Some wished to be actively involved in project management: '*We are part of the association and we have a right to make decisions about our project, and that is the way it should be. This is our project*'[218], and *'I bought a stock of the Hydroelectric company, it is my right to vote and decide the future of the project and the company.'*[219] Others wanted to be informed rather than actively involved in decision-making: *'I just want to be informed about the project, we are paying a fee and the least they can do is keep us informed; we want to know what is happening'*[220]*.* While in some Guatemalan communities, *community participation* meant to be able to make project-related decisions, some users in Nicaragua communities considered it to be informed of the happenings of the project.

[218] Hydroelectric user in Chel, Guatemala
[219] Hydroelectric user in El Naranjo, Nicaragua
[220] Hydroelectric user in Sonora, Nicaragua

The ability to resolve conflicts related to the DRE systems is also dependant upon the governance structures, the existence of rules and norms, and how well these are enforced. Respondents did not report any religious or cultural conflicts. On the contrary, some people thought *'the project was an Act of God'*[221]. Respondents did indicate the existence of *social conflicts* related to DRE systems, such as between community members who do not benefit and those who did, or with those who use systems inappropriately to the detriment of other users.

Lack of cooperation, lack of payment and inappropriate use of technology are the main reasons conflicts arose in certain communities. Lack of cooperation might be caused by not attending the required meetings and assemblies; however, not attending meetings might also be evidence of non-cooperation. For example, a user indicated that *'not everybody cooperated; a lot of people didn't like the project. There are men that didn't want to work and now they want the light. More than half of the community didn't work'*[222]. Lack of payment is mainly attributed to users who feel they should not be paying a tariff because of frequent blackouts, or people who are behind in payments due to financial difficulties such as poor crop returns. For example, a solar PV user said that some of his neighbors *'got mad when we insisted they had to pay 20Q and they provoked problems with the community energy committee. They say it was government support and the Comité took the money'*[223]. Another respondent, a community-based technician, said that *'there are many blackouts, some components stop working and people don't want to pay so we don't have enough income to make needed repairs and*

[221] Hydroelectric user in Chel, Guatemala
[222] Hydroelectric user in Chel, Guatemala
[223] Solar PV user in Gualibaj, Guatemala

people get mad at us'[224]*.* Among hydroelectric projects, users who do not pay their tariff for a certain number of months are often cut from the grid. Removing delinquent users can cause conflict with them, whereas failing to remove them can cause conflict with other users who resent others' free riding. Lastly, inappropriate use of energy refers to users who do not follow agreed-upon rules. For example, in the community of Nueva Alianza, the micro-hydroelectric system is relatively small and all users are limited in the appliances they may use in order to limit energy consumption. A single user may overload the system, forcing it offline, and causing a general blackout. In this example, the user is fined and, after multiple fines, will be disconnected from the grid. However, these actions cause conflict between the censured user and neighbors. For example, a user said that *'there are people who don't have light; there are people that use more bulbs than they should and use sound equipment very loud. The bad use of energy is the main reason (for the conflicts). We have conflicts because people don't obey what they are told'*[225]*.*

Lack of faith in or dislike of the project was a barrier to social acceptance mainly seen in areas affected by civil conflict because of the lack of trust that exists within communities and between community members and outsiders. Additionally, the false expectations created by some potential donors and developers in the past make community members wary of foreigners. A respondent stated that *'we should be consulted; we should be asked what we want and not have people do things behind our backs'*[226]*.* This was particularly important in Chel; a number of families did not believe the project would

[224] Technician in El Bote, Nicaragua
[225] Hydroelectric and biodiesel user in Nueva Alianza, Guatemala
[226] Hydroelectric user in Chel, Guatemala

actually exist and did not contribute labor hours. When the project started operating, they were required to pay the connection fee and they could not afford it, also creating a source of conflict. A non-user respondent indicated that *'Many of us don't have energy yet because we aren't able to pay it, but we still need it, we are still poor, there are many people in disagreement over the Committee and how they handle sanctions.'*[227]

Perception of users towards the system and the consistency between their expectations and the donor's goals had an impact on the systems' overall sustainability. Like the previous issues, this is discussed in more detail in Chapter 6. The clearest example of this is the PVBCS project in Nicaragua, in which the communities requested, and were promised, individual PV lighting systems; however, the donor decided to install PVBCS. The users (about 1/3 in each of the five beneficiary communities) are not happy and the batteries have, in the best cases, lasted half as long as manufacturers' stated lifetimes under normal maintenance conditions. Some households do not take proper care of their battery hoping stand-alone PV systems will be donated. Here, we can see a clear relationship between expectations and system sustainability. Respondents said *'We wanted a PV panel in each home, and they promised it to us, and we are spending a lot of money charging batteries'*[228]*, 'Are you going to donate us the solar panel we were first promised? Or can you at least give us a new battery? We would really want to have our own PV panels so we can have our own businesses'*[229]*.*

[227] Hydroelectric user in Chel, Guatemala
[228] PVBCS user in Francia Sirpi, Nicaragua
[229] PVBCS user in Francia Sirpi, Nicaragua

One of the main barriers to social acceptance and greater energy cost savings were the blackouts users of DRE technologies faced due to technical failures, either caused by poor quality components and installations or poor system governance. Systems that were installed using low-quality equipment often caused not users and others in their communities and social networks to lose trust in DRE technology.

Although all these topics are discussed in Chapter 6, it is important to highlight here that the use of low-quality components is a problem faced in many countries and has caused lasting negative impacts. Duke et.al. (2002) provide the example of the hardships that Kenya's solar PV users face when they purchase cheaper equipment, and conclude that the mandatory enforcement of international standards will provide 'stronger assurance' to users (Duke, Jacobson & Kammen 2002). Similar findings exist for Mexico and Central America and diverse efforts have been carried out for norm and standards compliance, although much work is still needed (Ley et al. 2006a, Ley et al. 2006b, Hanley et al. 2002, Foster 1998). Some studies suggest the local manufacture of PV systems to increase market share (Moner-Girona et al. 2006), however, there is no discussion about their code compliance nor or quality control, raising once again the question of health and safety hazards towards users.

5.3 Environmental Responsibility

As explained previously, the only indicator used to evaluate environmental responsibility was the adequate disposal of solar PV system batteries. Most training sessions focused

on the proper care and maintenance of the batteries but very few discussed proper disposal. Discussed in more length in Chapter 6, I also found sufficient and adequate training to be a factor for environmental responsibility. Users whose systems had been installed more than three years prior to the interviews did not remember exactly what they were taught in the training sessions. Users would store their old batteries, discard them in the mountain or give them to their children to play with without being aware of the real consequences: *'I gave the battery to my two boys to play with and take apart, they are having fun playing with it'*[230].

Table 37 summarizes the poverty alleviation indicators for all the projects included in the research, with the 'x' meaning that the project met the indicator. The early warning systems projects are not included in the table, because although they can directly help meet poverty alleviation goals, they were not analysed for these indicators.

[230] Solar PV user in Chiis, Guatemala

Table 37. Summary of poverty alleviation indicators

Project			Poverty Alleviation and Improvement of Livelihoods				
			Poverty Alleviation		Social Acceptance		
			Quality of Life	Cost Savings	Consistency with local context	Consistency of expectations	Governance Structure
Guatemala	D	Nueva Alianza	Improved dramatically for domestic, productive and communal applications.	X	X	X	X
	CDM	San Jerónimo	Not perceived by the surrounding communties because of the project	Grid connected			
	D/VCO	Chel	Improved dramatically for domestic, productive and communal applications.	X	X	X	X
	A	Cahabón	Improved during the short time the solar PV systems were working because there was better quality lighting	The majority of the systems do not work anymore	X	X	
	D	ADIM PV	Improved mainly at the household level, although some businesses were started	X	X	X	X
	D	Cancuén	Improved for those involved in the tourism project, although the benefits were expected to be communal	Project exists because of RE system	X		X
	D	Chapín Abajo	Improved for the women involved in the weaving cooperative, although they have not had much additional income	FDN maintains system	X	X	X
	D	MEM PV	Improved mainly at the household level, although some businesses were started	X			X
Nicaragua	D	PVBCS	Improved for those who were benefited with an lighting kit, although most of the batteries completed their life cycles prematurely.	Not clear based on how users use the charging stations and the frequency with which batteries are charged			X
	D	El Trapiche	Improved only because the community receives potable water during climate hazards. The project has created internal conflicts and the land available for crops is only sufficient for self-subsistence.	Donor maintains system			X
	D	Río Bravo	Improved dramatically for domestic, productive and communal applications, especially for those users who used to rely on traditional energy sources	Cost of energy higher than national utility, but lower than diesel generators or traditional biomass	X	X	X
	D/CDM	El Bote	Improved dramatically for domestic, productive and communal applications, especially for those users who used to rely on traditional energy sources.	Cost of energy higher than national utility, but lower than diesel generators or traditional biomass	X	X	X
	D	Women's solar center	Improved communications and social relations among women in three communties	Project exists because of RE system	X	X	X

Note:
D means Development projects
A means adaptation projects
CDM means Clean Develoment Mechanism projects
VCO means Voluntary Carbon Offset projects

5.5.4 Case Studies

The selection of case studies below show specific details of how the projects met, or failed to meet quality of life, energy cost savings, and social acceptance goals.

5.5.4.1 Contrasting Development Projects: Nueva Alianza micro-hydroelectric and biodiesel projects, Chel mini-hydroelectric plant, Francia Sirpi and Awastingni PV Battery Charging Stations, and Totogalpa's Women's Solar Center

The following case studies contrast the implementation approach taken by the communities, local development organizations, and international donor agencies in primary development projects.

Nueva Alianza micro-hydroelectric and biodiesel: Community members feel that the DRE systems have helped them achieve development goals. The community-owned and -managed DRE projects have enabled their local income-generation activities (coffee and macadamia nut production, water purification for retail sale, and local eco-hotel accommodation), facilitated the *finca's* management by powering office equipment, and provided light and electrical outlets for limited appliances in homes, and community applications including the communal store, school, church and the health clinic. With the income generated from economically productive activities facilitated by

DRE, they have been able to make progress in paying off the loan they obtained to buy the finca. The remaining income is divided: people get paid based on how they work and on their positions. As such, management type personnel earn more than those who work on the specific projects. Furthermore, a small reserve is managed communally to help individuals with financial burdens associated with illnesses, deaths and celebrations. There has not been any major resentment or social tension except for the misuse of the DRE systems by some families. One of the unconnected families expressed that *'We are happy because the rest of the community is able to benefit. We have the (income generation) projects and we have a job'.*[231]

Chel mini-hydroelectric project: Tremendous development has been observed in Chel as the project has also represented a shift in perceptions and a way of thinking and working. Besides providing a modern source of energy, the DRE system has helped build trust and enabled additional projects: the construction of a road to the community, solar PV satellite phone service, and numerous productive uses. Four wheel drive vehicles can now reach the community, in part because of the new hydroelectric plant being built, allowing trade with urban centers, the nearest being two hours away by vehicle. Many businesses have been created, many relying on electric-powered grain mills or refrigerators. Other productive use applications include carpentry workshops, a tire repair shop, pharmacies, several stores selling electric spare parts, a stationary shop with a photocopy machine, a hot dog vendor, bakers, a hotel and some stands selling pirate DVD's.

[231] Respondent in Nueva Alianza, Guatemala

The Hydroelectric Association has been empowered and is able to manage the system. They are decreasingly dependant on the local NGO that was involved throughout the entire planning and implementation process, and are improving their technical, management, financial and computer skills. They were able to secure funding that will, in the near future, enable the creation of additional micro-enterprises. As this chapter was being written, they had extended their grid to ten additional communities.

It is not clear whether users are spending a lower percentage of their income on energy. Electricity provision has certainly enabled productive use applications and alternate income sources, as well as the use of electricity consuming appliances. Having said this, people seem happier with the electricity, although the blackouts caused by failures in the plant have prompted users to complain, especially those who have refrigerators as they lose produce and, therefore, income.

Francia Sirpi and Awastingni PV battery charging stations: This project has improved the quality of life of its beneficiaries as users enjoy better quality lighting. Some households have opened stores, bars and even movie houses with TV's and DVD players, although these are not suitable applications for the system type[232]. Despite providing these benefits, the project has also created internal social conflicts as only one third of each community is a beneficiary. Users indicate they had requested stand-alone individual systems and are not entirely satisfied with the charging stations.

[232] As detailed in Chapter 6, misuse of the system can be a cause of lack of training and understanding of the system and may be a cause of social tension which could lead to the failure of the systems.

Instead of saving for battery replacements, some families are seeking donations as their current project is not what they had expected and were promised.

PV battery charging stations '*can be abusive both to the technology and the people: the battery doesn't get charged when it's supposed to, drastically shortening the life of the battery. People have to carry the battery, sometimes over long distances, to the charging station. During the rainy season, they have to carry it through the mud and people can get hurt*'[233].

Both communities have experienced social tensions related to the projects. For example, when Hurricane Felix hit the region, it damaged some of the charging stations and destroyed some of the houses. Not all home installations have been repaired, and not all homes have been rebuilt. It remains unclear how the homes which systems were repaired/rebuilt were chosen and that in itself is a cause of tension between system users. Some of those whose installations have not been repaired complain they expect better service because they have paid all their fees. One of the rules defined within the governance structure that was created was that the technicians in charge of the charging stations should help pregnant and elderly women carry their batteries. Unfortunately, this has not happened and has resulted in several women getting hurt while hauling the 70 lb. batteries and has also caused damage to the batteries. To conclude, there are factors within this project that have both improved and worsened quality of life. A more detailed analysis of this case study is shown in Chapter 6.

[233] Interview with Robert Foster, New Mexico State University, on April 18th, 2009. Mr. Foster provided technical assistance to this project.

Woman's Solar Center of Totogalpa: The women built a solar center that houses most of their activities and is powered by home-made PV panels used for illumination and for powering office equipment. They currently build solar ovens and PV panels and want to expand their production. Proof of their development has been the awards they have received from national and international agencies, such as from the United Nations Development Programme, to continue strengthening the group's activities. A committee member summarized the impact of the project: *'We feel empowered, we know we can achieve what we set out to do, we all work together and we are happy promoting the use of renewable energy to other communities and open our homes to volunteers from other countries that come help us'*[234].

5.5.4.2 Carbon Project: San Isidro small-scale hydroelectric plant

This case study highlights the approach taken by a primary climate change mitigation project in meeting development and poverty alleviation goals.

In this project I observed a lack of consistency between the perceptions and definition of development of the community and the perceptions and definition of development of the utility company. The communities surrounding the hydroelectric plant are connected to the grid; therefore, they do not perceive any differences in quality or cost between renewable and fossil-generated energy. One important aspect of analysis of this project

[234] Solar PV user in Sabana Grande, Nicaragua

is the poverty alleviation perception of the communities: despite this being an energy project, energy provision is not among the communities' priorities. Their main concern is water supply: the communities depend heavily on water for irrigation and their water supply had a number of disruptions because of the hydroelectric plants storing water in their dams for peak hour generation. Therefore, the communities would like to see improvements to the current water management agreement to better serve all watershed users, as one already exists. Additionally, they would like the utility company to contribute more to road maintenance. For example, a community member said that *'They drive on these roads with their heavy trucks loaded with material and they damage it and then they leave us with broken down roads that get ruined easily in the rainy season. They should do a better job of maintaining it. This is what we want but they don't listen'*[235]. While the utility contributes to a limited degree to road upkeep, it meets its stated goals of development and poverty alleviation by working in local schools (contests among students on the topic of renewable energy, painting or refurbishing the buildings) and health projects. Another community member expressed *'yes, we are happy with their school contests, and sometimes they help us with school projects we need, like when the building needed to be painted, but they still need to cooperate more with the roads'*[236].

The utility states that it is meeting development goals as they have been certified and validated under the CDM process. Because of this, representatives refused to be interviewed as they consider this study to be 'redundant'. In conclusion, the main

[235] Respondent in Matanzas, Guatemala
[236] Respondent in Matanzas, Guatemala

challenges this project faces in terms of poverty alleviation and improved livelihood goals is the lack of consistency between the expectations, perceptions and goals of the communities and the utility.

5.5.4.3 Climate Change Adaptation Project: Cahabón Disaster Relief and Reconstruction

This case study highlights the approach taken by a primary climate change reconstruction project in meeting development and poverty alleviation goals.

The solar PV panels, designed for the use of two compact fluorescent lights, installed in the communities of the municipality of Cahabón in Guatemala, were part of a bigger reconstruction effort following the aftermath of Hurricane Mitch. Respondents indicated an improved quality of life with the systems as they could see better with the CFL's and could hear news; however, this improvement only lasted one year at most as, according to community members, approximately 80% of the systems were sold within the first year of installation of the systems[237]. The lack of proper training on system use and maintenance is the main reason this project had little success. As it was a reconstruction project, the funds had to be spent within a year, marking a sharp distinction with the way development programs are carried out. The few homeowners who still have their panels are happy with them; while those who sold the system or had them robbed wish to get a new one as *'living again with candles is not the same*

[237] The problems leading to this are described in Chapters 2 and 6

anymore[238]*'*. The implementation process of reconstruction projects needs to be improved; however, I would like to highlight in this specific case study that there is a high potential to meet poverty alleviation and improved livelihood goals had users been consulted on whether solar PV systems were a priority and had the proper implementation mechanism been used.

5.5.4.4 Development and Carbon Project: El Bote mini-hydro

This case study highlights the approach taken by a joint development and carbon project in meeting development and poverty alleviation goals.

The municipality heads have mainly benefited from energy cost savings as their prior energy source was diesel based. The middle and higher income households have benefited from the project to a higher degree as they are the ones able to afford the connection fee and as such have access to electricity. There are numerous stores and other productive applications such as grain mills, carpentry shops, soldering equipment, and mechanical workshops. Despite the evidence of poverty alleviation and improved livelihood goals being met, there is fear the project may be increasing the inequality gap because the lowest income households are still unable to pay for the connection fee, and thus, remain unelectrified.

[238] Former solar PV user in Seazir, Guatemala

The results differ for the municipality head of El Cuá as they used to have a micro-hydroelectric plant, switched to diesel generators when their micro-hydroelectric was destroyed by heavy rains, and finally connected to the national grid when the El Bote project was being built. Which energy source was more reliable is debatable, but the interviewees suggest it was their original micro-hydroelectric plant as the current one still has many blackouts[239]. El Cuá has seen the development of numerous micro-financing offices which have opened to facilitate productive use activities. According to the beneficiaries, this is mainly due to the arrival of the project. A local solar company has made considerable profit in the surrounding communities by selling solar systems to the unelectrified homes, providing financing schemes to help some of the families acquire a solar PV system, and offering other services that people connected to the hydroelectric plant also take advantage of, such as a range of AC appliances and cable TV service. It is unclear how many of the families that were not able to connect to the hydroelectric have a solar panel as many of the unelectrified families interviewed still use candles and gas lamps and, despite the financing schemes provided by the solar company, still can not afford changing energy source.

5.6. Summary

The results indicate the value of DRE systems in improving the livelihood assets as portrayed through its five capitals.

[239]The blackouts are due to the bad condition of the grid which needs an overhaul. The connection point is particularly weak causing El Bote to go off-line. The hydroelectric has started operating as an island, however, the plant does have some technical failures. Although they have been decreasing, they are still causing power outages. This situation is discussed in more detail in Chapter 6.

The ***quality of life*** indicators show that DRE systems can help improve human, physical and financial capitals.

Financial capital was enhanced because of the number of productive use applications enabled by modern energy sources. Alternate productive applications have helped increase the income of some families and create new jobs. Management and long-term upkeep of the systems have also encouraged the creation of savings mechanisms, whether for system operation and maintenance of replacement of batteries for solar PV users.

The DRE systems have brought in needed or improved infrastructure to rural communities. As evidenced through the results, the majority of the communities used traditional energy sources, and the renewable energy infrastructure has enabled a number of services and products. Furthermore, the DRE systems have helped the introduction of new technologies and household appliances, helping to build up *physical capital.*

Finally, quality of life indicators also showed an impact on *human capital* at the domestic, productive and communal level. The main benefit perceived by all the users was a better quality of lighting which was impacted in a number of ways: ability to see loved ones over dinner, work and/or do homework at night, cook in the morning, and visit with neighbors after dark. Additional benefits perceived by the users were

improved services, such as public lighting, education[240] and health care[241] services. Some schools have taken advantage of the electricity to bring in new equipment, such as TV's and VCR's to use distance education material available in other parts of the country[242].

With the arrival of the DRE systems, villagers have had to learn about the technology and in most cases are in charge of the system's operation, maintenance and management. Throughout the process they have learned different technical, administrative, financial, and accounting skills. Skills and knowledge have also been improved with the new jobs and income generation alternatives they have created.

Energy cost savings indicators presented mixed results for *financial capital*. The cost of energy has decreased as compared to traditional energy sources (based on candles, gas/kerosene lamps, and batteries for flashlights) or fossil fuel generation (based on the occasional use of small diesel generators or larger scale decentralized generators). Although the cost of energy has decreased, some families found themselves spending

[240] Night classes for adults had been planned from the outset, but this has rarely taken place in the communities. In some cases, this is due to a lack of teachers available. More commonly, light in schools is used in the evenings and night to hold community meetings.

[241] Although one of the goals of having electricity in health centers is to have better lighting and to power medical equipment, in some communities, this goal has not been met as there is still a lack of health care professions. The improvement of services has not improved this situation to the degree that in the community of Puerto Viejo, Nicaragua, the health center remains closed during daytime on some weekdays. Of course, this health center is not open at nighttime either.

[242] The exception to this is in the community of Sta. Clara, Guatemala. The solar PV system, together with the TV and VCR, were installed approximately five years ago, and distance education material was never sent to the community. The school only provides elementary school education and the villagers had wanted middle school education to be included. However, the Ministry of Education stated that the community was too small and isolated to send a professor there and if the students wanted to study middle school they had to travel to the nearest bigger community (Chel), which is about 8 hrs away by foot. This completely defeated the purpose of the project and some NGO's and community leaders have issued formal complaints to the Ministry of Education. As this is being written, no solution has been provided.

more on energy because of their increased energy consumption. With the arrival of electricity, families purchased a number of appliances ranging from refrigerators to televisions, which they previously did not have. This was more evident in the hydroelectric projects. Although some of the more prosperous families have declared spending more on energy, it is important to point out that this comparison is not level as the quality of the services is not the same.

Some users indicated loosing income because of two main reasons: they are not able to sell traditional energy sources anymore, such as candles (except for those homes that remain unelectrified by the DRE systems), or they have purchased refrigerators to store cold drinks, popsicles, and meats and lose their produce when there are long blackouts. Besides having to cover their losses they also have to pay their electricity bill.

Overall, there has been a positive impact on financial capital as micro-financing schemes have been or are in the process of being enabled and a culture of savings is being created in some communities. Additionally, there has been a creation of jobs, either related to the upkeep and management of the DRE systems, or through the new productive applications available.

Lastly, ***social acceptance*** indicators also proved to have a positive impact on *social capital*. The positive perception that users have of their systems is based on a number of factors, including that the project (and the way it was implemented) is consistent with the local context. In recent years, there has been a shift from projects that are

technology oriented to context oriented and some of the projects evaluated exemplify this. For example, implementation processes that include community meetings and local labor and training sessions help build trust among community members and with outsiders and encourages community leadership. This has proven to be especially true for areas affected by civil wars. The structures that are put in place to govern the energy systems help build *social capital*, independently of the governance structure itself (for example, whether it is a community association, committee or concessionary). Social capital issues are discussed in more detail in Chapter 6 as governance structures are also a cross-cutting issue that affects development, climate change mitigation and climate change adaptation projects.

The case studies presented in Section 4 additionally show that projects with a primary development objective are better at meeting poverty alleviation and improved livelihood goals than those with a primary emissions reductions or adaptation objective. It is important to highlight that two development projects are also carbon projects, although the development objective was the primary and original objective.

DRE systems have brought a range of benefits to the communities, and despite the numerous experiences of their use in rural applications they still face numerous barriers, some of which were observed in the case studies. Technical issues constitute a problem especially when technical quality is lacking, both in the manufacture of components and in the installation of systems, as well as when pirate equipment is used. It is important to keep in mind though that technical failures do not necessarily

indicate problems with the technology. The case studies show different non-technical barriers that have been the root problem to the technical failures. As detailed in Chapter 6, oftentimes this is due to a series of cross-cutting issues, including lack of proper training, community participation, and congruency of expectations between the users and the donors. Some examples are the battery abuses in the PVBCS project in Nicaragua because some families did not follow the instructions. Moreover, the project received was not what they had requested and were promised; therefore, users were not very keen on their system upkeep as they are still expecting their stand-alone PV panels. PV projects have stopped functioning for a variety of reasons, including that users did not receive sufficient training on the importance of a charge controller[243] and the upkeep of the battery[244]. Sometimes parts are not replaced because the closest urban center where they can purchase them is a long distance away. In some cases, the roads are quite dangerous as drug trafficking activity has increased in some rural areas and villagers and system vendors are weary of traveling. The frequent blackouts that hydroelectric users have suffered represent a barrier to DRE as some people would prefer using the grid. The most damaging consequence of these barriers is that users lose confidence in DRE technologies and after a bad experience, are quite reluctant to use DRE technologies again. Although they might eventually use the same or another DRE source, it usually takes more planning, training, and socialization, increasing the overall budget of the project. Besides the lack of trust, some families have also reported a loss of income due to the high electricity bills they have to pay, together with the loss

[243] The charge controller is oftentimes bypassed as the users think it drains the battery. By bypassing it, they can not tell when the battery is fully charged or discharged, thus shortening its life span.
[244] Users not always fill batteries with distilled water and sometimes do not fill them at all, causing damage.

of produce during the blackouts. Additionally, when blackouts are frequent, families have a reserve of candles, gas or kerosene and flashlights, which now constitute and additional expense.

CHAPTER 6: EXPLANATIONS OF PROJECT SUCCESS: CONTEXT, GOVERNANCE, FINANCING, EXPECTATIONS AND TECHNICAL QUALITY

6.1. Introduction

As summarized and concluded in Chapters 3, 4 and 5, there are a number of cross-cutting issues that enable DRE systems to simultaneously meet the triple objective of sustainable development and climate change mitigation and adaptation. These cross-cutting issues, or project success drivers, include the relative roles of local historical background and physical characteristics, type of community governance, funding source and project implementation process, and technical quality of DRE systems. Table 38 summarizes the results of Chapters 3, 4 and 5.

Table 38. Summary of climate change adaptation, climate change mitigation and sustainable development indicators

Project		Adaptation (Chapter 3)			Mitigation (Chapter 4)		Sustainable Development (Chapter 5)							
		Good (1)	Bad (2)	Neutral (3)	Energy Savings (4)	Emissions Reductions (5)	Domestic Uses (6)	Productive Uses (7)	Communal Uses (8)	Cost Savings (9)	Social Acceptance (10)	Governance, Exists, Works (11)	Governance, Exists, doesn't work (12)	Governance, Doesn't exist (13)
Guatemala	Nueva Alianza	✓			✓	✓	✓	✓	✓	✓	✓	✓		
	San Jerónimo			✓	✓	✓				Grid connected	?			✓
	Chel			✓	✓	✓	✓	✓	✓	✓	✓	✓		
	ADIM PV			✓	✓	✓	✓	✓	✓	✓	✓	✓		
	Cancuén	✓			✓	✓		✓		Project exists because of RE system			✓	
	Chapín Abajo			✓	✓	✓		✓		FDN maintains system	✓	✓		
	MEM PV			✓	✓	✓	✓	✓		✓	✓		✓	
	CONRED PVEWS	✓			✓	✓	✓		✓	NA	✓	✓		
Nicaragua	PVBCS		✓		✓	✓	✓	✓		?		✓		
	SINAPRED PVEWS		✓		✓	✓	✓		✓	NA	?			
	El Trapiche			✓	✓	✓			✓	Donor maintains system			✓	
	Río Bravo			✓	✓	✓	✓	✓	✓	Cost of energy higher than national utility, but lower than diesel generators or traditional biomass	✓	✓		
	El Bote			✓	✓	✓	✓	✓	✓	Cost of energy higher than national utility, but lower than diesel generators or traditional biomass	✓	✓		
	Women's solar center			✓	✓	✓		✓		Project exists because of RE system		✓		

Notes:
(1) Indicates these projects are good examples of the use of DRE during climate hazards, or that performed well during a climate hazard
(2) Indicates these projects are good examples of the use of the inappropriate use of DRE during climate hazards, or that were damaged during a climate hazard
(3) Indicates these projects have not sufered through a climate hazard
(4) Indicates these projects are good examples of DRE as an energy savings measure (as compared to their previous energy source, mainly traditional biomass)
(5) Indicates these projects are good examples of DRE reducing GHG emissions
(6) Indicates these projects included domestic applications
(7) Indicates these projects included income generation applications
(8) Indicates these projects included communal applications
(9) Indicates these projects caused a savings on the monthly income spent on energy sources.
Grid connected means that the project is interconnected to the national grid; therefore, users are subject to the tariffs set by the national regulatory agency.
Where an external source maintains the system, it indicates that there are no energy costs to the DRE beneficiaries
The cases of Río Bravo and El Bote are further explained in Chapter 5
(10) Indicates these projects are considered as socially acceptable by the users and/or these projects have not caused social tensions to arise
(11) Indicates these projects are good examples of how communal governance structures have been a DRE project success driver
(12) Indicates these projects are good examples of how communal governance structures have not been a DRE project success driver

This chapter will detail each of the project success drivers separately by presenting the specific research questions, data analysis methods, results and case studies. The *historical background and physical characteristics* driver looks at the role that local language and culture has played in the project's planning and implementation. I also take into account the civil war conflict that some of the communities visited suffered and the aftermath that it has caused, such as the displacement of survivors to more mountainous hidden areas with very difficult access and the lack of trust. This section concludes with the role and consideration that site specific historical background and physical characteristics should be given during project planning as the failure to do so can hamper project success. The *type of community governance* analysis focuses on

the existence and type of structure that governs the DRE system. I put special attention to three aspects: gender and social equity, community involvement, and existence of a tariff structure or maintenance fund. For those communities that have other commons, I look at how these are governed and if they have had any influence over how the DRE system is governed, or vice versa. The *funding source and project implementation process* centers on consistency of drivers between the funding obligations of the donor and the needs and capabilities of the users. I also evaluate the stages that have led to the existence of the projects: project feasibility and its consideration of social, economic and cultural aspects; project implementation that is inclusive of users participation, labor and decision-making; and project follow up that contains elements leading up to long-term system sustainability. As can be seen, the different aspects evaluated here also overlap with the first to project success drivers. Finally, *technical quality* mainly looks at how the DRE systems met quality and safety norms and standards, what the main technical failures are and why they occur, and how the community resolves these problems.

For each project success driver I highlight different case studies, as summarized in Table 39.

Table 39. Project success driver case studies

Project		Case Study Focus				
		Historical and Environmental Background	Governance	Commons Resources Management	Implementation Process of Projects	Funding Entities
Guatemala	Nueva Alianza	X	X	X		
	San Jerónimo				X	X
	Chel	X	X	X	X	
	ADIM PV	X	X	X		
	Cancuén		X	X		
	Chapín Abajo		X	X		
	MEM PV		X			
Nicaragua	PVBCS	X	X		X	X
	El Trapiche			X		X
	Río Bravo	X	X	X		X
	El Bote	X	X	X		X
	Women's solar center			X		

These project success drivers, together with the previous three chapters, will help answer the main research questions of this dissertation on whether DRE systems can simultaneously meet the triple objective of sustainable development and climate change mitigation and adaptation and what drivers lead to the DRE systems meeting, or not, the triple objective. The concluding section of this chapter will summarize how the case study projects can meet the triple objective, based on the findings of this dissertation.

6.2. Type of Governance Structure

The existence and type of governance structure affects project success. The community dynamics and relationships, together with the knowledge of how to care for the system, both technically and financially, will impact the long term sustainability of the project as well as future relationships within the community. This section analyses the

governance structure set-up, implementation and follow-up process for the DRE projects and its usefulness in meeting the triple objective. The role that governance, as a project component, plays within donor agencies is discussed in the following section[245].

One of the hypotheses of this research is that the existence and type of governance structure affect project success. For this analysis, I use the Earth System Governance framework. Although earth system governance is primarily focused on the impact of human activities, institutions, and regulations on environmental change and adaptation on the earth (Biermann et al. 2010), I use this methodology to analyse the impact of human activities, institutions, and regulations on the management of DRE systems, both inside and as common property resources. Specifically, I lean on the five core analytical problems identified in the earth system governance research (architecture, agency, adaptiveness, accountability, and allocation and access) to better understand and measure the effectiveness of the governance structures created for the DRE systems.

I use **architecture** to analyse the *private vs. common property* characteristics of the projects as it is defined by the 'institutions, principles, norms, regulations, decision-making procedures' (Biermann et al. 2010). Through this framework I also analyse a subset of Ostrom's commons management rules (Ostrom 2002), including *management rules, their enforcement and type of sanctions, and decision-making procedures*. *Community participation* is analysed through **agency** and **accountability.** I use agency

[245] Different donors and development entities view governance with different degrees of importance.

because of the participation that community members, among other actors, have in the different phases of the project implementation and its follow-up. Accountability is used to ensure legitimacy and transparency in the different processes that take place for the proper management and upkeep of the systems. Agency and accountability also allow to analyse other rules designated by Ostrom including availability of low cost adjudication and accountability of other officials to users. I use **allocation** and **access** to analyse *equity* and *tariff structures* as they seek 'the pursuit of fair allocation and access, and the un-doing of perceived injustices' (Biermann et al. 2010). As has been seen throughout this dissertation, inequality has been identified in several projects, and continues to be a problem in current projects, which can hamper projects meeting their stated goals. Finally, **adaptiveness** is used to measure how the communities and their respective governance structures cope with and adapt to extreme weather events, particularly their impact upon the DRE systems and the other projects and activities the DRE system enables.

Despite the Earth System Governance framework being used in a smaller scale and specifically for DRE systems; the results of this analysis can provide valuable feedback towards the framework.

The projects included in this dissertation have diverse governance structures, as detailed in Table 40, and were analysed using specific indicators to evaluate the role that governance structures have for the intended functionality of the renewable energy systems.

Table 40. Summary of governance structure case studies and indicators[246]

Project		Type of Governance Structure
Guatemala	Nueva Alianza	Committee
	San Jerónimo	Association
	Chel	Association
	ADIM PV	Committee
	Cancuén	Committee
	Chapín Abajo	Committee
	MEM PV	Committee
Nicaragua	PVBCS	Committee
	El Trapiche	None
	Río Bravo	Community utility (concesionaria)
	El Bote	Association, which also acts as a utility
	Women's solar center	Committee

The main **research question** asks this:

1. **Do community governance structures influence whether projects meet their stated goals? If so, how?**

1. What are the relative roles of community participation and community governance structures in projects meeting their stated goals?
2. Do renewable energy projects owned under a commons scheme have a different community governance structure than those privately owned? What are the common's rules that govern? How does this affect the success of the project?

[246] In Chapín Abajo, there is a Women's Weaving Cooperative using a photovoltaic system, managed by an energy committee.

Governance structures vary in each country and have different purposes. In Guatemala, the specific type of governance entity depends on its main interests. For example, if the main goal sought is economic, there are cooperatives whereas associations, civil societies, or foundations exist if social interests are predominant. The main entities seen in Guatemala are cooperatives, associations, and committees. The basic principle of COOPERATIVES is self help through the effort of its members. A cooperative is defined as *'an association of people with the same needs that voluntarily unite with the objective of discussing and resolving such needs based on self help and their own effort',* They are characterized by being politically and religiously neutral, having equity of rights and obligations, being of voluntary participation, and seeking social and economic improvement of its members (not necessarily the entire community). An ASSOCIATION'S basic principle is to promote, enforce and protect collective interests and they do not seek to do business. Associations are created with more than one interest in mind and seek to promote social leadership, which can be difficult in small communities. They are legally established, can act like a business, but are not obligated to pay taxes. For example, in the case of the DRE projects described, an Association can be formed as a governance entity of a DRE project, and will not have to declare taxes on the tariffs it imposes. COMMITTEE'S are not legally established and they only need approval to raise funding for a specific community activity. A disadvantage for this structure is the lack of internal rules and a lack of direct control of the community over the leadership of the committee, which can lead to corruption. Despite this, community committees have created their own set of internal rules and regulations for their functioning.

Because of Nicaragua's electricity market structure, community scale utilities are formed in each project and they function in a similar way in which utilities usually work: users are obligated to pay their respective tariffs and they have the option of buying into the utility by purchasing stocks, which makes them eligible to make decisions.

Ideally, project designs entail a plan for its proper use and long-term sustainability after the donor and developer are no longer involved. In this section, I analyse the different approaches that were used to establish project governance by evaluating what specific structures were put in place, the role that community participation and equity had within them, and the corresponding tariff structures. The specific indicators used are listed:

- Existence, understanding and enforcement of *roles, rules and regulations*,
- *Equity* within the community for decision-making and its benefits from the project,
- *Administrative training* to ensure the proper financial and administrative management of the DRE systems,
- *Technical training* to ensure the proper functioning of the system's physical components,
- Existence, understanding and enforcement of a *tariff structure*, that allows for proper maintenance to take place, and on occasion, training.

These indicators are used as a proxy to determine the *level of community involvement* and the *equity*, or lack thereof, that exists in each case and their relative importance in projects achieving their stated goals. This evaluation also allowed me to determine the existence of power groups, dominant figures, exclusion or other influences that could affect the proper upkeep and sustainability of the systems.

To answer the second research sub-question, I analysed whether the 'design principles for common property resources' identified by Ostrom (Ostrom 2002) also apply to community-owned renewable energy systems and to the communal management and administration of individual home-lighting systems. I also tested the validity of Wade's (1998) statement that 'low-cost exclusion technology' is a facilitating condition for the management of common property resources (Wade 1988), by considering the renewable energy system as the 'low-cost exclusion technology'.

The data analysed for this section was obtained from interviews to project developers and community members. Within each community I interviewed people from the following groups:

- Community leadership groups
- System users and non-users
- Technicians in charge of system maintenance

- Committee members in charge of the administration and management of the system, in the cases in which they were not members of the community leadership group
- Women's groups, if applicable

6.2.1 General Findings

Results confirm the hypothesis that the existence and type of governance structure affects projects success. Ownership structure, level of engagement, training, and tariff structures enforced impacted project outcome.

The types of governance structure implemented mainly varied according to the projects' country and its primary stated objective. In this section I analyse the impact of the different structures chosen on the projects' outcome using three different parameters: community participation, equity, and tariff structure.

This section reviews each parameter and presents the relevant case studies.

6.2.1.1 Community Participation

Community participation is analysed through three different parameters (the meaning of *community participation* given by respondents, its dependency upon an external entity,

and the form decision making is carried out) that respondents considered important, influential over their own participation and, ultimately, the project's outcome.

Meaning of *community participation*: As has been discussed in previous chapters, the meaning of community participation varied by user and community; therefore, the analysis of its importance was based upon the responses received and not upon some previously designated definition. For example, if a respondent indicated he/she felt there was a high level of community participation even if that participation did not meet any other academic definition, for analysis purposes, it was accounted for as positive. Donors and development entities of each project carried out socialization meetings to inform the communities of the project and to respond to concerns. The number of socialization meetings varied depending on the donor and development entity, although this did not always lead to inclusive community participation. In some occasions, meetings were considered as informative as they gave the status of the project, rather than trying to get community members involved. Some respondents were satisfied with their levels of participation after attending meetings and being informed about the project (*'I attended all the meetings that were carried out and all of us that went knew what the project was* about'[247]) while others thought their participation was insufficient (*'They (the developer) only did a few meetings with us before they started constructing the project, but they never consulted us for anything'*[248]). Some families wanted to actively participate by being able to make decisions regarding the project and have a role in its longer term sustainability (*'When they extended the grid here, they just told us*

[247] Hydroelectric user in Chel, Guatemala
[248] Hydroelectric user in San Jerónimo, Guatemala

about it, but we weren't able to participate more, just with labor. Now we only pay the bills, but nothing more. I wish we could be more involved'[249]), but were not able to.

I found the difference in meaning and perception to be stronger when making a technology and country comparison. A hydroelectric plant requires more communal labor and organization than stand-alone PV home lighting systems, while individual solar PV users need to be more knowledgeable at the household level as opposed to users of hydroelectric projects. In comparing countries, Nicaraguan respondents were more eager to participate in decision making but were not always able to because of their low income levels. For example, a user indicated *'I can't afford to buy stocks, so I can't be a decision-maker, I can attend all meetings, but I'm too poor to buy'*[250] while another indicated that *'I attended all the initial meetings, but can't afford to get connected, I'm too poor'*[251]. On the contrary, in Guatemala projects were more inclusive in the decision-making process. One user indicated that *'We have general assemblies very often to discuss the different problems and decide what to do. When something happens that needs immediate attention, we have extraordinary meetings and we all try to solve it'*[252].However, there were exceptions, with one unhappy user stated that *'We wanted to participate, but there weren't any men in the family to provide labor, so we just live like before, using our candles'*[253].

[249] Hydroelectric user in La Pitilla, Nicaragua
[250] Hydroelectric user in Río Bravo, Nicaragua
[251] Hydroelectric user in La Chata, Nicaragua
[252] Hydroelectric user in Chel, Guatemala
[253] Respondent in Chel, Guatemala

Development process of community participation: I define this process as being internal, led by the community, or external, led by donor and development entities. Although in most projects analysed, community participation developed into an internal process during their execution, in some of them it started and remained as an external one. In these cases, sources external to the communities, such as the donor and/or development entities, were the main drivers and decision-makers and community members were only being informed. For example, the communities surrounding the San Jerónimo hydroelectric project were informed of project activities, but were limited in their participation to labor providers during the execution phase of the project. One user expressed the sentiment of the surrounding communities *'We thought we'd all be part of the project, it's one watershed, and we all use it, why shouldn't we participate?*[254]*'.* Another user indicated that *'the best thing we can do is mediate the use and quality of the water we receive down here (downstream). There are crops, fish and ostrich farms who depend on that water, we need to work together for that'*[255]*.*

Decision making; rules and regulations: Decision-making and the establishment of rules and regulations, along with roles and responsibilities, are specific to projects that had an 'internal' community participation process. In these cases, development entities enable communities to take responsibility and ownership of projects. *Rules and regulations* are set to ensure long-term functionality of DRE projects and are considered to be the basis for long-term administrative and financial management, and physical operation and maintenance tasks. Besides empowering the energy users to be part of

[254] Respondent in Chilascó, Guatemala
[255] Respondent in Salamá, Guatemala

the process, rules and regulations help users better understand the project and the underlying reasons behind such rules and regulations. Although people know of these rules, not everybody remembers their function (*'We pay a monthly tariff since we received the panels years ago, but I don't know why we pay it, most of us in the community pay it'*[256]) and in some cases, people have started disagreeing with them. A dissatisfied user complained that *'we pay more with this hydroelectric plant, we have many blackouts, I lose a lot of money on my meat that spoils and if I don't pay, then they cut my service! They should keep their quality, when one complains, they treat us bad'*[257].

Lastly, some communities found it important to determine how energy rights, including participation and decision-making rights, were passed from one generation to the next, especially when the main effort (labor) was put in by the present generation. For example, in the community of Chel, those who provided labor are distinguished from those who arrived after the DRE system was in operation, which was important to them because of the hard work the original members had contributed. Similarly, in Nueva Alianza, each head of household had to determine how his land and their earnings would be distributed to the next generation. Subsequent generations do not participate as long as the previous generation head of household is still alive and maintains the right to vote. New generations enjoy other benefits directly or indirectly resultant from the DRE system, including salaries, goods distribution, and health benefits, but do not vote or participate in decision making until they have inherited that right. In contrast,

[256] Solar PV user in Sta. Clara, Guatemala
[257] Hydroelectric user in El Cuá, Nicaragua

labor contributed by children could be used to provide the connection right to parents for the Chel hydroelectric project.

In conclusion, beneficiaries value knowledge of and decision-making authority regarding their energy systems, although this was not seen to be a determining factor for long-term sustainability in all the case studies, such as in San Jerónimo in Guatemala and El Bote in Nicaragua. The case studies of San Jerónimo and El Bote are examples of this. The results of the research indicate that decision-making varied depending on the type of governance structure set in place. Three distinct examples highlight this finding.

The three communities of the Chel, Guatemala project formed an Association in which all the users are members. The 'Asamblea General' or General Assembly is the meeting in which all Association members gather to discuss project related matters and vote on any decisions that need to be made as well as vote for the Association's officials which rotate.

In the project of El Bote, Nicaragua, the organization, originally an NGO, that helped develop the project (ATDER-BL) is the main managing entity and keeps the users informed. This organization functions like a utility and is the only decision-maker. Some users would like to be more involved in the decision-making process, but under the current structure, it is not possible. However, unlike the other Nicaraguan community utilities, users can not buy stocks. Once the World Bank loan is paid off, electricity users might have a more participatory role.

Finally, in Río Bravo, Nicaragua, a community utility (concesionaria) was formed. All electricity users can become decision-makers as long as they buy company stocks. In an effort to earn more income, the utility sells stocks, but there is an argument that this method increases inequality as the poorest segment of the population is unable to buy stocks and does not have a say in the project.

The contrast of these three examples shows how different governance structures enable different levels of community participation. I found that communal Associations or Committees lead to the highest levels of participation, leaving the degree of participation up to the individual. The schemes of utility, or similar to a utility, may open the door to a high level of communal participation, but this participation is dependent upon financial means. If a family is willing to participate more, but can not afford it, then they are not able to contribute. It is important to highlight that in these examples there is no linkage between community participation and project satisfaction.

6.2.1.2 Equity

Although equity is considered within the dynamics of community participation, it merits separate discussion because of the role it played within the case studies. Different projects saw different degrees of inequality with different results. The most interesting finding is that power groups or a single influential person can ensure proper system upkeep, which would not be self-evident at all. The case studies of El Bote and

Chuisibel demonstrate that consolidated power can in fact help systems be properly maintained, as long as the power figure remains in power. The project of El Bote was championed for years by the same person who created an NGO, which is now the utility that runs the project. This person was in charge of dealing with the government and donor entities and is responsible for the loan payments to the World Bank. Although she employs people from the surrounding communities and considers the project to be communal, she is ultimately in charge of all decisions and is the only person knowledgeable of the entirety of the project. In this case, although it has been positive to have a power figure for the project's sustainability, it still raises the question of long-term sustainability. At the time field work and all the interviews took place, she was the only person capable of responding questions regarding the project. All other respondents would refer me back to her, even for simple day to day routines and tasks. In the case of Chuisibel, an engineer from the United States helped design and install the system and currently lives in a nearby community. He is the person who has helped mobilize support to rebuilt the system after it was twice destroyed. Community members look up to this engineer and they know that as long as he remains with them, they will have electricity.

Other projects saw certain segments of the population, such as women and the poorest, suffer from inequality and exclusion.

In many rural regions of Guatemala and Nicaragua, there is a cultural barrier to women's involvement in activities outside the household. Even though household

electrification will benefit women to a higher degree than men, they are not decision-makers within each household and many times are not allowed to participate. This poses difficulties as women are the ones that understand household energy needs and who would mostly benefit from energy for productive use applications. Many donor organizations have increasingly been willing to have greater women's participation in development projects and we are beginning to experience a paradigm shift, although not all regions and projects experience it to the same degree. For example, in Nueva Alianza, one of the requisites of the UNDP was the creation of a women's group that would support the project they were funding. Although the group ceased functions at the end of the project, the women involved considered it to be meaningful to them and do not discard the idea of creating another group and carrying out new projects. They still highlight difficulties at the household level and assimilation from men over their involvement in projects outside the household.

Low income families, especially in the case of hydroelectric projects, are usually excluded because they can not afford the connection fee. By remaining unelectrified and not being able to benefit from electricity services, including productive use applications, the income gap continues to expand. In Nicaragua, families who are not connected and low-income families who can afford the connection fee and monthly tariffs, but can not afford to buy the utility stocks, are excluded from decision-making activities. These rules can be considered as expanding communal inequality when it is thought (or even expected by some) that development programs will benefit the totality of the communities. A complaint often heard is that poor families will always remain

poor because projects only benefit those with money. For example, a respondent stated that *'we need electricity as much as our neighbors, but we will always be poor and there is no way to improve, the government does not help us'*[258], and *'it's not fair that we can not make decisions here, but we don't have more money, we can barely afford the tariff, and we can't pay for the stocks, so what else can we do'*[259].

Donor and development entities strive for DRE projects to be self sustaining as they will eventually withdraw their support; therefore, communities, in conjunction with the development entity, must enable the project's technical and financial wellbeing. Keeping this in mind, without external support it might be difficult for projects to subsidize the poorer segment of the population who is not able to afford the electricity service. Nicaragua presents an interesting case given its division between the concession and non-concession zones of the national utility. Nicaragua subsidizes electricity tariffs for a segment of the population based on their monthly consumption. As long as they do not exceed a specific number of kWh/month, they pay a flat, subsidized rate. Customers outside the concession zone who connect to the utility, to either sell or buy electricity, can also opt for this subsidized tariff. The downturn that DRE projects face is that for electricity purchases from the grid, the entire project is considered by the utility as *one* customer. Naturally, the aggregate consumption will be higher than the subsidized limit and all the customers of the DRE project are subject to normal tariffs when purchasing electricity from the grid. A government official expressed *'it is unfair that the unelectrified population has to pay these tariffs when they*

[258] Respondent in La Pitilla, Nicaragua
[259] Respondent in El Naranjo, Nicaragua

finally grid connect because of World Bank and other donors projects, but that is how the law is written and unfortunately, we can't do anything about it right now'[260].

6.2.1.3 Tariff Structure

Most projects had a tariff structure set in place at the beginning of the project with the purpose of ensuring the financial sustainability of the projects. With the exception of the solar water pumping system of El Trapiche, Nicaragua, all the other case study projects included payment of a tariff, although not all of them worked as intended. This tariff was required in order to receive the benefits of the DRE system and ensure funding for maintenance and component replacement. The parameters that respondents indicated as making a difference within the tariff structure and tariff payment are explained in this section:

Centralized or decentralized nature of the DRE infrastructure: Tariff (and governance) structures established in communities with centralized DRE systems were more effective than those implemented in communities with decentralized infrastructure. Centralized infrastructures include the hydroelectric, biodiesel and the PVBCS projects, where there is a central physical plant and all the individual home installations depend upon the plant itself, the operators and some manager. For individual household systems, considered decentralized infrastructure, such as the stand-alone PV home lighting systems, tariff structures did not meet their intended objectives as each

[260] Government official from the Ministry of Energy and Mines, Nicaragua

homeowner preferred to be responsible for their own system maintenance, replacements, etc. The model of individual tariff collection and communal technical assistance was predominant in communities that had stand-alone PV systems, although this was not the model that was initially implemented. Trust, or rather mistrust, was the main reason communal tariff collection schemes did not work.

The governance structures for the hydroelectric projects of Guatemala and Nicaragua, both located in civil war stricken areas, follow two different approaches as seen previously, but the tariff structures are similar as they both charge per kWh consumed.

In the case of the stand-alone PV systems in Guatemala, indistinctly of the donor and development entity, an energy committee was created in each community to serve the same purpose as the hydroelectric associations or utilities. However, because each household has its own system, and in some cases because of lack of trust and understanding of the committee's functions, not all committees met their intended objective and some stopped functioning altogether as soon as six months after the systems were installed. In some communities, the elected treasurer was caught stealing from the communal funds. In the end, each household managed their own savings. A user indicated *'how do we know if they save the money or not? If I have to replace my battery, then I should save the money myself as I know when I will need it changed'*[261]. Another shared that *'our treasurer left the community with our money; he wanted to use it go to the US'*[262]

[261] Solar PV user in Juá, Guatemala
[262] Solar PV user in Sta, Clara, Guatemala

Training: Training is a central part of all projects, and considered a requirement for long term sustainability, as it will prepare the communities to face future difficulties and ensure the proper functioning of the systems. I evaluated administrative and financial training for the management of the systems and technical operation and maintenance procedures. The latter is discussed in Section 3 of this chapter. This section only focuses on the training required to implement and manage sustainable tariff structures.

Within each committee, association or community utility, elected community members were trained as administrators and accountants. Training topics included how to manage accounting books, open bank accounts, provide receipts after payment, and make sure that there was sufficient funding in the account in case of emergency needs, such as repairs. In some projects, new computer software was being introduced to make the task easier and more organized.

Training sessions and workshops were well received and although they were useful, attendees indicated they were not sufficient and it was necessary to have them more often. Training has certainly brought the desired results; however, there is always doubt as to what will happen when there is no further donor support for further training and follow-up. The Chel project is the only one to include training sessions as part of the tariff calculations but thus far it has been insufficient. Chel's training sessions have been funded with their own earnings together with financial and technical support from donor entities. Other projects, such as the women's weaving cooperative of Chapín

Abajo, have depended upon other development entities to support their training needs. The community of Chapín Abajo has been working with the environmental NGO of Fundación Defensores de la Naturaleza who has been including the use of renewable energy technologies within their protected area management work. In this case, it has been a win-win as this NGO has successfully increased the use of RE in research stations and communities within the national protected areas they manage.

To conclude, although the importance and need of training is widely recognized by donors, developers and users; the occurrence of such re-training sessions (considered after the project is installed) is not secured as funding is not allocated from the outset. In some of the projects observed, fundraising for future training sessions occurs when the need appears, while in others, such as Chel, the amount allocated is not enough and it would be unsustainable for the project to increase the electricity tariff. Donors have realized this as a problem and although some recognize the need for more training resources and have defined a minimum of 10% of the project budget, this does not seem likely to happen as donor's indicators tend to be based on number of beneficiaries. That is, donors prefer to spend available budget on new projects rather than on re-training sessions.

Cash flow availability: Results show that long-term tariff payment was highly dependant upon users' cash flow availability. In areas of extreme poverty, where a savings culture does not exist, I also found it was difficult for the families to save each month to pay their tariff, independently of the DRE technology used. Although the cost of candles

and kerosene is higher, users spend small amounts of money several times a week rather than one higher amount each month. I found that this is not so much of a problem in hydroelectric projects as it is in PV ones, the main reason being that the continued use of traditional energy sources is more predominant in solar PV projects, as explained in Chapter 5. Also, the tariff collected for PV systems is mainly used for battery replacement, which has an expected life of four to five years. There are several difficulties with this:

1. As each family cares for their own system, some families (and communities) do not see the need to pay a third person for the care and maintenance of their systems. Although initially they knew they would receive technical support, very few have actually used the service. In these cases, each family prefers to manage their own system.
2. The expected life of batteries, considering four or five years, can seem a long time. Especially in locations with high levels of mistrust there is uncertainty of what will become of the money each family has invested and if indeed it will benefit all.
3. Some families misuse (abuse) the systems and need their battery replaced with more frequency, as explained in Chapter 5. In a communal tariff collection system, if each family pays the same amount each month, those who need to replace their batteries first will use the existing funding while those who care for their systems and replace it at the end of the expected useful life might not find sufficient funds in the account for their replacement. This causes a situation of

inequality where responsible users would be ‘punished’ and who ultimately are not willing to put money into a common pool knowing they might not benefit from it at all.

4. When the batteries stop working and there is not sufficient funding to replace them, families stop paying because they are not receiving any service. As such, batteries will never be replaced if payments are withheld.

Table 41 summarizes the findings discussed above.

Table 41. Summary of Governance Findings

Project		Governance						
		Roles and Responsibilities	Rules and Regulations	Equity	Type of Governance Structure	Administrative Training	Technical Training	Tariff structure
Guatemala	Nueva Alianza	Well defined and followed	Well defined, although not everybody follows energy usage regulations	Yes, although the women's group has lost power at the conclusion of the UNDP project	Committee	Yes	Yes	In place, but not sustainable
	San Jerónimo (for water)	Well defined and followed	Well defined, not followed thoroughly	Not entirely as those in the upper watershed almost always dictate the water usage of the entire watershed	Association	Yes	NA	In place for those who are members of the Irrigation Association
	Chel	Well defined and followed	Well defined and followed for the most part	Yes	Association	Yes, although an improved system is required with the connection of the ten additional communities	Yes, and re-training of technicians is necessary	In place and adequate
	Cahabón	Defined, but not fully enforced nor followed	Defined, but not fully enforced nor followed	Yes	Committee	None	One informative session	Was not properly implemented nor followed
	ADIM PV	Well defined and followed	Well defined, but not always followed or understood	Yes	Committee	Yes, but the accounting system needed to be improved	Yes, and re-training of technicians is necessary	In place, but not sustainable
	Cancuén	Well defined, but not followed	Defined, but not followed	No, only involves those that are part of the tourism project and their relatives	Committee	Yes	No	Not followed, causing conflict and an unsustainable project
	Chapín Abajo	Well defined and followed	Well defined and followed	Not all women are involved, some claim they were excluded. This women's group does not work with other community committees, even when invited	Committee	None	Only for the NGO, not the women's group	None
	MEM PV	Defined, but not always followed	Defined, but not always followed	Yes	Committee	Yes	Yes, and re-training is necessary	In place, but not always followed
Nicaragua	PVBCS	Well defined and followed	Well defined, but not always followed	No, only one third of each beneficiary community has a battery kit and the burden of battery hauling has fallen on women, including older and pregnant ones	Committee	Yes	Yes, and re-training is necessary	In place, but not sustainable
	El Trapiche	Defined at the beginning, but a source of conflict	Defined at the beginning, but a source of conflict	No, the conflicts have caused exclusion of some members and not all benefit equally	Committee	None	None	None
	Río Bravo	Well defined and followed	Well defined and followed	Partially as homes far from the main project grid and poorer families can not afford the connection fee	Community Utility (concesionaria)	Yes	Yes, and re-training is necessary	In place and adequate
	El Bote	Well defined and followed	Well defined and followed	Partially as homes far from the main project grid and poorer families can not afford the connection fee	Association, which also acts as a utility	Yes	Yes, and re-training is necessary	In place and enforced, although users complain of the high cost of electricity for the quality of service they are receiving. Additionally, the project still has to sell surplus to the national grid in order to meet all their expenses
	Women's solar center	Wee defined and followed	Well defined and followed	Partially as some committees have generated conflict and some women complain that they have been excluded (some of them because of their level of commitment to the project)	Committee	Yes	Yes, and re-training is necessary	In place and enforced through their educational activities and workshops

6.2.1.4 Common Property Resources

In this section, I analyse the role of DRE systems within commons and as commons, by studying Ostrom's 'Common Property Management' rules (Ostrom 2002), Hardin's 'Tragedy of the Commons' (Hardin 1968), and the role of DRE systems in facilitating commons management (Wade 1987).

In most of the case study projects, the DRE system is the commons being studied and they were analysed following Ostrom's rules, which mainly concern their management and governance structure. In other cases, such as the archaeological site of Cancuén and the women's weaving cooperative of Chapín Abajo, the archaeological site and the weaving cooperative are considered the commons, respectively, and the analysis focuses on the role of the DRE in facilitating their management and in the influence, if any, of the common's governance structure upon the governance structure of the DRE system.

Both Ostrom's and Hardin's theories were proven in the case studies. I start by reviewing Ostrom's common's rules and how the DRE projects complied or not with them.

1. Resource system characteristics

    a. Well-defined boundaries

Boundaries for the DRE systems depended upon the type of renewable energy resource being used. In the case of solar photovoltaic systems, this was limited to the area of the solar panel and its location within the users' household. In the case of hydroelectric systems, boundaries are defined by the location of the resource, for example, a water fall; the land tenure of areas occupied; and respect towards natural resources as infrastructure is being installed on the ground. Although these boundaries exist, they are not always respected. One clear example is in San Jerónimo, Guatemala where the hydroelectric plants located in the upper watershed still dictate the water schedule of user's in the lower watershed.

2. Group characteristics

    a. Well-defined boundaries

The main boundaries are the governance structures set in place, such as the committees, associations, and cooperatives explained above. These governance structures define who the users are as well as their main roles and responsibilities. All the projects included in this research had one.

(1 and 2) Relationship between resource system characteristics and group characteristics

This relationship had mixed outcomes. The main problem stems from misuse of the renewable energy systems, usually demanding more power than what the system can deliver. For example, in Nueva Alianza, each household was provided with a fuse to control electricity consumption; however, despite this, some households exceeded the allotted capacity causing blackouts throughout the community. Problems such as this tend to cause social tension among users.

3. Institutional arrangements

    a. Locally devised access and management rules

All the projects had access and management rules, enforced through the leadership of the respective governance structure.

    b. Ease in enforcement of rules

In some cases, rules were not enforced because of a lack of oversight or because those violating the rules knew they could continue to do so without getting sanctioned, mainly because of the existence of a power figure or group.

    c. Graduated sanctions

Half of the projects included did have graduated sanctions. For example, the rules of one project stated that for the first delayed or non payment there would be a reminder, for the second one a penalty fee and the third one a disconnection of the service. Not all projects that had graduated sanctions implemented them when cases arose.

d. Availability of low-cost adjudication

Because of the specific contexts, backgrounds, and locations of projects, this was not always possible. In some cases, such as in the ADIM PV projects, it was not possible to enforce the tariff payment in all communities because of their distance from the ADIM headquarters. It was difficult for the headquarter based personnel to go out to each community, and sometimes, the people in charge in each community did not want to handle a specific problem and would wait for headquarters people to help solve it. In other cases, such as in the archaeological site of Cancuén, it did not matter if someone broke the rules because there was nobody with enough authority willing to implement sanctions. Because of this, the community of La Unión was able to unfairly benefit more from the eco-tourism project, to the detriment of the other two 'partner' communities.

e. Accountability of monitors and other officials to users

The internal rules of the governance structure indicated that, through General Assemblies, or their equivalents, officials would be held accountable. These meetings have the purpose of updating users on the technical, financial, and administrative status of the project. Chel is an example of a successful project in which the leadership group has been held accountable as members are voted in and out. On the contrary, El Bote is a project in which, although the communal utility should be held accountable, it does not happen mainly because of a predominant power figure.

(1 and 3) Relationship between resource system and institutional arrangements

Although all the projects, with the exception of El Trapiche, had some kind of internal regulations to follow, only four projects had a good relationship between resource

system and institutional arrangements, among them, Nueva Alianza and Chel. In other projects, this relationship was ‘average’ mainly because despite having the tools, they could not be enforced. For example, the ADIM PV projects were installed under a robust governance structure, however, because of the context and location of the communities, several institutional arrangements could not be implemented, or would be too costly and unsustainable to implement. Finally, some projects had a poor relationship between resource system characteristics and institutional arrangements. The most telling examples are in El Trapiche and the PVBCS, both in Nicaragua. In both cases, social tension arose as one of the main problems after the installation of the DRE system.

4. External environment

    a. Technology

The role of technology is analysed separately as, in most case studies, the technology itself, is the commons being analysed.

    b. State

        1. Central governments should not undermine local authority

Except for the PV Early Warning Systems in which central governments play a crucial role, this rule did apply to the other case studies. In the EWS projects, especially in Guatemala, the role of the central government enabled disaster prevention and warning through the continuous upkeep of the PV system and the training of the communities involved.

2. Nested levels of appropriation, provision, enforcement, governance

Except for the PV Early Warning Systems, El Trapiche and El Bote, this also proved to be true. In El Trapiche, the main reason this did not occur was because of the foreign donor that designed the whole project (and subsequent projects) based on his belief of what could be beneficial and on the community's reluctance to complain or turn down the projects for fear they would not receive anything. In El Bote, the main reason is the existence of a power figure that is currently in charge of the entire project. Of course, this also proves to be unsustainable in the long-term as the project might collapse when the power figure is no longer there.

(Ostrom 2002)

Table 42 summarizes the results per project for Ostrom's common's rules and Wade's theory.

Table 42. Summary of results per project for Ostrom's common's rulels and Wade's theory

Project		Ostrom												Wade
		Renewable Energy Resource System Characteristics	Group (users) characteristics	Relationship between resource system characteristics and group characteristics	Institutional arrangements					Relationship between resource system characteristics and institutional arrangements	External environment			Low-cost exclusion technology is a facilitating condition for the management of common property resources
		Well-defined boundaries	Well-defined boundaries		Locally devised access and management rules	Ease in enforcement of rules	Graduated sanctions	Availability of low cost adjudication	Accountability of other officials to users		Technology (RE system)	Central governments should not undermine local authority	Nested levels of appropriation, provision, enforcement, governance	
Guatemala	Nueva Alianza	Yes	Yes	Energy consumption limits are exceeded	Yes	Yes	Yes	Yes	Yes	Good	Has helped meet development goals and strengthen management skills	Agree	Yes	Agree
	Chel	Yes	Yes	Good (at the time this is being written, service has been extended to ten additional communities and now blackouts are more frequent because demand exceeds generation)	Yes	Yes	Yes	Yes	Yes	Good	Has helped meet development goals and strengthen management skills	Agree	Yes	Agree
	ADIM PV	Yes	Yes	Batteries are abused	Yes	No	Yes	Yes	No	Average	Has helped meet development goals and strengthen management skills	Agree	Yes	Agree
	Cancuén	Yes	Yes	Good, especially during the rainy season when equipment is disconnected and put away to avoid damage	Yes	No	No	No	No	Poor	Has helped meet some development goals but has created tension and conflict between the communities	Agree	Yes	Agree
	Chapín Abajo	Yes	Yes	Good	Yes	No	No	Yes	No	Average	Has helped meet development goals although might have increased inequality conditions for women	Agree	Yes	Agree
	Mucbil'ha	Yes	Yes	Some panels were stolen	Yes	No	No	Yes	Yes	Good	Has helped meet development goals and strengthen management skills	Agree	Yes	Agree
	CONRED PVEWS	Yes	Yes	Good, although it's CONRED who provides maintenance	Yes	N/A	N/A	N/A	Yes	Good	Has helped with disaster prevention and warning	Disagree (because of nature of project)	No	Agree
Nicaragua	PVBCS	Yes	Yes	Batteries are abused	Yes	No	Yes	No	No	Poor	Has helped meet some development goals but has created tension and conflict between the communities	Agree	Yes	Disagree
	SINAPRED PVEWS	Yes	Yes	Good, although SINAPRED doesn't know of the adequate use of the systems so can't provide appropriate training to families	Yes	N/A	N/A	N/A	No	Average	Needs to be improved to meet its intended goal	Disagree (because of nature of project)	No	Agree
	El Trapiche	Yes	Yes	Conflict between users	Yes	No	No	No (?)	No	Poor	Has helped meet development goals	Agree	No	Agree
	Río Bravo	Yes	Yes	Implementation of reforestation projects	Yes	Yes	Yes	Yes	Yes	Average	Has helped meet development goals and strengthen management skills	Agree	Yes	Agree
	El Bote	Yes	Yes	Implementation of reforestation projects	Yes	Yes	Yes	Yes	No	Average	Has helped meet development goals and strengthen management skills, although there has been some conflict with some users preferring their previous energy system	Agree	No	Disagree
	Women's solar center	Yes	Yes	Good	Yes	Yes	No	Yes	No	Average	Has helped meet development goals and strengthen management skills	Agree	Yes	Agree

Different governance structures within the same community can work independently if they each have clearly stated goals and target specific population segments. This is especially true in the case of women's groups studied as the community committees are usually formed by men. In recent years, project developers and donors have addressed the gender inequality by requesting that women be included in these committees. In some cases, women's committees are formed to promote their participation within the project and in the community in general. Communities like Chel and Chapín Abajo in Guatemala used two different approaches. In Chel, the women's group was created under the Hydroelectric Association with the goal of having the women participate in the hydroelectric project and benefit from the energy by spearheading their own productive use projects. The current problem is that the Association does not have any funding available to help the women jumpstart their own projects, but are hoping to raise funds to help them once they start selling energy to the other communities. For example, the women would like to open a dining room and start other arts and crafts projects. In contrast, in Chapín Abajo, a local NGO started a weaving cooperative and created a women's group to be in charge of it. This women's group is separate from the Community Development Committee (COCODE), which is entirely formed by men. Both committees have their own projects and do not cooperate with each other. Each one cites exclusion from the other; however, the COCODE indicated that they have tried to work more with the women's group. Here, it is important to keep in mind that indigenous women are oftentimes shy and timid and do not speak for fear of reprimand as it is not within their culture to do many activities outside their homes.

Governance structures are called communal even when they only represent a subset of the population, disregarding the reason (whether personal or external) of the decision to not participate in the energy project. That is, the willing or unwilling exclusion of some members does not influence the communal nature of a governance structure. Within each community, there are people who are against or do not want to participate in a project. In other occasions, people are purposefully not included in the project.

Wade (Wade 1987) states that 'low-cost exclusion technology is a facilitating condition for the management of common property resources'. This was especially true in projects in which the DRE was the commons being considered. That is, in projects in which the DRE was being installed in a common property resource, such as an archaeological site, or an eco-tourism project, the DRE system did not appear to facilitate its management. Results indicate that the DRE project could facilitate the common's management in the future if certain conditions changed, but that the initial context of each project did not allow for it.

In Cancuén's archaeological site, the introduction of the eco-tourism project and the DRE system created social tension as described previously. Because of the bad practices of one community, tourism has not increased since the installation of the DRE system. Although the intent was for the DRE system to facilitate the management of the archaeological site, it has not served its purpose and the eco-tourism project can not self-sustain itself. With a new governance structure, new rules, and new leadership, the DRE could meet this goal in the future. In Chapín Abajo, the PV system used for

illumination to enable the women's weaving cooperative to work at night has actually increased their workload. The end result of the project was not expected or planned initially: women would have to work at home during the day doing their regular chores and then work all afternoon weaving. One member said *'our days are very long, our husband's expect us to do all the work at home like usual, and then we have to come work, so we come here, but we also have to care for our husbands and families'*[263].

In projects such as the hydroelectric plants of Nueva Alianza, Chel, and Río Bravo, management structures were created for the DRE projects (considered as a common property resource) and these enabled the creation and implementation of other productive use applications. The additional projects being carried out in Nueva Alianza are a proof of this.

6.2.2 Case Studies

The ten case studies presented contrast the different issues discussed above. Table 43 summarizes the focus of each case study.

[263] Women's weaving cooperative member in Chapín, Abajo, Guatemala

Table 43. Community governance case studies

Project			Governance			
		Type of Governance Structure	Community participation	Equity	Tariff structure	Commons resource management
Guatemala	Nueva Alianza	Committee	X		X	
	San Jerónimo	Association		X		
	Chel	Association	X			
	ADIM PV	Committee			X	
	Cancuén	Committee	X	X		X
	Chapín Abajo	Committee				X
Nicaragua	PVBCS	Committee		X		
	El Trapiche	None				X
	Río Bravo	Community utility (concesionaria)	X		X	
	El Bote	Association, which also acts as a utility	X			
	Women's solar center	Committee	X			

6.2.2.1 Community participation: Nueva Alianza, Chel, Río Bravo, el Bote, and Women's Solar Center

These case studies present different community participation schemes and their impact upon project outcome based on their specific circumstances.

Nueva Alianza: The community of Nueva Alianza presents an excellent example. Their energy systems (micro-hydroelectric, biodiesel and formerly biogas) together with their projects (coffee, macadamia, purified water, pigs, and ecotourism) are centralized. The community has worked with a lot of unity and communication, derived from the hard work of all the family members to repurchase the land. There is a 'Junta Directiva' of men and women, with each project's leader reporting back to the Junta Directiva. One

relevant aspect of this governance structure is that there is equality in decision making as well as in benefits, including profits, including salary, illness benefits, and special occasions.

Chel: The socialization activities started early on in the process and after approximately three years, the three communities decided to form an Association. Association members, who are mainly the ones engaged in the project and who provided labor, participated actively throughout the project and were decision makers. They voted on the name of the Association, elected the committee officials, developed their own 'internal reglament', and held a contest to design the Association's logo, promoting more interest and involvement from the 3 communities. The Association was key for other community development projects that took place, such as road access and the PV powered satellite phone. They are currently involved in a grid extension to other communities and in enabling job creation and facilitating micro financing schemes to promote productive uses. The Association has also trained and hired community members as machine operators, electricians, and administrative staff and the Association as a whole gets trained periodically on topics that range from technical to computing to financial. As this is being written, they are migrating to a new financial system. Except for the daily blackouts that occur because of the faulty machinery (which has already been replaced), and problems with some uncalibrated meters, beneficiaries appear to be happy with the Association.

Río Bravo: In the rural hydroelectric plants in Nicaragua, independently of the donor and development agency (with one exception described below), the Ministry of Energy and Mines (MEM), has established the structure of communal companies to act as utilities. There is the 'Junta Directiva' that is formed by elected officials that rotate every 2 years without pay. They oversee the operation of the plant and manage the company's activities. The company has administrative, accounting and technical staff that takes care of all the operations. All users are customers with the right to purchase stocks, with only stockholders having decision making power. The goal of the company is to sell more stocks so they can increase their income for future projects and watershed protection activities. In general, people seem content with the company, except for those too poor to afford the connection fee and/or purchase the utilities' stocks. The nearby hydroelectric project of El Naranjo has a similar governance structure.

El Bote: The project, and therefore the community participation, of El Bote differs from the other hydroelectric projects of Nicaragua because of the donor. The organization that started the project and secured its development is in charge of all project related matters: maintenance, operation, administration, billing, grid extension, new connections, etc. Community members expressed they have not been involved in the process at all, although some informative meetings did take place: *'In the beginning we were told what was happening with the project, but now they only bill us and we don't know of new plans or what else they are doing'*[264]. Users compare their local company with the abysmal national utility due to the high number of blackouts and high energy

[264] Hydroelectric user in El Bote, Nicaragua

tariff which includes public lighting costs even when most communities do not receive this service. Some respondents said they would have preferred it to be communal so they can be more involved and know what is going on with the project. The NGO/company has created jobs by training and hiring machine operators, electricians, linemen and administrative staff, but there has been a lot of personnel rotation primarily due to the low salaries, although the low salary has been a complaint in all the projects visited. During the interviews, the answer to many questions was 'Ask the company, they know'. Even within the company, answers lied within one person. Long-term, this could lead to the failure of the project as it will be very difficult to provide continuity. The current plan is to transfer the project to the municipality once the World Bank loan is paid; however, the municipality has only been engaged in the upkeep of the roads. Users feel differently and state the project should be transferred to them. Whether the project is transferred to the municipality or the communities, information sharing is essential. Of course, the transfer of the project to the municipality can create conflicts as there are two municipalities involved: El Cuá, where the headquarters of the company is located, and El Bote, where the hydroelectric plant sits.

In terms of operability, the Chel Association and the Río Bravo and El Naranjo hydroelectric utilities are working well, with few problems. Besides the bigger differences that exist between an association and a company, such as legal structures, statutes and objectives; the main difference from the community participation perspective is who has a decision-making role: the community at large or the stockholders. In any case, the two approaches that have direct community participation

were the ones in which respondents seemed the most pleased and had fewer complaints. Especially for the Nicaragua cases, poor families would like to see the companies help them benefit from the project and not increase inequality.

Women's Solar Center: In other cases, people are willing but unable to participate in the project. The women's group of Totogalpa, Nicaragua, has a long list of requirements to join the group. Among them, women have to put 50 hours of voluntary labor in the Solar Center before they are considered part of the group. Once accepted as group members, they do not necessarily receive a salary, and commonly, most of their work remains voluntary, except for when they get funding for a project and not all women are in the possibility of donating hours. It is unclear how much unity has been created, or broken, because of this, and if this is a matter of concern. Thus far, the group seems to be working well, except for some complaints of the current Junta Directiva's bias.

6.2.2.2 Equity: San Jerónimo and PVBCS

The case studies presented in this section show that lack of equity within a project can lead to social tensions and threaten the sustainability of the projects. In some cases, social tension began with the arrival of the DRE projects.

San Jerónimo: The San Jerónimo watershed presents a very different governance model as the resource governed is water and not energy. As detailed previously, two of

the hydroelectric plants are privately owned by the same utility, the third one is publicly owned, and the downstream irrigation users are represented by an Irrigation Association. These three entities (private company, municipality and Association) have to work together for the well-being of the watershed and the water users. Although the best interest of all the water users is always sought, it is not always possible as those in the upper watershed usually dictate what happens in the lower watershed. In recent years, however, the utility, the municipality and the Association have been able to reach agreements on some topics for a win-win situation. The equity problems arise as those in the lower watershed, primarily the irrigation users, are subject to the water quality and quantity delivered by those in the upper watershed. Irrigation users include ostrich farms, several fish (tilapia) farms and diverse crops. The municipal hydroelectric project also claims inequality as they can not always generate when they would like to as their water supply is subject to the activity of the two private hydroelectric projects upstream. This situation endangers the sustainability of this project as they can not reach projected profits because they can not always sell to the country's electricity market when needed.

Cancuén: This project presents an example of how a lack of community participation (within each community and among the three communities) can lead to inequality and exclusion towards those who are not directly involved. Members of the 'Junta Directiva' of each community, and their immediate families, are the only ones who benefit from the project's income. Other community members know of the existence of the project and either do not know details of it, or indicate that they know of it although they do not

benefit as there is not enough profit to develop communal projects. Therefore, although the original intent of this project was to create joint participation between three communities that individually would not be able to attract and manage the tourism and archaeological site, those involved seem to be jealous of their positions and do not allow much participation from community members outside their 'inner' circle. The Junta Directiva argues that *'we do not make enough money to hire more people, if we get more tourists, then we will ask for more people to participate'*[265] although some women indicate that *'we are excluded from being called to cook for tourists because our husband's are not involved, so they don't let us participate'*[266].

PVBCS: In this example, we explore how the change in focus on behalf of the donor led to inequality and exclusion. As explained previously, the Ministry of Energy and Mines (MEM) of Nicaragua, with World Bank funding, installed PV battery charging stations (PVBCS) in 5 communities, out of which 2 were visited. These projects are considered communal because of the centralized structure, and have a community energy committee even though approximately only one third of the communities benefits from the system. There was not enough funding to provide a battery system to each household and a selection criteria process was created to benefit those families with the highest possibility of maintaining their battery systems. The committee appears to only look after the families that are benefiting from the project and it remains unclear if the committee is also seeking other electrification alternatives for the remaining two thirds of the population. The committee is in charge of monitoring the use of the batteries,

[265] PV user in La Unión Guatemala
[266] PV user in El Zapote, Guatemala

assisting users charge their batteries, maintaining the charging station and billing and saving the money for battery replacement. A common problem found is that people do not charge their batteries as often as they should; besides drastically decreasing battery life; the collected tariff is not sufficient to replace the batteries. These deep cycle batteries have an expected life of between 4 and 5 years and most of them are at the end of their useful life at 2 to 2.5 years. The committee seems to have adopted a new role: seeking a new donor to replace the used batteries, bringing new batteries for the unelectrified homes (which includes installing additional PVBCS for the added capacity) or installing individual domestic systems. From the beginning, people wanted to have individual PV systems, and were afraid they would not receive any project if they rejected the PVBCS proposal. Perhaps their desire for having another type of renewable energy system deters them from enforcing better use and operation guidelines and stopping users from abusing the batteries (for example, bypassing the charge controller and connecting alternate current equipment, such as refrigerators, TV's and DVD's, directly to the battery, when the battery can only take a limited number of 12 V direct current appliances). As discussed in the following section, funding sources and development entities impact the outcome of projects and this project is an example of how a new electrification approach intended for use as a case study has led to dissatisfaction and social tension within the beneficiary communities.

6.2.2.3 Tariff structure: Nueva Alianza, ADIM PV, and Río Bravo

The different tariff structures presented in these case studies portray the ways in which communities have sustained their projects.

Nueva Alianza: Because all families in the community have been working together, they decided to pay a flat electricity tariff. Homes that are farther away from the distribution lines have to pay an additional fee to cover the extra wiring required, but as long as their electricity consumption remains within a specific range, the tariff is the same. The committee has a set of rules in case of late payment (for one or several months), lack of payment and high electricity consumption. The community has tried to impose rules on electricity use as their demand is higher than their generation capacity. Each home is equipped with a fuse to monitor their consumption; when the fuse needs to be replaced, the home owner has to pay for its cost plus a penalty fee. Most families pay their tariffs promptly; however, there are some problems that can hamper long time sustainability of the biodiesel and micro-hydroelectric projects. The established electricity tariff does not cover the maintenance requirement of the DRE systems. Furthermore, with some families still consuming more than their specified limit, together with other technical design failures of the system, the systems need more repairs than what a properly designed and maintained system would require.

ADIM PV: The ADIM and MEM PV projects had set up 'energy committees' in each community they worked in. In both cases, the committee members were elected by the community, including a treasurer in charge of collecting the monthly fee and deposit it in a bank account, and one or several technicians that could assist the community members with repairs. In Sta. Clara, a community under the ADIM project, people were paying their monthly fees even after the previous treasurer had run off with the money hoping to cross illegally into the US. However, they were unaware of the benefits they were entitled to by paying the fee, such as technical assistance from their own energy committee and ADIM and battery replacement. One family paid their fee; however, every time their battery died they would purchase a new PV system. On the other hand, other communities that benefited from ADIM stopped paying their monthly fees and some do not know who to contact should they encounter a problem with their system. In the communities where MEM loaned PV systems, people would call the community leader who would then call the MEM. The MEM tries to go out to each community once a year, or when there are problems, such as panels being sold or robbed. Otherwise, the communal energy committees did not meet their initial objectives. As a conclusion, except for the case of Sta. Clara, all the other communities preferred to keep the finances individually and this has been successful in some communities, especially in south east Guatemala, although this is related to cash flow availability, as described earlier.

El Trapiche: There is no established tariff in this project. The donor subcontracts a German PV company based in Nicaragua to provide all the required maintenance. As

long as the community continues working on the purchased land, the donor will continue supporting the upkeep of the existing projects as well as developing new ones. This set-up has created social tension besides creating unsustainable projects: if the donor should step away from the community or the community decides to abandon the land, the community will not be able to sustain their multiple projects as they lack the technical and financial capacity.

Río Bravo: The electricity tariff is based on users' monthly consumption. The tariff also includes a fee for public lighting, although not all communities had it at the time I surveyed the project. As of now, they are not able to charge an 'industrial' fee for those who use power equipment for workshops and productive applications, although they intend to implement one in the future. The communal utility has employees who read the meters each month, issue the bills, receive payment and provide receipts. There is also a treasurer who makes sure there is available funding for required operation and maintenance as well as for grid extension to surrounding communities.

6.2.2.4 Commons resource management: Cancuén and El Trapiche

Lastly, these two case studies show the role that DRE's have played within other commons, with the DRE system itself also considered a common.

Cancuén Archaeological site: The archaeological site is jointly managed by three communities who have formed a tourism association named Asociación Américas. Each

community has a particular role within the Association (transportation providers, guides, rangers); however, despite the Association's rules and regulations, there is mounting inequality that has caused detriment to the project. One of the communities is situated in a key location: the side of the river that constitutes the only access to the archaeological site. This community formed its own tourism association (Asdetun), completely independent from Americas, to regulate the water transportation earnings. This, in itself, does not represent a problem; however, Asdetun sought its own interests and benefits above those of Americas' causing damage to the tourism of the region. Asdetun established a high transport tariff to the archaeological site and tourists did not want to pay an 'additional' entrance fee, creating unhappy tourists and frustrated tour guides. Asdetun does not give any percentage of their earnings back to Americas and refuses to lower the transportation fee, claiming the cost of the lancha (boat) is too expensive. The lancha, however, was donated to them by an international aid organization promoting tourism in the region. This international aid organization has, together with local NGO's, promoted a tourism corridor benefiting several communities. Asdetun's actions have caused Americas' members to close the archaeological site tourism activities as there is not sufficient income and the workers have to look for alternative jobs.

In this specific case, the definition of 'common' varies. The archaeological site is considered a common good of the three communities; however, the only ones that see a benefit are those directly involved: the community leaders, the trained tour guides and other staff. Some have been deliberately excluded because they or their spouses are

not in a leadership position. These people do not perceive any benefit nor consider the site communal. Despite these problems, other communities have been interested in joining the Association but it has not been possible thus far.

El Trapiche: The land the German professor purchased, together with the solar pumping system, are common property for the benefit of the entire community. Despite this, community participation in this project has declined and social tension has increased over the years, mainly due to the lack of consistency between the donor's objectives and the user's needs. Although not everybody benefits equally from the use of this land, support of current and future projects depends upon its maintenance. Few people work the land for the benefit of the entire community, which is not entirely due to the community's reticence: there is just not sufficient land for all the families to work at the same time so families have had to seek other jobs. Even though the entire community looks forward to receiving more projects from the German professor, when social tensions peak, community leaders tend to exclude other members from participating and cut them from other services, such as water supply to household taps.

In practical terms, neither the land nor the PV solar pumping system, are commons, a situation that could have been avoided had the community been consulted and involved in the planning process. This example highlights the problems caused when a donor imposes their will, despite them having good intentions.

6.3. Project Management and Financing Sources

Project management and financing sources affect the success of projects. The objectives, requirements, and long term commitment of the funding sources and the manner in which project management is put together and structured can have an impact upon the projects' outcomes. The funding source or sources determine the availability of resources for feasibility studies and follow-up activities, and the depths of these. In some cases, funding might simply not exist for these aspects, or not be feasible because of the donors' timeframe; in others, donors might be interested in only funding other aspects of the project.

One of the hypotheses of this thesis is that projects' funding sources and development entities, and the project management structure they put in place, affect project success. Carbon financing, development financing, or both provide the majority of funding for renewable energy projects, as explained throughout this section. Some projects originated with development funds alone and are now being complemented by carbon financing.

The projects included in this dissertation have diverse funding sources and development entities, as detailed in Table 44. Table 45 describes the different funding sources and development entities mentioned in Table 44.

Table 44. Summary of funding and development entities, by project.

Project		Primary Funding Source Type	Main Funding Entities	Main Development Entity
Guatemala	Nueva Alianza	Various - Multilateral development organizations and local university	UNDP, Universidad de San Carlos	Community
	San Jerónimo	Private	ENEL	ENEL
	Chel	Various - national and international civil war reconstruction, multilateral development organizations	FONAPAZ, USAID, European Union	Fundación Solar
	ADIM PV	Various - national and international civil war reconstruction	FONAPAZ, USAID	Fundación Solar
	Cancuén	Bilateral aid organization	USAID	CI
	Chapín Abajo	Local NGO	FDN	FDN
	MEM PV	National government	Guatemala MEM	Guatemala MEM
Nicaragua	PVBCS	Multilateral development organization	World Bank	Pana Pana
	El Trapiche	Private	German Professor	German professor and students
	Río Bravo	Multilateral and bilateral aid organizations	UNDP, Swiss Cooperation	Nicaragua MEM
	El Bote	Multilateral development organizations	World Bank	ATDER-BL, Nicaragua MEM
	Women's solar center	Local university	Grupo Fenix, National Engineering University	Grupo Fenix, National Engineering University

Table 45. Description of funding and development entities.

Funding entities	Multilateral and international development organizations	Organizations formed by several countries, either globally, or by region, to work on its member countries', or other developing countries, best interests and needs
	Bilateral aid organizations	National organizations created by individual countries with the purpose of providing aid to developing countries
	National governments	Entities within each country that work on a particular sector's priorities. For the case studies, the main national government entities were the energy and environment ministries.
	Private sector	Companies with private funding
	Public universities	Universities with national government funding
Development entities	Local non-governmental organization	Non-governmental organizations created and/or based in the country in which the projects are being implemented. For the case studies, these have a grass-roots approach and are focused on either development or environmental causes. For example, FS, Pana-Pana and ATDER-BL have a development focus while FDN and CI have an environment focus
	Private sector	Companies with private funding

Literature on project financing has mainly focused on the post-investment phase, how the project will be financially maintained after its installation, which has been discussed in Chapter 5. Literature focusing on the role that funding sources have on project success is scarce. Eberhard and Gratwick (2011) analyse the role of 'development finance institutions along with the development origins of the firms' as a determinant of success in energy sector projects in Sub-Saharan Africa (Eberhard, Gratwick 2011). Although their study includes independent power producing (IPP) schemes, they find the need for a coherent communication and coordination between the entities in charge of designing energy demand plans and those creating accurate supply forecasts. They

also identify some differences in project planning, implementation and outcome from varying funding entities, recommending what has helped and what can be improved. In a parallel study, Malgas and Eberhard (2011) coincide in the conclusion to link planning, procurement and contracting activities to avoid future problems with the project, both during implementation and after commissioning (Malgas, Eberhard 2011). As in the case of the DRE projects included in the case studies, oftentimes there are different funding entities involved in different project phases, which may have specific development goals which do not necessarily meet the needs of intended beneficiaries.

The specific indicators that were used to evaluate the role of financing entities are the implementation process of each project (planning, execution and follow- up) and the consideration that was given to community participation within each phase.

The main **research questions** ask:

1. **How do projects' funding sources influence projects meeting their stated goals?**[267]

1. Is there consistency between donors' objectives and users' needs and expectations?
2. What implementation process is followed?
    - Are enough resources allocated to each phase within a project?
    - Is adequate planning carried out?

[267] Projects' stated goals are as defined throughout the previous chapters of this dissertation.

- Is there sufficient community participation?
- Is there an appropriate follow-up plan?

The terms *enough, adequate, sufficient, and appropriate* are based on the responses of interviewees. They are not indexed to, for example, the number of meetings, training sessions, or communal activities carried out. Rather, they indicate whether system beneficiaries considered the implementation process to be complete enough to enable them to care for their systems in the long term.

The data analysed for this chapter was obtained from project profiles developed by funding entities and developers, as well as from community, developer, donor and government surveys. In this section, I analyse consistency between donor objectives and user expectations and between project funding sources and project management structure as indicators for project success.

Project funding and development entities have their own specific goals, objectives, funding and schedules, which may or may not coincide with those of the host country, and ultimately, those of the beneficiary communities. Users also have individual needs and expectations of the projects. Users' expectations may not coincide with what the projects will ultimately deliver; however, respondents in this study indicated that misguided expectations led to displeasure with projects, and in some cases, social tensions. As such, the specific indicators used are these:

- *expectation* is used as a proxy to determine the *level of community participation* through the project and as an *indicator of objective and needs consistency*.
- *consistency of drivers (that is, consistency between stated objectives and community needs)* is used as one of the indicators of project implementation process by helping infer levels of *socialization, training and community input* in the project. This indicator allowed me to deduce the following:
  a. if and how community needs and ideas were included;
  b. how much consideration was given to the local setting (such as cultural, social and religious context); and
  c. the level of community engagement engendered to allow the project to be transferred to the users and for users to realise project ownership.
- *community participation, socialization and training, project planning, governance and tariff structure* indicators to analyse the variation depending on the funding entities involved in the projects.
- *technical inspection protocols* to evaluate if and how *technical standards* were applied and if any *follow-up inspection* has been carried out to date.
- *private or communal ownership* to determine the role and influence of funding agencies and community members over the projects.

6.3.1 General Findings

I found that project funding sources impact implementation processes, which in turn affect some indicators considered important for project sustainability: consistency between users' needs and expectations and donors' objectives, definition and level of

community participation, technical quality of DRE systems, and extent of follow-up on projects.

Consistency between donor objectives and user expectations is considered by project beneficiaries to be an important factor affecting project success. However, user expectations were not the only indicator of consistency. Some users indicated that while their expectations had been met since they received energy, they had not been met in the process, for example, by not being included in the planning phase. Therefore, two additional survey questions were included to complete the analysis of driver consistency:

1) Has the project had a negative impact in your daily activities? and,
2) Is there any part of the project that is not successful?[268]

Users' expectations were not met for a variety of reasons which were found to be derived from some aspects of the project phases as described below.

The project evaluations were tools to examine the existence of the different project phases and how these changed according to the funding and development entities. Three different phases are identified: pre-investment (feasibility studies, project planning, socialization), investment or execution (actual system construction and user training), and post-investment (project follow-up by all involved stakeholders). The results confirmed the hypotheses that funding sources dictate whether a project

[268] As in the previous chapters, the definition of success is perceived differently by each user; therefore, the analysis carried out is qualitative.

progresses through all three phases and that problems in one or more of the project phases can hamper project success.

6.3.1.1 Mismatch of donor objectives and user expectations

Lack of agreement or understanding on the system's capabilities and uses: The original expectations of users were sometimes not met because the energy systems were not designed to power all the appliances the users wanted. The best example occurred with PV home lighting systems, where capacities ranged between 12 and 50 W. Although their main purpose was illumination, they also allowed for the use of a radio or a small black and white television. Some users had expected to use bigger appliances such as color televisions and refrigerators, for which the PV systems were not designed. In some of these cases, there was not enough socialization with the beneficiaries as their misunderstanding was not clarified. There were, however, other cases in which socialization and training was done with users being instructed what they were able to use. Despite this, larger appliances were still connected, damaging the system and creating social tension[269].

There are also cases in which user expectations are not met for reasons that are external to the DRE project, despite good quality of service and community participation. The mini-hydroelectric plant of Río Bravo is an example. In anticipation of the project, many families purchased television sets. However, they have not been able

[269] Please refer to the case study of Nueva Alianza, presented in Chapter 5.

to watch TV, not because of a problem with the hydroelectric plant, but because the mountainous region in which they are located is not within the service territory of broadcast television. For example, a user complained that *'I want to watch soap operas, not old movies. I have to keep buying DVD's and the quality is bad. We were all expecting to be able to watch TV'*[270]. In this case, the provision of electricity was a consistent beneficiary expectation and developer goal. However, some users were none the less disappointed with this unanticipated limitation.

High number of blackouts caused by technical failures of the systems: The reasons varied from bad technical design and installation to non-existent or inappropriate maintenance protocols[271]. Examples of these were seen during fieldwork and are explained in detail in the following section of this chapter.

Lack of community participation: The definition of community participation varied across countries, as described in the previous section of this chapter, and ranged from knowledge of the project and being informed of updates to being decision-makers in issues related to the energy project. At the very minimum, users wanted to be aware of what was happening with the project, not just to be aware of its existence.

Lack of follow-up. Systems failed to meet expectations when they were working poorly (per user responses and perceptions, not necessarily per technical inspection protocols, as explained in the examples above) or stopped working entirely. For the purposes of

[270] Hydroelectric user in Río Bravo, Nicaragua
[271] In some cases, appropriate protocols were unusable because of poor technical design of the DRE system. An example of this is presented in Section X of this chapter.

this study, follow-up means work done by the donor or developer after the installation of the systems is completed and project ownership gained by the community for its long term sustainability.

Lack of appropriate timing: Another important finding is the need for consistency in timing: for a successful and functional project there must be consistency between the time in which the budget needs to be spent and the time required for the proper planning, execution and follow-up of the project. In some of the projects, the budget allocated did not suffice to carry out all the required socialization and training; in others, the budget expired before all these activities could be completed. The communities described in Chapter 3 that were provided with PV home lighting systems as part of a hurricane reconstruction program are a good example: the project had to be fully executed within one year, in sharp contrast to longer timeframes typically allotted for rural electrification under development programs. The initiative did not allow for the longer-term socialization and training for the operation and maintenance of the PV systems that is usually necessary. As was described in greater detail in Chapter 3, after installation users reported that almost 80% of the total installed systems had been sold to a 'recycling man'[272] who knew of the project's weakness.

Although the municipality of Cahabón received good emergency response, the reconstruction efforts did not lead to the expected improvement in community

[272] It was later discovered that the so-called recycling man was the vendor of the equipment, who was aware of how the project had been developed and implemented. During my fieldwork, I found some of the original systems in other parts of the country, where the vendor resold, sometimes for many times as much as he paid beneficiaries.

adaptation to future extreme weather events. The most recent storms of 2005, 2010 and 2011 devastated the region; poverty alleviation indicators did not improve and, although this research did not analyse changes in the region's adaptive capacity, it is evident that this did not improve.

Table 46 summarizes these findings.

Table 46. Summary responses of mismatch donor objectives and user expectations

Project		Mismatch of donor objectives and user expectations			
		System's capabilities and uses	Cause and number of blackouts	Community participation	Follow-up
Guatemala	Nueva Alianza	Consistent	Frequent blackouts with the micro-hydroelectric plant because of faulty design and components	Consistent	The community has done proper follow-up, but the same can't be said about the different donors
	San Jerónimo	Yes, this is a project connected to the national grid. Nearby communities do not perceive any difference in the electricity they receive nor the tariff they pay	Minor technical failures and for preventive and reactive maintenance	Community members were only informed, but were not decision-makers	Consistent
	Chel	Consistent	Technical failures every day until the problems were fixed after fieldwork was completed	Consistent	Consistent
	ADIM PV	Consistent	Batteries are not properly maintained nor changed. Some families use appliances that aren't suitable	Consistent	Lacking
	Cancuén	Consistent	Lack of system maintenance	Only for those involved in the tourism project. Other families are not included.	Lacking
	Chapín Abajo	Consistent	Consistent	Consistent	The staff of the NGO helping the community can improve their understanding and training on solar systems.
	MEM PV	Consistent	Lack of system maintenance, mainly battery upkeep	Consistent	MEM visits the systems twice a year if possible, but it would be highly beneficial if they could go more often.
Nicaragua	PVBCS	Yes, users wanted individual home lighting systems and wanted to be able to use more appliances	Users use more appliances despite the limitations of the system causing batteries to discharge quickly and shortening its life	Somewhat, only one third of each beneficiary community got a battery kit as there wasn't enough budget for the entire communities; therefore causing tension.	Batteries were recently replaced, although more follow-up is needed. Users (and non-users in the community) except to eventually get their individual lighting systems
	El Trapiche	Yes, community abides by what donor wants to do to continue receiveing projects	NA	Somewhat, some users continue working on the project because they want to continue benefitting from the donor, other users have quit the project because it really does not benefit as aspected.	Users only know to call the system vendor
	Río Bravo	None, except that some users wanted to watch TV and there is no TV signal reaching the communities, which is not related to the hydroelectric project.	Demand has grown and there are blackouts during peak time	Some users want to have greater involvement, although not can afford being a stockholder	Project is ongoing
	El Bote	Consistent	Mainly related to the connection to the national grid	Users are informed, although they had expected greater participation, better service and lower tariffs	Project is ongoing
	Women's solar center	None - although initially the project had another objective	Consistent	Only for those involved in the project	Consistent

6.3.1.2 Problems in Project Implementation

Paucity of community participation was a root cause of problems discovered in all parts of project implementation, including planning and follow-up. As indicated above, *community participation* meant different things in the different communities, and although not all system users wanted to be heavily involved or become decision-makers, all wished to be heard, understood and informed of project happenings. Depending upon implementation phase, lack of community participation – using any of the definitions provided – had different consequences.

Within the planning phase, the main consequence was a lack of full knowledge of the project, leading to a lack of consistency between project objectives and user expectations, as explained above. Within the construction or implementation phase, lack of community participation resulted in a lack of knowledge and, more importantly, a lack of ownership as it limited their involvement. Finally, within the follow-up phase, the prior lack of community participation and involvement will lead to a lack of sustainability due primarily to the lack of an appropriate transfer mechanism and, therefore, a lack of ownership.

Interviewees pointed out how their participation could have harnessed their willingness to have greater ownership of their DRE system and therefore improve the DRE system's outcome. Trust between all the stakeholders, and mainly between the users and the developer and between the users and the equipment vendor, is crucial. One

case study showed how this trust link was built over many years, with numerous focus groups to socialize the project. This ensured that this project, completed after 14 years of hard work, is still functioning almost eight years after completion and expanding thanks to the leadership within the community. A user expressed *'Fundación Solar (the NGO that developed the project) worked with us from the beginning and we've all worked hard together, like a community does.'*[273] The opposite happened in another project where only a small subset of the users were involved from the beginning: the NGO in charge of the project is being compared with a for-profit utility company. A user said that *'I am upset I have to pay so much, the service is bad, I am not even informed of what is happening with the project, I just have to pay,'*[274] while another expressed *'At the beginning we were informed with greater frequency, but right now, they are just expanding the system and the workers are very rude. If we don't agree with the tariff they'll just cut the service, like Unión Fenosa (the utility that operates in the concession zone).'*[275] The PVBCS of Nicaragua also posed this problem: *'We didn't want this project; we want our own PV systems, and we are waiting for another donor to come.'*[276]

As explained previously in this chapter, good governance practices are considered necessary to define roles and responsibilities for the adequate care of the project, conflict resolution, and technical and financial management guidelines. Good governance practices derive from community participation; therefore if good governance can not properly be attained, it can hinder long-term sustainability.

[273] Hydroelectric user in Chel, Guatemala
[274] Hydroelectric user in La Pitilla, Nicaragua
[275] Hydroelectric user in Peñas Blancas, Nicaragua
[276] PVBCS user in Francia Sirpi, Nicaragua

To summarize, community participation is an important factor in ensuring the congruency between project goals and user expectations. Having open and honest communication will ensure that users are knowledgeable of the project, their expectations are realistic and are being met, and their rights and responsibilities are well defined. Users who have not had adequate opportunity to participate in the project expressed that *'They only asked for my opinion at the beginning, after that they only come to charge,'*[277] *'I wanted to use a blender and a refrigerator, but the battery doesn't last long; I can't use the appliances I've always wanted,'*[278] and *'I was told I had to pay a tariff, but I don't know what it's for.'*[279] Notably, not all responses obtained were related to a lack of community participation: in some cases, users did not believe that the proposed project would come to fruition and did not get involved until they saw a successful project. For example, community members in Chel indicated that *'We were war refugees, our family members were massacred, we didn't believe in anyone. We didn't believe the project would actually happen'*[280] and *'I didn't want to put labor into something that wasn't going to happen! I have to work to earn money for my family.'*[281]

As can be inferred then, one of the key findings is the importance of the presence and drive of a local leading NGO that works closely with community members to ensure their participation throughout all the project phases.

[277] Hydroelectric user in La Pitilla, Nicaragua
[278] PVBCS user in Francia Sirpi, Nicaragua
[279] PV user in Sta. Clara, Guatemala
[280] Hydroelectric user in Chel, Guatemala
[281] Hydroelectric user in Xesaí, Guatemala

Below I describe specific problems during the planning and follow-up phases.

Pre-investment/planning phase: All of the case study projects included a pre-investment phase with some level of community involvement. At a minimum, meetings were carried out to inform communities about the project and its benefits. Degree of community involvement varied by funding source. Based on the case studies included in this dissertation, projects with private funding which were to remain in private hands emphasized community participation less. Projects led either by the community or by a local NGO used a grass-roots approach in which community participation was one of the main pillars.

While the private funding/development agencies may have carried out few sessions with a primary goal of providing information about the project, the communities may have had greater expectations: *'We had a few meetings, and we were all hoping to be part of the project, but they just came to inform us in the beginning.'*[282] It was also unclear if and how community concerns were addressed and what user perceptions were at the beginning of the project, as described in the case study of the Matanzas small-scale hydroelectric project included in Chapters 4 and 5.

Projects with a grassroots approach usually involved a breadth of leveraging donors. This funding paradigm allows more flexibility in meeting community objectives: a dominant donor may drive a project to comply primarily or solely with its own objectives, where a variety of donors may support a project to meet a variety of objectives. This

[282] Hydroelectric user in La Chata, Nicaragua

breadth of objectives is more likely to include objectives important to the community. The micro-hydroelectric project of Chel had numerous donors, whose objectives ranged from broad civil war reconstruction to specific goals like the expanded use of renewable energy technologies. Chel's project was developed by the community-led association, with substantial support from a local NGO.

In another example, the community members of Nueva Alianza were the main drivers of a series of renewable energy and other projects, without the ongoing support of any single NGO or government agency. They sought and received considerable external support ranging from international NGO's to a local university. Other entities and individual professionals assisted with the development of project proposals and provided technical assistance and training. This community was also able to leverage the funding of the different donors to meet multiple objectives, including the use of renewable energy, women's empowerment, and community economic growth.

Although all projects included some degree of project planning and developed feasibility studies, they focused primarily on technical aspects of the energy systems. Social feasibility studies were occasionally carried out. Environmental impact assessments were focused on the impact of the technologies on the environment, rarely considering the impact of the environment on the technologies, such as potential consequences of extreme climate events on the RET's and subsequent effect on users.

To conclude, community involvement during the planning phase proved to be an important first step to a successful project.

Follow-up: Users and developers interviewed for this research agree that more training is required and that the usefulness of two or three hour training courses is overstated. A government official indicated that *'these short courses do not work and they need to be periodic, intensive day-long trainings.'*[283] This sentiment is shared by the majority of users interviewed, who expressed a desire to have re-training, preferably hands-on, and indicated that the original trainings were insufficient. For example, a solar PV user said *'by the time we had to change the battery, three or four years after the installation, we forgot what the training said to do, and then nobody comes out again, so we don't get help.'*[284], while another stated that *'if we had received sufficient training our systems wouldn't have broken down,'*[285]. The former quote is important as it emphasizes the importance of retraining: concepts need to be relearned to ensure that knowledge remains with the project users when needed, when problems arise. Although government and users argued in favor of more training, donors argued that it would increase project costs and needed commitment. This suggests the need for another evaluation of consistency between donor and user goals: some of the donors indicated that they were being evaluated by the number of installations done per year rather than the long-term sustainability of systems installed, whereas users are clearly interested in the availabilities of their own systems over the long term. An official expressed with regret that *'we are evaluated by the number of beneficiaries, therefore, our number of*

[283] Interview with a Nicaragua Ministry of Energy and Mines official
[284] PV user in Col. Agrícola San Juan, Guatemala
[285] PV user in Chiis, Guatemala

installations is the most important measure of success, and we need to make sure we use our budget efficiently (to meet that goal).'[286] Under these circumstances, it is unlikely that increased budget will be allocated to training purposes as it might decrease the number of systems installed. Program evaluation indicators (and therefore, driver consistency), can and will change over time, and it is important to keep track of how donor's requirements and objectives change, and to know if these changes are still consistent or compatible with those of the project and of the communities' needs.

The continued presence of a local entity is needed in most cases and funding must be made available to enable this. The most successful example happens in the community of Nueva Alianza. Other successful examples in which there is a minor role of a local entity include the communities of Chel and Chapín Abajo where the DRE systems continue working. But in cases like Cahabón, where the local NGO was in the country and there was no funding for them to do more extensive training and follow-up, the project collapsed. A Cahabón user lamented that *'When the system's started to fail, we didn't know what to do, or who to call. We felt abandoned.'*[287]

In the specific case of PV systems, follow-up was absent for several reasons: lack of funding for the developer to visit systems periodically; lack of re-training, which was deemed necessary by the users; lack of or inadequate vendor-user warranties; and increased crime rates by gangs and drug cartels that make it difficult for vendors to visit the systems or users to buy spare parts. Many PV systems had not been inspected

[286] Interview with a US Department of Energy official
[287] PV user in Chaslau, Guatemala

since they were installed, with respondents indicating either that there were no past visits, or that past visits did not include exhaustive inspections, and consequently failed to detect problems that could have been resolved. For small scale hydroelectric plants, the main reason was lack of funding for personnel to conduct follow-up visits or, in some cases, to buy replacement parts. In some hydroelectric projects visited, community members indicated there are plans for re-training; one community had already carried out additional training, although operators stated that they needed more. Other hydroelectric plant technicians were enthusiastic: *'The NGO that has been helping us has said they'd give us more training, we had one a few months ago and we will receive a new one.'*[288] While comparing the follow-up afforded to PV and small scale hydroelectric systems, note that the life of the projects and their years in operation were considerably different. Some of the PV projects visited were 10 years old while some of the hydroelectric plants had only been operating for 2 years. Nonetheless, recurrent training was a topic for users of both system types: '*it would be good to have training more often so we always know what to do if there's a problem. They come once to train and then they forget us.'*[289]

6.3.1.3 Nature of project ownership

The private or communal nature of project ownership is determined by the funding source. Based on the case study projects, private financing sources, which are more frequent in larger scale hydroelectric projects included in this research, more often

[288] Hydroelectric user and technician in Chel, Guatemala
[289] PV user in Gualibaj, Guatemala

finance private project ownership. Examples of this are seen in the hydroelectric plants in the San Jerónimo watershed of Guatemala. The two larger capacity small-scale hydroelectric plants[290] that are located in the upper watershed are privately owned. According to members of the surrounding communities, their benefits to local populations are minimal: *'they (the private company) hired some of us to build the plants, but afterwards only very few kept a job,'*[291] and *'we wanted them to help us repair the roads, as they also use them, and they use heavy equipment and big trucks; we don't. But they focus more on education and health programs, and only sometimes help us with what we really want.'*[292] Large scale hydroelectric plants have long been a source of conflict in rural areas in many Latin American countries, since the communities think they should get more benefit from the use of 'their' natural resources.

Only projects that involved international aid organizations or a variety of donors showed evidence of full community ownership. Projects with financing from multilateral institutions had a varying degree of communal ownership, which depended upon the mission and objectives of each financing institution. As concluded above, the success of systems under community ownership supports the hypothesis that communal participation is a key factor that enables long-term system sustainability. Communal participation is found to be a precursor of communal ownership of DRE systems. The degree to which the developer engenders communal participation relates to the ultimate degree of community ownership, as seen in Nueva Alianza and Chel.

[290] Small scale hydroelectric plants are defined as having a capacity between 101 kW and 5 MW. As can be seen, there is a big difference as the lower range capacity is more suited towards community applications while the upper range capacity is more suitable for grid connection systems.
[291] Respondent from San Jerónimo, Guatemala
[292] Respondent from Matanzas, Guatemala

Table 47 summarizes the results described in this section.

Table 47. Summary responses to problems during project implementation

Project		Problems in project implementation			Project Ownership
		Pre-investment/planning phase	Community participation	Follow-up	
Guatemala	Nueva Alianza	No problems	No problems	Only with a subset of the projects in which the donor didn't always give proper follow-up, such as the case of the micro-hydroelectric plant	Communal
	San Jerónimo	Communities were informed of the project, some expected greater involvement	No problems	No problems	Private
	Chel	A lot of trust-building was required due to the civil war past of the region	Because of the lack of trust, community participation evolved as a better understanding of their benefits became clear over the years.	No problems	Communal
	ADIM PV	A lot of trust-building was required due to the civil war past of the region	Because of the lack of trust, some people didn't trust their appointed committee members, or if they did, they did not know exactly what their role was or why they were paying a tariff.	There hasn't been budget to do proper follow-up except for occasional system inspections (and these don't always include budgets for system replacements)	Individual
	Cancuén	No problems	None (the problems that are present now are mainly due to governance and organization issues)	It is greatly needed to get the system working to its full capacity again.	Communal
	Chapín Abajo	No problems	No problems	No problems	Communal
	MEM PV	No problems	Although energy committees were set up in every community, they only functioned for months at the most and afterwards each household took care of their own system independently.	The communities receiving these systems are those which will receive grid electricity in the short to medium term. Some users who have already been grid connected refuse to return the panel as the panel is more reliable than the grid electricity, which causes problems within MEM and MEM does not have the capacity to deal with the problem.	Individual
Nicaragua	PVBCS	Yes, users did not get what they wanted as there was not sufficient budget and the donor wanted a case study of a different approach	Yes, only those who received a battery kit participated, creating tension within the communities	It has been carried out to some degree but can certainly be improved	Unknown (not entirely communal as the entire communties aren't invovled)
	El Trapiche	No problems	Yes, problems with leadership and functionality of the project itself	Donor always takes care of problems as users do not know operation and maintenance protocols.	Communal
	Río Bravo	No problems	No problems	Project is ongoing	Communal
	El Bote	Communities were connected as budget became available and as the project progressed, so those connected after the plant was built did not go through this phase and were just informed of it.	They were informed, but were/are not decision makers. A subset also participated with labor in the construction of the plant	Project is ongoing	Private
	Women's solar center	No problems	Some women feel excluded, others have abandoned the project because of conflicts with the project's leadership	Project is ongoing	Communal (women's group)

6.3.2 Case Studies

The case studies presented below were chosen for representing a range of funding entities, which allows for a comparison of the indicators described above.

6.3.2.1 Specific Objective Funding: Chel, post-civil war

Although the micro-hydroelectric project of Chel was funded by multiple donors, this case study will only focus on the main objective of post-war development. This project had one main development entity, a local NGO that worked with the communities throughout the course of the project's implementation. The NGO helped create and strengthen the communities' hydroelectric association and continues to do follow-up activities. The Association has been in charge of the project since its formation and has been instrumental in obtaining additional funding to complete the project as well as funding for other development projects, such as the construction of a road to the community. During the 14 years the project took to be implemented, there was ample community participation and training, and the three beneficiary communities have been fully involved.

Although initially there was some struggle as families did not believe that the project would come to fruition, the entire process of building the DRE system helped strengthen an aspect that might be more important than the electricity provision itself: trust. Consisting of refugees from the civil war and displaced into mountainous regions, the communities of Chel, Xesaí and Las Flores were in need of development aid. This project can boast consistency between what the communities needs and the donors'

objectives as stated in the Peace Accords. The national government and international community made funding available to help affected populations. Even though there is this consistency in drivers, the role of the local NGO was key to project success as their different workshops, focus groups and other communal activities helped build and strengthen trust bonds and eventually made Chel a success story in the country[293].

6.3.2.2 Multilateral Development Funding: El Bote mini-hydroelectric, Francia Sirpi and Awastingni PV Battery Charging Stations

These two case studies focus on the role of the main multilateral development funding entity and the lack of consistency between project/institution objective and user expectation indicators.

El Bote: This project presents a good example of the influence of the donor on the project, though some issues remain unclear. The project developer, a development organization that became the private company (utility) which owns the project, stated that *'we had to connect to the national grid in order to sell the energy surplus and pay off the World Bank loan'*[294]. The developer added: '*because they were connected to the national grid, the World Bank gave us a loan instead of a grant*'[295]. In any case, because of the loan and its interest rate, the company does not have funding for 'social subsidies' such as the provision of flexible financial mechanisms for lower income

[293] At the time fieldwork was carried out, the Association was extending the grid to ten additional communities, which were not considered for this research.
[294] Interview with project developer, Nicaragua
[295] Interview with project developer, Nicaragua

households to connect, or the electrification of all schools that require service, as detailed in Chapter 5. Despite these problems, it is quite unlikely the project would have been possible without the funding of the World Bank. Additionally, the utility formed to manage and operate the project is the primary decision maker, although some users would like to be better informed about the project or be part of the decision making, as explained previously. At present, users compare their local utility unfavorably with even the nation-wide monopolistic utility. To conclude, the pre-investment phase focused primarily on the municipality seats that would most benefit the most, and on the communities in close geographical proximity which provided most of the labor. Other communities were later brought into the project as consumers rather than partners.

PVBCS: As with the previous example, the donor also influenced the outcome of the project. As described in the previous chapters and sections, the users in the communities in which the PVBCS were installed had originally requested, and were promised (according to the community), stand-alone domestic solar systems. The donor's main objective for this project was to create a case study for sustainability of PVBCS as a rural electrification option, which changed the scope of the project. The communities indicated they never agreed to this arrangement and therefore, have not put much care into the systems. Users indicated that *'we are currently seeking new donors to provide us with individual solar panels what we had originally requested'*[296]. In general terms, there is consistency between the donor goals and the user expectation of electricity provision, although there is a difference in expectation as to how this electricity is to be obtained and maintained. An additional incongruence between funder

[296] PVBCS user in Francia Sirpi, Nicaragua

and user expectation was in the available electric capacity: users expected to use more appliances than the design of their systems allowed. The community did not want to reject the project because *'we were afraid if we said no, we wouldn't get anything at all, so this is better than nothing'*[297]. However, the communities are faced with the burden of battery replacement[298]. As explained, the life of the batteries has been shortened and the funding collected thus far is not sufficient to replace the batteries, leaving them using traditional energy sources again while they hope for a new donor to give them the individual home lighting systems they so much desire. At the end of the interview, a responded asked *'will you be able to help us get our individual panels for our homes?'*[299]

6.3.2.3 International Funding: Nueva Alianza

The community of Nueva Alianza has been able to manage the funding of all its projects itself. A number of donors have stepped up to fund the different clean energy and productive use applications, many of which were successful. In this case study, I highlight the role of the UNDP in a productive application project consisting of macadamia nut production. Upon receiving the grant request, the UNDP required that the community form a women's committee to manage the project. Initially, women were nervous and shy about the prospect, but were encouraged by the community leaders to step forward and not lose the funding. A woman explained *'My husband didn't want me to get too involved, he said it's better to leave others to do it, but our community leaders*

[297] PVBCS user in Francia Sirpi, Nicaragua
[298] As I write this, the Ministry of Energy and Mines has purchased new batteries for replacement. This had not been done at the time fieldwork was carried out.
[299] PVBCS user in Francia Sirpi, Nicaragua

helped and encouraged us and I'm happy I did it. It's an improvement for our community[300]*.* As explained, cultural differences are sometimes a barrier for women to be involved in development projects. Some males in the community do not consider it appropriate for women, especially their wives, to work or participate in activities outside the home. For the sake of the community and to be able to take advantage of the funding they received, the community as a whole worked internally to overcome the barriers and successfully formed a women's group. The women's group continues to exist after the completion of the UNDP funding, and although it has a minor (almost non-existent) role, its members think it was meaningful for them to participate and for a donor to consider them a driver for the project. It is worth noting here that most of the women seen who were active outside the home were either widows or young unmarried women.

6.3.2.4 Other Funding: El Trapiche PV Water Pumping System

This case study highlights the consequences of having a lack of consistency between donor objectives and user needs as well as of not having sufficient community participation and an appropriate ownership transfer mechanism.

A German Professor visited the community of El Trapiche, Nicaragua, and purchased a small piece of land so community members could collectively cultivate it. Together with some German students and a local German company, he installed a tracking photovoltaic water pumping system for irrigation. He got the community organized in

[300] Women's group member in Nueva Alianza, Guatemala

groups to work the land; his original idea being that each group would rotate after one harvest season. If that did not work, he suggested the land be divided in smaller parcels to have more families work it at the same time. He has returned to the community every year to bring new projects, such as water taps and solar panels for each household, with the condition that the land continued to be worked on.

The families thought that working the land would be enough to provide income to sustain their families, but the piece of land was so small that the crops were only enough for self consumption. During some harvests they lost all the produce because they were not cultivating correctly or were growing the wrong crop, a consequence of the lack of proper training on crops and harvesting techniques. The families were unhappy because they did not want to work on two lands: one for self consumption and one for income generation. Working together caused many internal conflicts and slowly, families started abandoning the land to the degree that there are currently only two or three families working on it. Some people left because of the conflicts and some because the current leader excludes them. In conclusion, while some families try to work the land so the donor continues supporting the community with more projects, it is undeniable that some internal conflicts that now exist were generated with the arrival of the project. The focus of the research in El Trapiche was on the communal water pumping system and not on the water taps nor on the solar panels, although these have also been affected by the land conflict. The well from which water is drawn for irrigation also provides the water for each household tap. On occasion, when there is increased conflict within the community, the leader turns the main tap off leaving all the families

without water. During brief interviews regarding the solar systems, I found out that the donor pays for all system replacements, so there is no tariff structure or homeowner responsibility over the system. That is, once the donor stops paying for operation and maintenance, there is a huge potential for the systems to be abandoned since there has been no training or information provided. Because of this, some families are afraid of completely abandoning the land as they do not want the donor to stop supporting the community. In conclusion, the long-term sustainability of the water pumping, the potable water and the solar projects are dependent upon the land being used for crops. The donor did not consult with the community what their immediate needs were, and by trying to help the community, may have done more harm. This example shows a clear lack of consistency between users' expectations and donor goals. Moreover, this project hightlights that some development interventions may create more harm than good over the long term. That is, not all infrastructure interventions are positive.

6.3.3 Summary

The findings of this section support the hypothesis that financing entities can affect the long term sustainability of projects. Comparisons between the different kinds of funding and the adequate funding for DRE projects, based on their location, technology, and capacity, among other characteristics, is vague. Eberhard's (2011) study compares funding from private institutions with and without a strong social and economic development commitment, finding that the latter have a greater degree of success in African countries that are still striving to meet multiple development goals. Eberhard

et.al. also found that, although funding from multilateral and bilateral development institutions took considerably longer, they provided a wealth of assistance they would have otherwise not obtained.(Eberhard, Gratwick 2011). This discussion, together with the conclusions found in this research, can help guide the ideal funding sources by project type.

6.4. Technical System Failures

As has been discussed in previous sections, blackouts are a leading cause of user dissatisfaction. Blackouts led systems to not meet their stated goals. In the case of climate change adaptation, blackouts could lead to greater vulnerability of the users towards extreme climate events. In climate change mitigation projects, blackouts led to an increase in GHG emissions as fossil and traditional sources were used in place of renewably-generated electricity. Finally, blackouts hampered poverty alleviation goals by causing economic losses in productive use applications that depended on the use of electricity, such as good that require refrigeration. In some cases, there is also the need to spend money on expensive energy sources to enable their productive uses during blackouts. All these examples have been explained in Chapters 3, 4, and 5, respectively. As also explained in Sections 2 and 3 of this chapter, occurrence of blackouts can be influenced by the governance structures and financing and development entities. In this section, I analyse the main causes of these blackouts.

Causes of technical failure observed in this study varied from bad technical design and installation to inappropriate or null maintenance protocols,[301] as summarized below:

Poor technical design and installation: Some project designs and installations did not follow minimum safety and quality standards, consequently posing threats to users' safety and decreasing system performance. Common cases of inappropriate design and installation were PV systems that lacked protection mechanisms, two of those visited were struck by lightning. Use of poor quality components in both PV systems and mini-hydroelectric plants caused blackouts. Poor-quality PV systems provided electricity for fewer hours each night, and users attributed the problem to charge controllers. A user said *'We have 3 PV panels, and none of the batteries work, the controller doesn't work either'*[302] while another attested that *'The energy goes away at 9 pm, the controller isn't well placed, I think that's the main problem'*[303]. When users bypassed charge controllers, battery lives were shortened due to over-charging and over-discharging. As maintenance funds were accumulated based on the expected lives of appropriately-used components, insufficient funding had been accumulated, so batteries were not replaced or they were replaced by less expensive and inappropriate batteries. A user said *'The battery exploded after 3 years, it just broke. The charge controller stopped controlling after that and didn't do anything'*[304]. A three year life on a battery is not out of line, however, in this case the battery should have not exploded, indicating another problem.

[301] In some cases, the appropriate protocols could not be used because of poor technical design of the DRE system would not allow for it.
[302] Solar PV user in Sta. Clara, Guatemala
[303] Solar PV user in Sta. Clara, Guatemala
[304] Solar PV user in Chapín Abajo, Guatemala

The PVBCS projects in Nicaragua lacked proper design and installation protocols, leading to problems throughout systems' lives. Initially, the design of the charging stations was not allowing the optimum charging of batteries as the charge controllers and conduit were not properly sized. Furthermore, users over discharged their batteries and most battery owners had to charge it more often. A user complained that *'in the charging station, the people who charge the batteries failed (the committee trained local 'technicians' to be in charge of the stations. Users leave their batteries with them and pick them up at the end of the day), the lines didn't charge them, the controller failed in all the charging stations. Some bypass the charge controllers even though they know that's bad for the batteries, but at least we get more light'*[305]. This fact, in conjunction with some homeowners' misuse of their batteries, drastically shortened battery lives. Users talked about how they use their home battery kits which help explain the high expenses they were incurring in battery charging and the fast replacement period: *'I bypass the charge controller, it uses too much energy and drains the battery'*[306] and *'I bought a TV to watch movies, people come to the house to watch movies, I charge them, and then I can also serve cold drinks now that I have a refrigerator'*[307]. The former example represents the great majority of users by bypassing charge controllers. As noted previously and throughout the dissertation, by bypassing the charge controller the user is not aware of how much the battery is charged and discharged. In the latter example, the use of appliances that exceed the system's capacity reduces the life of the battery, especially when the charge controller is bypassed.

[305] PVBCS user in Francia Sirpi, Nicaragua
[306] PVBCS user in Francia Sirpi, Nicaragua
[307] PVBCS user in Francia Sirpi, Nicaragua

Inappropriate design and installation procedures were also seen in some of the hydroelectric projects. The first example is the project of Río Bravo which faced design difficulties which were soon corrected. Nonetheless, some users indicated *'the pipe (penstock) kept bursting, there were a lot of problems. The Siemens (control) panel gave a lot of problems. We lost the signal of the screen, we couldn't turn it on'*[308]. The more drastic case of a flawed design was seen in the micro-hydroelectric plant of Nueva Alianza. The engineer who did the design did not follow basic safety rules and it would appear that went for the *cheapest* option. As the community is not trained in proper hydroelectric design and installation, they trusted the donor (who was also the implementer of the project) in what they were doing and were not aware of the problems that would lead to failures in electricity supply.

<u>Inappropriate operation and maintenance protocols and practices:</u> In most cases, users indicated a lack of follow-up and re-training. Usually, training is carried out during the pre-investment and investment phases, and rarely carried out years after installation. This has contributed to a lack of proper care for PV systems' charge controllers and batteries, a common problem observed in this study.

- In one instance, users forget what they were taught and therefore, provide inappropriate care. A user complained that *'we replace batteries after three or four years, but we don't remember exactly what we need to do, and the donor*

[308] Hydroelectric technician in Puerto Viejo Pijibay, Nicaragua

doesn't come back, so it's hard for us to do it correctly'[309]. Another user covered the batteries with wool blankets, which contributed to its overheating rather than in any way preserving the battery (*'My battery foams when it gets too hot, so I put a blanket on top of it'*[310]); and multiple users put them in inappropriate locations that could be dangerous to the household, including near the bed. Over the years, and as the life of batteries decreased, users were connecting the load directly to the battery by bypassing the charge controller thinking that the latter was the main cause of the problem: *'We've had problems with the batteries, lamps, controller. The panel burns or the batteries, and that's why people get rid of the systems'*[311]. Some users indicated that they had wanted to contact somebody but either did not know who to contact or did not have cell phone coverage: *'Who do we call? After the project was over nobody came back, we didn't know what to do'*[312]. Although not considered 'inappropriate protocols', users also forgot the rationale of paying a monthly tariff. A user said *'We thought the system would only last 4 years. Little by little the lamp started going off and loosing energy. People thought it wouldn't work or that it was a donation and then they got mad when we started collecting the monthly fee of 20 Q, they didn't understand, so that never happened'*[313] indicating also that the proposed tariff structure was not followed. This same user indicated that after a few months, people lost interest in paying the monthly fee and did not understand the

[309] Solar PV user in Seazir, Guatemala
[310] Solar PV user in Visiquichún, Guatemala
[311] Solar PV user in Seazir, Guatemala
[312] Solar PV user in Chiis, Guatemala
[313] Solar PV user in Gualibaj, Guatemala

need to keep paying for it. Unfortunately, as many have stated, the donor and/or development entity never returned to some of the communities.

Another user pointed to physical insecurity, a problem which is increasing and becoming a barrier to further development projects in Central America in general and in particular in some of the communities visited. *'It is too dangerous for us to go into the town to get spare parts, and vendors don't want to come here either because of so much crime in the roads'*[314].

In other cases, training was more effective. Some users were still aware of the care they needed to provide their system. A user was proud to say *'I wipe the panel at 6 am with a cloth. I fill the battery with water each month. The battery lasts 5 years and it's the first one I buy. I bought it 3 months ago and I still use my charge controller'*[315]. Others have found ways to keep their systems working, albeit not following proper operation guidelines: *'We don't use the charge controller, we put the panel direct to the battery and it works better'*[316]. And, some have also found ways to properly dispose of their batteries: *'I sold my battery; there are people who rebuild them'*[317].

Inappropriate O&M was also seen in the hydroelectric projects, especially within the home installations (cables, switches, sockets). Although initial training and

[314] Solar PV user in La Bolsa, Guatemala
[315] Solar PV user in Col. Agrícola San Juan, Guatemala
[316] Solar PV user in Vista Hermosa, Guatemala
[317] Solar PV user in El Zapotal, Guatemala

information sessions indicate the capacity of the plant and the appliances that each household can have, some households purchased appliances that exceeded this capacity, just like in the case of the solar PV systems. Contrary to the case of the PV systems in which each household is responsible for their own system, the peak loading of a hydroelectric plant causes the entire system to go offline. Those who depend on the electricity for productive use applications, including refrigerators, would lose product during the blackouts. A user expressed *'I have to coordinate with them (the Association) when I do my bread. The bread gets damaged if I leave it out of the oven for more than 5 hours'*[318]. As a consequence, users also started complaining about the cost of energy: '*the quality of energy is so bad; there are many blackouts, why should we pay for the service?*[319].

Hydroelectric project technicians also indicated they require more training (or retraining) sessions periodically to ensure that they are still following proper procedures. Although some technicians might put their best effort in solving problems, not all users believe that and some blame both the technicians and the system itself. For example, one user reported *'The machinists lack experience and capacity. There is a lot of water pressure, and the regulator doesn't work. For example, a lot of water can come with high pressure. The plant is OK, the machinist is part of the problem'*[320]

[318] Hydroelectric user in Chel, Guatemala
[319] Hydroelectric user in Bocay, Nicaragua
[320] Hydroelectric user in Chel, Guatemala

- Some supply vendors have taken advantage of users' lack of knowledge to sell them unnecessary and/or inappropriate items at a much higher cost. The most common example was the sale of *battery electrolyte* (dubbed by them the *'Red Bull'* for batteries) instead of distilled water. The cost of one gallon of distilled water is equivalent to the cost of one litre of battery electrolyte: *'During the training sessions we were told to use distilled water, but when I went to the gas station to buy some, the guy there told me to use the electrolyte. It is very expensive'*[321]. Another user complained that *'nobody worried after CARE (the program donor) left and it was when they decided to sell… When the bulb blows off we go to the gas station and they sell them for 400 Q (110 Q for the bulb and 300 Q for the ballast)'*[322]. In this case, a vendor was trying to sell a different kind of compact fluorescent light that cost much more than the one the users required.

- Finally, project developers who try to reduce budgets can lead to decreased life of system components. This is mainly seen in solar PV projects. In one case visited, rain water was used for the batteries instead of distilled water, reducing by half the life of the batteries. Although the project developers were properly caring for the systems by periodically inspecting them and filling the batteries with water, they used rain water instead of distilled water to reduce their budget. Consequently, had to replace the battery in two and a half years instead of in four or five years.

[321] Solar PV user in Col. Agrícola San Juan, Guatemala
[322] Solar PV user in Chiis, Guatemala

Inappropriate operation and maintenance protocols and practices due to poor technical design: The implementation of appropriate, code-compliant operation and maintenance protocols is limited when there technical design and installation standards are not met. This was evident in one of the micro-hydroelectric projects evaluated, where seemingly no safety or quality standards were applied and basic engineering design practices were overlooked. This caused operators to put more labor into the operation of the plant. Sadly, one of the operators was injured by doing something that could have been avoided had the design been correct. A bad design, tied with inappropriate O&M can cause, as observed, numerous blackouts. In this specific case, the micro-hydroelectric plant has to be re-built with an adequate design that uses quality components and for which appropriate O&M guidelines can be applied.

There are some cases in which, despite a good technical design of the DRE system, blackouts were still present. Grid connected systems, especially in Nicaragua, failed because of the poor condition of the national electric grid: *'We have problems with voltage variation in the grid of Unión Fenosa (the utility)'*[323]. This was most evident in the project of El Bote where, as long as the national utility does not overhaul their substations, transmission and distribution lines, the hydroelectric plant will continue to suffer blackouts unless they fund their own new substation with a new connection point to the existing national grid. Although technically feasible, budget is not available leaving the project with the option of operating as an island, without connection to the grid. Because of the loan this project received for its development, it is not financially feasible for it to operate as an island as it depends on the electricity it sells to the grid to

[323] Hydroelectric user in El Cuá, Nicaragua

maintain its financial balance. But the constant blackouts constitute a hardship to the users. A user indicated that *'there are a lot of blackouts and the bulbs burn, they charge a lot. There are some days there isn't light from 3 pm until the next day'*[324]. A business owner complained that *'The national grid has a lot of failures, it goes away suddenly. We've spent 8 days without energy. We had chicken in the refrigerator and it got ruined'*[325].

This being said, it is possible to provide adequate O&M despite poor design or installation protocols. For example, some solar PV systems inspected did not entirely follow appropriate installation guidelines; however, users ensured their care and functioning. In stand alone domestic PV systems, the most common example is of systems that are not grounded, or use the wrong type of controller and battery. In the PV water pumping system of El Trapiche, the original design consisted of a solar tracking system, which stopped working. The users modified the system: *'The (tracking) system didn't last long, it would be sideways in the morning. Now it starts pumping at 7 am, it doesn't always move, it's static so we left it fixed (instead of tracking system).* [326]

Most users requested retraining and/or more in-depth training, even though most project donors do not envision this as economically feasible. But this section portrays how the donor and development entities and governance structure dynamics can have an impact upon technical failures of systems.

[324] Hydroelectric user in Bocay, Nicaragua
[325] Hydroelectric user in La Chata, Nicaragua
[326] PV water pumping system user in El Trapiche, Nicaragua

Although not a technical failure problem, the proper disposal of system components is also important and some components, particularly the batteries, can be dangerous if not done correctly. A user indicated that *'I save my old batteries here at home after they stop working'*[327]. In a more dangerous situation, a user said '*the children took it apart. We don't know what happened. I work in the field. When I noticed, the battery had disappeared. They used it as a toy'*[328], while another system owner said that *'We threw our battery in the trash, we didn't know what else to do with it'*[329]. In more extreme cases, families have disposed of their entire systems after the first battery ended its useful life. A former PV user stated that *'the service of the system ended after four years, that's why we dumped the system in the garbage'*[330]

[327] Solar PV user in Ilom, Guatemala
[328] Solar PV user in Col. Agrícola San Juan, Guatemala
[329] Solar PV user in Pataxte, Guatemala
[330] Solar PV user in Gualibaj, Guatemala

CHAPTER 7: CONCLUSIONS

This final chapter summarizes the main findings of the dissertation and seeks to answer my questions about whether the triple objective of sustainable development, climate change mitigation and climate change adaptation can be simultaneously met through the use of distributed renewable energy systems. It points out the key drivers of success and the main elements that need to be improved to enable the triple objective.

The research case studies demonstrate that, under certain circumstances and design considerations, it is possible to meet a triple objective. Although the design of some case study projects did not allow for the triple objective to be currently met, this does not preclude the projects from meeting it in the future. Indeed, some DRE projects can be more robust, and some have already been rebuilt after specific extreme weather events, such as the Chuisibel micro hydroelectric plant after Hurricanes Mitch and Stan. As was seen throughout this dissertation, a number of factors played a role in the projects meeting their own stated goals.

Table 48 below summarizes the results of this dissertation by indicating whether they met climate change adaptation, climate change mitigation, and sustainable development goals, and it highlights some of the indicators used to measure whether the goals were met or not. The notes below explain in greater detail the concept of each column.

Project		Adaptation (Chapter 3)			Mitigation (Chapter 4)		Sustainable Development (Chapter 5)							
		Good (1)	Bad (2)	Neutral (3)	Energy Savings (4)	Emissions Reductions (5)	Domestic Uses (6)	Productive Uses (7)	Communal Uses (8)	Cost Savings (9)	Social Acceptance (10)	Governance, Exists, Works (11)	Governance, Exists, doesn't work (12)	Governance, Doesn't exist (13)
Guatemala	Nueva Alianza	✓			✓	✓	✓	✓	✓	✓	✓	✓		
	San Jerónimo			✓	✓	✓				Grid connected	?			✓
	Chel			✓	✓	✓	✓	✓	✓	✓	✓	✓		
	ADIM PV			✓	✓	✓	✓	✓	✓	✓	✓	✓		
	Cancuén	✓			✓	✓		✓		Project exists because of RE system			✓	
	Chapín Abajo			✓	✓	✓		✓		FDN maintains system	✓	✓		
	MEM PV			✓	✓	✓	✓	✓		✓	✓		✓	
	CONRED PVEWS	✓			✓	✓	✓		✓	NA	✓	X		
Nicaragua	PVBCS		✓		✓	✓	✓	✓		?		✓		
	SINAPRED PVEWS		✓		✓	✓	✓		✓	NA	?			
	El Trapiche			✓	✓	✓			✓	Donor maintains system			✓	
	Río Bravo			✓	✓	✓	✓	✓	✓	Cost of energy higher than national utility, but lower than diesel generators or traditional biomass	✓	✓		
	El Bote			✓	✓	✓	✓	✓	✓	Cost of energy higher than national utility, but lower than diesel generators or traditional biomass	✓	✓		
	Women's solar center			✓	✓	✓		✓		Project exists because of RE system		✓		

Notes:
(1) Indicates these projects are good examples of the use of DRE during climate hazards, or that performed well during a climate hazard
(2) Indicates these projects are good examples of the use of the inappropriate use of DRE during climate hazards, or that were damaged during a climate hazard
(3) Indicates these projects have not sufered through a climate hazard
(4) Indicates these projects are good examples of DRE as an energy savings measure (as compared to their previous energy source, mainly traditional biomass)
(5) Indicates these projects are good examples of DRE reducing GHG emissions
(6) Indicates these projects included domestic applications
(7) Indicates these projects included income generation applications
(8) Indicates these projects included communal applications
(9) Indicates these projects caused a savings on the monthly income spent on energy sources.
Grid connected means that the project is interconnected to the national grid; therefore, users are subject to the tariffs set by the national regulatory agency.
Where an external source maintains the system, it indicates that there are no energy costs to the DRE beneficiaries
The cases of Río Bravo and El Bote are further explained in Chapter 5
(10) Indicates these projects are considered as socially acceptable by the users and/or these projects have not caused social tensions to arise
(11) Indicates these projects are good examples of how communal governance structures have been a DRE project success driver
(12) Indicates these projects are good examples of how communal governance structures have not been a DRE project success driver
(13) Indicates these projects lack a communal governance structure

Renewable Energy and Climate Adaptation

DRE systems have been seen to both increase and decrease vulnerability to extreme climate events. Policy makers and project developers have tended to view DRE systems as pertaining to the fields of poverty alleviation, mainly if they are small scale, and/or climate change mitigation, mainly if they are large scale. To date, the potential response to extreme weather events of DRE systems has hardly been considered. That is, the energy sector in general and the electricity sector in particular, whether in small or large scale, is vulnerable to extreme weather events and not taking the necessary precautions or considering all the factors can hamper projects' abilities to meet their stated goals, similar to any other infrastructure. Vulnerable DRE systems can pose direct and indirect harm to users and when not properly planned and/or designed, can be a hazard, as was evidenced in the Nicaragua case study of PV early warning systems and the PV battery charging stations. The case studies also showed the opposite case, like in Nueva Alianza, where their biodiesel system, after only one day of being installed, was robust enough to withstand the force of Hurricane Stan. In general, the case studies helped identify the main vulnerabilities of DRE systems to extreme climate events. Besides the proper design of the infrastructure, it is clear that adequate upkeep and maintenance of the systems are key in enabling DRE systems to serve climate adaptation.

Results also indicate that DRE projects can enable CBA by the use of different technologies and by increased community unity and trust. Users in communities

whose systems have not suffered from an extreme climate event, feel they are better able to cope with disasters as they are more united and organized to work together. In some cases, the DRE systems have already enabled better response to non-climate related emergencies.

The case studies also showed that communities in which adaptation goals are being met are communities in which, more often than not, development goals are also being achieved. Actions that enable adaptation also enable development, such as communications, alternate income sources and more community unity. However, the results in this dissertation also indicate that in most cases, adaptation to natural disasters is better in communities where there is a good governance structure and where the renewable energy system is commonly owned.

Renewable Energy and Climate Mitigation

Community scale DRE projects have encountered difficulties with the CDM despite them meeting emissions reductions goals. Besides the well documented barriers of a lengthy process not understood at the community level, and the high transactions costs, it is very difficult to calculate the net amount of emission reductions because of deficiencies in baseline emissions calculations. This is particularly true in projects where a subset of the beneficiaries enjoyed some kind of modern energy source, whether it was grid electricity or a diesel or gas generator. The project of El Bote exemplifies this as the baseline is calculated with the emissions factor of the country's energy mix, even when 18 of the 20 beneficiary communities used traditional energy sources, meaning their emissions are considerably lower. This

project, among others like Chel, also highlights the finding that DRE projects can increase emissions: as electricity demand increases through the use of new appliances, use of fossil fuels tends to increase when the DRE system can not supply electricity for those new appliances. The most common cases seen were in stores that relied on refrigerators, whether through a PV system or a hydroelectric plant.

The findings of Chapter 4 are focused on development oriented projects as there were no additional CDM projects that met the selection criteria. Because of this and the low energy consumption that exists in rural areas, DRE projects ought to be oriented mainly towards development or adaptation goals than on emissions reductions.

Renewable Energy and Sustainable Development

DRE projects were found to have a positive impact on livelihoods assets by improving its five capitals: financial, physical, human, social, and environmental. *Financial capital* was enhanced by energy cost savings, productive use and alternate income sources and the creation of savings mechanisms, although these were for system maintenance. Financial capital, however, was also harmed by failures in the DRE systems: during blackouts some lost refrigerated products or had to spend on fossil fuels in order to avoid losing them. *Physical capital* was improved by the introduction of the DRE infrastructure and other infrastructure that was enabled through the DRE projects, such as roads. *Human capital* saw improvements at the domestic, productive and communal levels. The DRE system enabled other

services, such as better education and health, and created more unity among neighbors. Through the projects, each user had the opportunity to learn new skills related to the project itself or to an application enabled by the electricity. Lastly, *social capital* was impacted through the social acceptance of the projects, especially in projects that had a strong communal participation component. This same social capital proved to be important for the DRE projects to meet climate change adaptation goals as was seen previously.

Cross cutting factors

Factors including the centralized or decentralized nature of the technology or of the institutions, along with governance and funding entities, can enable projects to meet their stated goals, and therefore, to meet the triple objective. For the former, all projects with a centralized infrastructure, with the exception of one project, had functional governance structures. On the contrary, with the exception of one community, all communities benefited with PV systems financially managed their systems individually and the governance structures set in place ceased functions relatively soon after the installation of the systems. For the latter, the primary goals and objectives of the donor and development entities and their interaction with the communities, was key in promoting, or not, proper understanding and upkeep of the systems. This also leads to the conclusion that when there are multiple institutions involved in the implementation of a project, coordination among them needs to be planned from the outset. Some of the case studies presented problems because they lacked such coordination. Cultural, political, economic and social differences also play a role and can be bridged through long-term social interaction and trust

building. Although this is possible and increasingly recognized, not all donor and development entities understand its importance nor the need to allocate appropriate resources. Social interaction should be a two-way learning process: the community learns about the project and the means to achieve it, and the donor/developer learns about the community (needs, background, etc.).

Projects that are privately funded, such as the small-scale hydroelectric project of Matanzas, may not be seeking joint ownership with community members despite the latter wanting to be more involved in the project. Although in this project there was dissatisfaction from the surrounding communities and there has been conflict because of water use, the project has been meeting its goals. It is meeting climate change adaptation goals because of the dam that regulates the water flow and could avoid the flooding of the valley. It is also meeting climate change mitigation goals as a CDM project and it can also be said to be meeting sustainable development goals by improving health and education conditions of the nearby communities. However, because of its nature, it is still ambiguous if sustainable development goals are really being met, mainly because of the difference in expectations between the communities and the utility.

Survey responses indicate that private projects could be more successful and have less disaccord with populations by informing them of operations and activities, listening to their needs and finding common ground with regards to expectations. The different visions on what ‘development’ means constitutes one common point of disagreement creating dissatisfaction and tension for all the parties involved.

This lack of communication, and sometimes understanding, between private developers and community members has set a negative precedence for the technology. There has been mass opposition, mainly in Guatemala, towards hydroelectric projects in which there is minor community participation.

The case studies analysed did not have a 'social funding' to help the poorest people, which still can not count on renewable energy as a modern energy option. Some projects, such as El Bote, would like to have one, but they presently can not afford one. Implementing one would require increasing the electricity tariff which is not possible. The lack of this 'social funding' mechanism is considered by some to increase the inequality gap. During the planning and execution phases of projects, social and economic differences among the population are not always considered, leaving the poorest population vulnerable. In some cases, they might require a subsidy in order to benefit from the electricity service, but in the rural DRE projects included in this study, this was not observed. Absent programs that specifically target the poorest members of a community, the rest of the community enjoys all the benefits of electricity, such as the use of modern appliances and the capacity to see each other better at night, while the poorest families still spend a greater percentage of their income on traditional energy sources and lack the development opportunities associated with DRE.

Technical quality was important in enabling project success. Poor technical designs and lack of appropriate operation and maintenance protocols have prevented some DRE projects from meeting stated goals: if the systems do not work as expected, people will continue to use torch pine, candles, gas lamps, or diesel gensets and will

not be able to carry out the productive and social activities the electricity has enabled. The most telling example of this is the micro-hydroelectric plant in Nueva Alianza. As was also seen in some of the case studies, poor technical quality can also make the DRE systems, together with the users, vulnerable to extreme climate events, perhaps defeating their main purpose. The PV Early Warning Systems in Nicaragua exemplify this.

In a subset of the communities, systems used very low quality components, including, for example, non-listed and non-certified[331] PV panels that were peeling within five years of being installed (when their expected life ranges between 20 and 30 years) and car batteries labeled as solar deep cycle batteries. Although this is an important finding, it is also disappointing to learn that the developer and vendor would take advantage of the users and other donors by installing these low quality components. Besides having sub-standard systems, this has been shown to damage to the technology's reputation. Of special concern should be the long-term impacts of this as the expected life of the system would be lower.

Follow-up and evaluations are essential to meeting the triple objective, although this was very rarely carried out. Some of the projects visited could be working today had proper follow-up taken place, like in the case of the PV projects in Cahabón, Guatemala. Besides the fact that technical assistance is needed in the communities, follow-up allows the documentation of experiences and lessons learned. One of the case studies, the Chel mini-hydroelectric project, where a developer had been involved for a decade, showed the value of follow up and learning lessons in the long

[331] This refers to the quality and safety certification electric equipment is subject to. More details are in Chapter 6.

term sustainability of a project. However, I found a number of communities where projects had failed which remain without electricity and there are few prospects for further investment.

The community of Nueva Alianza provides the best example of how meeting the triple objective is possible. In the short period of time the micro hydroelectric and biodiesel projects had been installed, the community has been able to reduce their fossil fuel consumption and therefore their greenhouse gas emissions, improve the quality of life of all the families and enable their survival and that of neighboring communities in the aftermath of Hurricane Stan. As highlighted in Chapter 3, this community survived through and coped with Hurricane Stan's destruction because of their biodiesel production and community organization. This is an excellent example of how a renewable energy source helped this community and neighboring ones that had no communication with the 'outside world'. Members of the Nueva Alianza community indicate that the rest of the world was 'out of communication with them'. The unity and strength the families already had certainly enabled the development of the DRE and productive use projects, but it can also be said that the development of these projects strengthened their bonds even more.

The results described in the previous chapters allow me to answer the questions of the existing challenges in integrating development and climate change policies in Central America and the potential role the international climate regime can have in achieving this.

Central American countries have prioritized climate change adaptation and poverty alleviation; therefore, countries are putting little to no priority to climate change mitigation, and therefore, renewable energy projects. Considering the percentage of global emissions from the region, the countries do not consider they should invest in renewable energy technologies as they are mainly seen as useful for emissions reductions. There needs to be a greater understanding of the diverse benefits provided by renewable energy systems in general, and DRE systems in particular, and the advantages of integrating development and climate change goals and policies, especially for the most disadvantaged population. The results of this dissertation can help broaden the understanding of DRE systems and their role within development, climate change mitigation, climate change adaptation and their integration.

As one of the most vulnerable regions of the world, infrastructure robustness is especially important for DRE systems to meet the triple objective. The case studies in Guatemala and Nicaragua show the importance of robust infrastructure in order to not increase the population's vulnerability to extreme weather events. In this sense, the main priority for integrating climate change objectives into development projects is accounting for the effect extreme weather events can increasingly have on DRE systems. That is, design protocols need to be adapted to the evolving geography.

The region in general, and Guatemala and Nicaragua in particular, are not on track to meeting the Millennium Development Goals by 2015. Guatemala and Colombia were the first Latin American countries to support the creation of the Sustainable Development Goals (SDG's) and have prioritized their needs. The evolution of the

NAMA (Nationally Appropriate Mitigation Actions) and NAPA (National Adaptation Programmes of Action) process can provide significant funding towards meeting these goals and DRE systems can certainly be a part of the solution. By prioritizing climate change adaptation and poverty alleviation, the countries can initially focus DRE systems to meeting a double objective. As was seen in diverse case studies, if DRE systems are properly designed, implemented and governed, they can meet the triple objective as they would also reduce emissions, independently if they are grid connected or not, as they will most likely be displacing traditional biomass or fossil fuels.

LIMITATIONS of this STUDY

There are several constraints and challenges that limited this study and should be addressed in future research. First, I was not able to identify projects or have the time which would allow a balanced and in depth exploration of the full range of climate adaptations and mitigation projects and governance.

Because of the specific circumstances of each case study, it was not always possible to answer whether the projects met the triple objective. For example, there were locations that have not been affected by climate hazards and where it was therefore hard to assess adaptation success. Having said this, people interviewed in some of these locations seemed open to working together as a community and the renewable energy supported technologies such as cell phones and radios, which could enable them to reduce vulnerability to emergencies.

I was only able to study one private project; therefore, it is not possible to state the degree to which private projects meet development goals. However, the case studies indicate that the projects in which development goals are being met are to a larger degree those in which users have some level of participation beyond that of being a user, and have the option to be a decision-maker, or at least be heard in project related matters. As explained in Chapter 4, I was not able to study a larger number of CDM projects that met the project selection criteria as the ones located in Guatemala and Nicaragua are not community scale and would not have provided good comparisons.

One case study was deselected because of its close proximity to drug cartel war-stricken areas. In fact, the solar PV refrigeration system was destroyed by arson shortly before the visit was scheduled. This system was located in a protected area and the forest rangers were shot at while patrolling the area. This was a general problem in that other possible PV installations were also located in regions where increasing conflicts between drug cartels made it difficult and dangerous to visit some areas. Besides the danger of traveling to certain areas, interviewing could have posed a threat to the interviewees. In one specific instance, I was not able to do further research in one community as the only day we were there we were being closely followed throughout the day by suspected cartel members.

For some interviews, especially those carried out in Northern Guatemala with indigenous Mayan populations, I had to rely on an interpreter. This limitation meant that I was not always able to do follow-up questions or that the proper messages and interpretations were being transmitted. There were also cases in which in some

households, the interviews were started by women but finished by men. In other cases, women were afraid or shy to answer and had to make eye contact with a male household member before answering, which may have biased their responses. In two households, the adult did not want to respond to the questionnaire and let their underage children talk. In these cases, the interviews did not continue and other homes were selected.

Some homeowners thought they would get a new or overhauled DRE system as a result of the interview. Despite clarifying this was not the case, some respondents promised they would take better care of a new system. In some cases I felt some of their answers were biased with the hope they would receive a new one. In these cases, those responses were not considered during the analysis.

POLICY RECOMMENDATIONS

Below I list a series of policy recommendations that can help put DRE projects on a path in which they can simultaneously achieve the triple objective, taking into consideration the cross-cutting elements necessary to success.

1. As described in Chapter 3, disaster reconstruction programs are implemented in a considerably shorter period of time than development and rural electrification programs. This causes basic socialization and training to be cut short because of timing and/or budget constraints. Recognizing that there are projects and infrastructure that need to be implemented in the short term, and that the priority is to benefit the largest number of people, the main policy

recommendation is to ensure that reconstruction programs be designed to respond to future extreme climate events and other hazards to increase the community's adaptive capacity. In the case study of Guatemala, these objectives could have been achieved had the program been set with phased objectives. The rural electrification component could have been implemented over a longer term to allow proper resources, both human and financial, to ensure an outcome equal to those of programs designed specifically for rural electrification. By limiting reconstruction programs to shorter timeframes in which budgets need to be executed, donors and developers risk, as was seen, installing projects that are not sustainable and which, in the long term, can cause harm to the populations it intended to benefit.

2. Policy makers and governments tend to relate the energy sector in general, and renewable energy projects in particular, to only climate change mitigation goals. In reality, as some case studies showed, the energy sector and the DRE projects are vulnerable to extreme climate events and in consequence can increase or decrease the vulnerability of the populations they serve. DRE projects should not be developed solely to meeting emission reduction goals but can also serve for climate change adaptation: DRE projects are vulnerable to extreme weather events, but can also be designed to enable adaptive capacity for example through coordinated and equitable use of water in a watershed. The San Jerónimo case study could improve the adaptive capacity of the watershed users through a more robust governance structure.

3. Poor technical designs and lack of appropriate operation and maintenance protocols and practices have prevented DRE projects from meeting their stated goals. This issue highlights the importance of government regulation or certification that ensures quality and safety codes and standards to avoid deceitful practices such as selling bad quality and/or pirated components. Even if the systems are privately owned, there should be government controls in place and an accountability system so not ‘anybody’ can install systems without having the appropriate knowledge, training and licenses. Most of the Central American countries have adopted the US National Electric Code (NEC) although not all have implemented it. Donors and governments implementing DRE projects should require the compliance with safety and quality codes and standards as well as product listing. Besides requiring the use of code-compliant components and equipment, donors and governments should ensure that project installers are also licensed and certified. This process will ensure project sustainability and a better use of limited development budgets.

4. One common response received from many system users and technicians was the need for more intense and periodic training sessions to ensure systems remain functioning. I suggest two policy recommendations:

    - Set a minimum required budget for socialization and training activities as the current spending level for this topic is not sufficient to cover users’ needs. Some government officials interviewed indicated the need to spend up to 10% of the total infrastructure budget on training.

In the case of PV systems, users expressed the desire to learn more, have more hands-on training and have more frequent training, especially when the time to change batteries approaches.

- Aid program indicators tend prioritize first and foremost the number of beneficiaries or system users. Because of this, donors are reluctant to allocate additional budget towards training activities. During the interviews, some indicated this was unrealistic as there were specific goals for system beneficiaries and re-allocating budgets would mean a smaller number of systems installed which might be interpreted as inefficient use of the budget. This point has greater implications if program follow-up was carried out more periodically: when systems stop working and communities rely once again on traditional energy sources, statistics are not modified to reflect this and aid programs do not target these populations anymore as they are already considered ‘electrified’ or ‘benefitted’. Meanwhile, the budget is accounted for as the project has already been implemented and in many cases, donors and developers do not know if, long-term, the projects are still meeting their stated goals. In conclusion, to be most effective, indicators must be both qualitative and quantitative to avoid using cheaper components, cutting on safety standards, and not providing sufficient training. Budgets should be allocated to benefit those who need the service for the greatest amount of time possible, keeping in mind the real life cycle of the DRE systems.

5. In rural indigenous populations in which other belief systems exist, such as with Mayan populations, donors and developers need an understanding of the cultural, political, economic and social differences to ensure that the appropriate ideas and expectations are being transmitted. In these cases, it would be appropriate for the Ministry of Culture, or its equivalent, to be involved so no rules, customs or traditions are being violated or misinterpreted. It would be highly beneficial that this be a requirement for projects located in culturally sensitive areas and be considered as a two-way learning process: the community learns about the project and the means to achieve development while the donor/developer learns about the community's background and needs in order to better meet their expectations. For example, the main developers of the Chel micro-hydroelectric project studied Mayan cosmology, which enabled the acceptance of the project.

6. As a follow-up to the previous recommendation, and especially for hydroelectric projects of any scale, an integrated watershed management vision ought to be implemented to ensure the well-being of the entire watershed and that lower watershed users do not suffer negative impacts of activities carried upstream. One of the Guatemala case studies, the San Jerónimo and Matanzas small-scale hydroelectric projects, highlights the importance of a proper coordination among watershed users.

7. Despite the poverty alleviation goals of many DRE projects, this objective is not always achieved. In some cases, the poverty level of the beneficiaries hampers the long-term sustainability of the projects. In the case of solar PV

projects, users are not always able to maintain and/or replace their batteries or other components. In the case of hydroelectric projects, the poorest families can not afford the initial connection cost. Some of the case studies showed how this can increase the inequality gap and leaves open the question if another aid program will eventually provide the service for those unserved homes. Based on this, governments might need to consider subsidizing the electricity service for the poorest segment of the population to avoid increasing inequality in rural communities. Likewise, a subsidy for social services can also be considered. As seen in the project of El Bote, rural schools can not benefit from the electricity service because the parents can afford neither the connection nor the monthly bills and the Ministry of Education rules indicate they can only cover the costs of schools located in municipalities,.

8. Some case studies pointed to one key element that is often times missing from projects and which can prevent them from attaining the triple objective: follow-up. Some projects visited could still be working properly today had they received adequate follow-up. Besides providing technical assistance to the communities, follow-up allows the documentation of experiences and lessons learned that will help enhance future projects and ensure that the triple objective can be a goal that any renewable energy project can achieve. In one of the programs evaluated, the ADIM PV project in Guatemala, I was able to see the evolution of projects of one developer over ten years and such lessons learned do exist, although there is a sad reality remains: the communities in which the projects were not successful remain unelectrified

and it is not clear whether another developer will work there again. This is a topic that merits further study.

I identified five main reasons why the projects did not meet the triple objective. The first one is *level of poverty* as people are too poor to afford the service (in the case of the hydroelectric plants) or save for operation and maintenance (in the case of solar systems) and access to available capital becomes important, if not necessary, for system upkeep. Government schemes, such as the loan of solar systems in Guatemala, seemed to work very well, except that the poorest people cannot afford necessary battery replacement. Whether government or privately owned, an important factor is the inclusion of productive use applications that can help families gain more income that could help maintain an available cash flow. The second reason is *inconsistency between users' expectations and donor's objectives.* If users are not happy; it can create conflict, leading to systems neglect. The third reason is *lack of community involvement*: users were not satisfied mainly in those projects in which community involvement was minimal or non-existent, as in the bigger projects with funding from multilateral development entities or private sector. Based on the different conceptions of community involvement, a recommendation is to gauge with the community how they envision their role to be throughout the project. *Unreliable energy* is the fourth reason: with multiple or constant blackouts, the intended goals of the projects are not entirely met and in some cases, can cause more difficulties or pose a danger to the users. Last but not least, *perceptions* had a clear impact. People form perceptions about renewable energy systems and their functioning from their own and other users' experiences. Such perceptions can make them wary of

using these technologies without adequate socialization and training. For example, in Nicaragua, a system with a bad design led to two trees being hit by lighting, and as a consequence, the family is afraid of using the system and has recommended against their use to others. It is also important to note here that positive experiences also enable greater use of DRE technologies. I also saw users purchasing their own system after seeing their neighbors' system or heard from some indicating they would purchase a new system if theirs failed.

FURTHER RESEARCH

These conclusions indicate several possibilities for follow-up research and also highlight how several *development paradigms* are problematic.

System/Project ownership has, for a number of years, been considered necessary for project sustainability. In this dissertation, I found that this was not always true, mainly because of lack of cash flow, and that other schemes, including the loan and lease of systems had successful results. This is an important area of further research as it could allow donors to develop or strengthen other schemes beyond that of ownership and to identify which scheme is the most suitable for specific conditions.

Although most survey respondents indicated that more training is required and that some donors also recognize the need to provide more funding for training, I did not make a comparison of project success based on the length and number of training sessions. Therefore, for more training to become a policy recommendation it will be

important to assess the impact of more training, the type and timing of training, and what is considered sufficient. In some projects; however, the need for more training was evident as basic operation and maintenance procedures were not followed – nor comprehended.

Much has been said of the role of community participation within project success, and the role that financing entities have in determining this participation. The case studies presented in Chapter 6 show a variety of financing schemes together with the project outcomes. A field of further research identified here is the *ideal* mix of financing sources depending on the nature of the project and the primary goal being sought. Some donors are more suited to a specific type of project and are more (or less) flexible to allow greater community participation. Additionally, the potential to increase community participation in private projects should be assessed. In the projects that were either private or managed by a utility, community members expressed a desire to be heard more. Outside the scope of this dissertation is the question of whether additional community participation is indeed feasible and possible in projects run by a utility company, whether private or part of a local association, like in the case of El Bote in Nicaragua.

Lastly, a greater sample of private projects can be analysed aimed at studying the degree to which the cultural, social, religious and environmental backgrounds are considered in project development, and if this could lead to greater community participation and increase project acceptance.

The theories of political ecology and CPR were useful and appropriate in this dissertation. For the former, the focus on root causes helped in the analysis of the Guatemala and Nicaragua case studies, considering their civil war histories, indigenous and gender inequality, increased opposition to mining and hydroelectric projects, and emerging conflicts, especially the growing drug war that is mainly affecting rural areas previously in the heart of the armed conflict. For the latter, the CPR analysis helped establish the feasibility of 'energy commons' as a way to achieving the triple objective.

For future research on this topic, I would recommend the continued use of these two theories. The approach taken to overcome the development and climate challenges amid the physical and social backgrounds of the countries can be a project success driver, as was seen in several case studies. This dissertation showed how previous development interventions have affected current projects and may continue hampering progress in the use of DRE systems. For CPR, the consideration of energy infrastructure as 'commons' can improve the way DRE systems are managed and may improve the relationship between indigenous populations and utilities as the private electricity sector continues to emerge.

APPENDICES

Appendix 1: Bibliography

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Appendix 2: Glossary and Acronyms

Adaptation	• Adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts (IPCC 2001) • Changes in processes, practices, or structures to moderate or offset potential damages or to take advantage of opportunities associated with changes in climate (Huq 2003) • Enabling people to manage climate-related risks without suffering reversals in human development (Sperling 2003)
Adaptation capacity	Potential or ability to adapt to the effects or impacts of climate change. The enhancement of adaptive capacity is a way of reducing vulnerabilities and promoting sustainable development (IPCC 2001)
CDM	Clean Development Mechanism
CEI	Clean Energy Initiative
CEPAL	Comisión Económica para América Latina y el Caribe (Economic Commission for Latin America and the Caribbean)
CO_2	Carbon dioxide
DRE	Decentralized Renewable Energy *For the purpose of this dissertation, I consider small-scale solar photovoltaics, wind, hydro and biomass. I also

	include the use of solar cookers and efficient stoves.
EESD	Energy Efficiency for Sustainable Development
ESMAP	Energy Sector Management Assistance Programme
Exposure	Change in climate and what is affected (Smith, Klein & Huq 2003)
FAO	Food and Agriculture Organization
GHG	Greenhouse gas
GVEP	Global Village Energy Partnership
HDI	Human Development Index
HDR	Human Development Report
IPCC	Intergovernmental Panel on Climate Change
IPCC TAR	Intergovernmental Panel on Climate Change Third Assessment Report
ITDG	Intermediate Technology Development Group
kW	Kilo Watts (thousand watts)
LDC	Least Developed Countries
Livelihood	Comprising the capabilities, assets (human, natural, financial, social and physical capitals) and activities required for a means of living (Chambers, Conway 1992)
Mainstreaming	Full integration of climate change policies into national development programmes (Huq 2003, Huq, Reid & Murray 2006)
MDGs	Millennium Development Goals
Mitigation	Anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC 2001)

MW	Mega Watts (million watts)
O&M	Operation and maintenance
PV	Photovoltaics
Renewable energy productive use application	Involves the application of energy derived mainly from renewable sources to create goods and/or services either directly or indirectly for the production of income or value (Cabraal, Barnes & Agarwal 2005)
Risk	Probablilty*Climate hazard*Vulnerability (Swart, Raes 2007)
Sensitivity	Direct effect of climate change on systems (Smith, Klein & Huq 2003)
SNL	Sandia National Laboratories
Sustainable development	• A balance between people and the planet, a balance that addresses the great challenges of today, while protecting the interests of future generations (Brundtland 1987) • Development that meets the social and economic needs of the world's population, current and future, without endangering the viability of environmental systems important to meeting those needs (Wilbanks 2007) • Management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations (Food and Agriculture Organization of the United Nations. Conference 1989)

Sustainable livelihood	A livelihood that can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base (Chambers, Conway 1992)
Sustainable livelihoods approach	An approach to development in which people's livelihoods are the focus of attention (Great Britain. Dept. for International Development 2000)
SWERA	Solar and Wind Energy Resource Assessment (SWERA 2006)
UKCIP	United Kingdom Climate Impacts Programme
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Climate Change Convention on Climate Change
Vulnerability	Exposure*Sensitivity/Adaptive Capacity (Swart, Raes 2007)
VCO	Voluntary Carbon Offsets