Title
Rural electrification, climate change, and local economies: Facilitating communication in development policy and practice on Nicaragua's Atlantic Coast

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Publication Date
2012

Peer reviewed|Thesis/dissertation

Rural electrification, climate change, and local economies: Facilitating communication in development policy and practice on Nicaragua's Atlantic Coast

By

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A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

Energy and Resources

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

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Spring 2012

Abstract

Rural electrification, climate change, and local economies:
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By

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Doctor of Philosophy in Energy and Resources

University of California, Berkeley

Professor Daniel Kammen, Chair

I explore the role of information and communication in the world of institution-led development. Through a series of case studies from the Atlantic Coast of Nicaragua, I present several projects and their implications for uncovering information that may lead to greater local benefit from externally-planned development projects. In order to construct policies and implement projects, development institutions collect, analyze, and simplify information, collapsing messy physical and social realities into narrow sets of metrics. In addition, local stakeholders often aren't privy to the analysis and assumptions of the "expert" planners. An evolved set of methods for dialogue and planning, which focus on sharing available information, can help facilitate outcomes that are more beneficial for targeted groups.

Carbon abatement cost curves provide a clear example where the relations of complex social, economic, and environmental systems are reduced to a narrow set of metrics, specifically the cost of carbon mitigation and the total tons reduced. When the carbon abatement cost curve is applied to the community level, it reveals information and allows for conclusions obscured by aggregated national level studies. I show that there are opportunities for augmenting the limited metrics of these cost curves to include those that relate to welfare, beginning to highlight how costs and savings are distributed among stakeholders. In particular, the benefits to the most marginalized groups are heavily dependent on planners taking a pro-poor approach.

However, planners typically remain blind to the priorities, capabilities, and values of the target stakeholders. There is a dearth of methods that effectively open up the development expert's black box of project designs, allowing their proposed solutions to be transparent to the target beneficiaries. I address this challenge through the presentation of a participatory modeling process that was utilized with groups of artisanal fishers. Participatory modeling places a greater emphasis on understanding processes, rather than just focusing on outcomes. The process facilitated the detailed exploration of local realities through the creation and playing of a board game that modeled their local fishing economy. Participants were able to look closely at the causal relations between several potential development interventions such as a cooperative-owned fish businesses and local ice production, gaining insights into possible costs and benefits.

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List of Acronyms and Abbreviations

AR4	(IPCC's) Fourth Annual Assessment Report
BAU	Business as Usual
CCE	Cost of Conserved Energy
CDM	Clean Development Mechanism
CDCC	Consejo de Desarrollo de la Costa Caribe
DIPAL	Desarrollo Integral de la Pesca Artesanal
ENEL	Empresa Nicaragüense de Electricidad
FADCANIC	Fundación para la Autonomía y el Desarrollo de la Costa Atlántica de Nicaragua
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
NGO	Non-government organization
TCC	Total Cost of Conservation
UN	United Nations
UNDP	United Nations Development Program

Acknowledgements

I am very grateful for my time at Berkeley's Energy and Resources Group (ERG). In the realm of university education, ERG has been exceptional, providing the freedom to engage in meaningful work abroad, and meander among the confining structures of 'disciplines'. ERG has done its work on me, providing an environment and culture that pushed me to evolve from a technical and quantitative approach to understanding, to one that is more aware of the complexity, uncertainty, and curiosity of interconnections and context.

My growth at ERG wouldn't have been the same without my advisor and dissertation chair, Dan Kammen. Dan supported my nonlinear path, providing unwavering support and opportunities, as my interests have taken me from wind turbines to playing games with fishers. No matter what idea or plan of study I designed, Dan would offer his advice, but was always willing to support it. I have greatly valued his generosity, always sharing ideas and opportunities, and putting a lot of faith in his students.

I am grateful for the attention, patience, and willingness of both Laura Enriquez and Isha Ray to support my desire, rather late in the game, to become more conversant in various areas in the social sciences. Laura's gentle guidance and encouragement has pushed me in my reading of development. I have benefited greatly from Isha's gift for succinct and insightful advice, as well as her intellectual guidance. I would also like to let Dick Norgaard know that I greatly appreciated his taciturn support.

I am thankful for the various funding sources that have supported my research: The UC Berkeley Chancellor's Fellowship, the Switzer Foundation, Energy and Resources Block Grants, the Karsten Family Fund Endowment of the Renewable and Appropriate Energy Laboratory, and UC Berkeley's Center for Latin American Studies.

My time at ERG would have been a much greater hassle, if it weren't for the friendly and caring help of many current and past ERG staff, notably Jane Youn, Sandra Dovali, Jane Stahlhut, Bette Evans, Lee Borrowman, Donna Bridges, and Kay Burns.

A large part of my learning took place in towns and villages on the Atlantic Coast of Nicaragua. I am grateful for the friendships and collaborations of the wonderful staff and volunteers who have been part of blueEnergy over the past six years. Mathias and Guillaume Craig and Lal Marandin have become close friends and collaborators. I have admired their thoughtful self-critiques and dedication to learning and evolving, in the world of institution-led development.

Of course, my experience at ERG would have been incomplete, and lonely, without the always thoughtful, diverse, inspiring, and fun group of students and friends. I greatly benefited from discussions with Carolina Balaz, Mike Dwyer, and Daniel Lavelle during preparation for my qualifying exams. I'm especially thankful for the many fun adventures, good humor, meals shared, and enriching conversations with Anand, Liz, Debbie, MK, Derek, Sintana, Lindsey, Niels, Josh, Danielle, Stacey, and many others. I will especially miss my weekly lunches with Anand and Debbie.

My dual life in Berkeley and Nicaragua would not have been so easy, if it weren't for my wonderful landlord, Harry, and my great neighbors, especially Barbara, Carlos, and Sandra.

I greatly value my many conversations with Dipti, whose care and thoughtfulness helped me think through both the limits and potential of institution-led development.

And last, but certainly not least, I am so grateful for my family. The tremendous challenges faced by my brother, Amy, and Riley, was a sharp reminder of what is really important, and the depth of human compassion. My mother and father have always been my biggest supporters, in all of the endeavors that I have undertaken. My mother's ethics and my father's sense of inequity have each made heavy marks on my thinking.

Introduction

My research examines the often dysfunctional interaction between the formation of institution-led development policy and the resultant planning and implementation of projects. An underlying theme within the following chapters is that failures of development are closely linked to insufficient efforts to observe and communicate micro-level information between the development actors and the individuals or groups who are the objects of development. Failure is therefore a result of both information discovery and communication.

Development can be viewed as an institution-led process of implementing expert-designed projects that seek to alter some defining aspect of a targeted system, environment, or group, either at the micro or macro-level (e.g., provide clean drinking water or health care for a community, create democratic elections, reduce deforestation, or stimulate greater export-oriented production) [1]. Development actors typically take the form of governments, development banks, multinational and local non-government organizations (NGOs), and private firms.

In order to construct policies and implement projects, development institutions collect, analyze, and simplify information, collapsing complex physical and social realities into metrics that can make certain characteristics visible and therefore susceptible to change. This process is what anthropologist Tania Murray Li calls the art of "rendering technical" observed problems, which often results in the deliberate exclusion of political and social aspects that can't be addressed with expert knowledge and project design (Li, 2007, p. 7).

The manner in which policy is crafted, and the information that is used to inform it, depends on the prevailing development narrative. These narratives, emanating from Western-dominated development institutions, have evolved over time, changing from a focus on economic growth to more nuanced frameworks that look at basic needs and human freedoms and capabilities (Gasper, 2007, p. 51). For example, agencies like the United Nations (UN) overtly subscribe to narratives of development informed by Amartya Sen's capabilities approach. The United Nations Development Programme's (UNDP's) 2010 Human Development Report, celebrating its 20th anniversary, states that "Amartya Sen's capability approach provided the philosophical foundations of human development, drawing on a long and august lineage of influential thinkers" (UNDP, 2010a, p. 16). Indeed, the UNDP's global framework of metrics for making aspects of global human development visible is largely based upon the capabilities approach (Robeyns, 2006, p. 351). At the theoretical level, the approach focuses on the means of wellbeing, rather than the ends, setting the goal of providing groups the freedoms and capabilities that would allow them to make their own development choices (Sen, 1999).

Challenges, however, come with implementation of a capabilities approach. Prioritizing specific capabilities requires understanding how different capabilities interact within the political, social, and cultural framework in which the targeted capabilities are embedded. For example, the capability to life a long life within a given community may require understanding

[1] Hart (2001, p. 650) distinguishes between post-WWII development as a deliberate intervention made by Northern countries into poor, primarily southern countries, and the global process of the development of capitalism. Many scholars cite President Truman's 1949 inaugural speech as a harbinger of the modern development industry (Riddell, 2007, pp. 24–25).

everything from the role of traditional diets to the need for regulating nearby industrial polluters.

On the receiving end of development are the heterogeneous communities whose realities are shaped by the development projects, often in ways that were not anticipated by either themselves or the planners. The vast array of stakeholders targeted by development projects will have different priorities regarding the capabilities that they want developed, in what order, and in what manner.

However, the way that capabilities are 'developed' by global institutions carries an implicit system of cultural and economic values. For example, supporting the capability to learn and be free from hunger, two capabilities targeted by the Millennium Development Goals (MDGs), can be approached in an infinite number of ways. However, the international project of targeting hunger has meant tying food production to global markets with reduced trade barriers and large-scale, mechanized agriculture reliant on synthetic inputs (Kaufman, 2009; McMichael & Schneider, 2011). Increasing the capability to learn has been defined as increasing boys' and girls' access to a classroom as well as a standardized curriculum and pedagogy of the dominant cultural, economic, and government systems (King, 2007; Tikly, 1999).

While various forms of participatory processes have become mainstreamed in the past decades, they primarily focus on eliciting more 'local' information to be used by experts in their project plans. The many assumptions, processes, and implications within experts' solutions aren't necessarily visible to the beneficiaries.

In the subsequent pages of this dissertation, I will present several tools that may help to increase the visibility of the diversity of project stakeholders to policy makers, as well as make aspects of their proposed projects more transparent to the targeted beneficiaries. The value of these tools will be dependent on the willingness of institutions to be 'observed', critiqued, and subsequently modified.

The birth and death of an energy project

The various parts of this dissertation derive from work and collaboration on the Atlantic Coast of Nicaragua, with most of the insights beginning with a particular development project in which I was involved. In 2008, an NGO based on the Atlantic Coast of Nicaragua was approached by a local member of the government's ruling political party, the Sandinistas[2]. The NGO was asked to help prepare a project proposal focused on increasing energy access to several communities in the Pearl Lagoon basin. Specifically, the project would target communities with Garifuna populations[3]. The initiative was being pushed by an agency within the Sandinista government, the Commission for the Development of the Caribbean Coast

[2] The official party name is the *Frente Sandinista de Liberación Nacional (*FSLN), although it will be referred to by its popular names, the Sandinista party, or the Sandinistas, throughout this dissertation.

[3] There are only a small number of communities that have a majority Garifuna population in Nicaragua, all of them located on the northern side of Pearl Lagoon. Orinoco is the largest Garifuna community, with a population close to 850 people, 80% of whom define themselves as Garifuna (Casillas, Sobalvarro, & Valverde, 2010, pp. 7–8). Garifuna populations are descended from African, Amerindian, and Arawak people. Not all of the communities that were defined as "Garifuna" by the project actually defined themselves as Garifuna. For example, the community members of Marshall Point predominantly define themselves as Creole.

(CDCC), which was responding to requests from a grass-roots organization within the Garifuna communities.

Several meetings were carried out between leaders from the grass-roots organization, a representative of the CDCC, and the local NGO[4]. The NGO would become the technical executor for the project, and the UNDP would find financial support from bilateral donors and administer the funds. It became clear that the project was loosely motivated by the Sandinista government's desire to reward several Garifuna communities that had historically provided strong support for the Sandinista party[5]. The government's national electric plan, at that time, did not have plans for extending grid electricity to these communities within the next several years. Thus, the project would also function as an interim solution for increasing electricity access in these communities, using donor funds. The development discourse surrounding renewable energy, as well as the importance of local participation, was clearly being used to support the political intentions of the government to respond to the demands of several communities. The following text is taken from a memo prepared by the NGO, addressed to the Finnish embassy in 2009, describing the initial formulation of the project:

> The Organization of Afri-Garifuna Nicaraguans (OAGANIC) has been working for a number of years to successfully solicit water and energy development projects in the five Garifuna communities of Pearl Lagoon. In 2008 [the NGO] was invited by the Commission for the Development of the Caribbean Coast (CDCC), an agency of the Nicaraguan government, to develop a project proposal to bring sustainable energy and water services to these five communities. The Garifuna communities include San Vicente, Brown Bank, La Fe, Orinoco, and Marshall Point, and range in size from 110 people in La Fe, to 1010 people in Orinoco. An electricity distribution system exists within the communities of Orinoco and Marshall Point, but provides limited hours of electricity, generated from a diesel power plant. Working with the communities, the aim of the proposal is to develop projects which will provide increased access to energy services and potable water as well as develop community capacity for maintaining and operating sustainable systems. Working with the UNDP and the regional and local governments, the proposed projects will be designed to help address aspects of the many social, economic, and environmental challenges facing these communities. The project will concomitantly address a number of the Millennium Development Goals (NGO, 2009).

In order for the UNDP to solicit donor funds, the entire project, hereafter referred to as the CDCC Clean Energy and Water Project, had to be designed and budgeted before detailed investigations could be carried out, with limited participation from any stakeholders. Thus, due to the UNDP's bureaucratic process, the initial project proposal was based upon very little information regarding the priorities, capacities, and local social and political context of the

[4] At this time I was volunteering as a technical advisor to the NGO, and played a role in the initial meetings, project design, and pre-investment projects, which involved socio-economic surveys in two communities, participatory workshops in one community, and an energy efficiency campaign.

[5] The largest Garifuna community in Nicaragua, Orinoco, has had strong historical ties to the Sandinista government. Community members proudly proclaim that they are one of the few communities that remained loyal to the Sandinista party during the counter revolution of the 1980s. Many community members observe that some of the most important development projects have been due to the Sandinista government. They received their first diesel microgrid in the 1980s. It stopped functioning in the 1990s and did not receive government support until the Sandinistas returned to power again after 2007.

target communities. The initial project was designed with the idea that if the project was funded, the initial stages would be participatory planning workshops within the communities, and the budget would then be re-allocated to more appropriately designed interventions based on community input. A three-year project proposal was developed. The initial budget was close to 800,000 USD, but quickly grew to 2 million USD, as new project ideas emerged and overhead for the UNDP and capacity development for the NGO were included in the proposal.

The Embassy of Iceland committed to funding the project. However, Iceland's economic collapse in September 2008 led to its necessary abandonment of the project. By the summer of 2009, the project budget had swelled to nearly 2.5 million USD, and the UNDP was trying to gain the Embassy of Finland's support for the project. One of the financial predicaments of the project was that potential funders now wanted to see evidence that the proposed energy projects were appropriate for the communities' infrastructure and capabilities, but the NGO didn't have the means to invest its own limited funds to conduct feasibility studies.

During June of 2009, the CDCC agreed to provide 10,000 USD to support several socioeconomic surveys and participatory workshops in the largest of the target communities, which would provide data to support the technical solutions being studied by the energy and water experts. The surveys uncovered demographic, economic, and energy use statistics, while the participatory workshops elicited community history, and current challenges and goals. In addition, in order to cheaply and immediately increase energy access within two of the communities, the Ministry of Energy and Mines (MEM) agreed to donate efficient light bulbs and educational materials for an energy efficiency campaign.

Following the workshops and energy efficiency campaign, a new iteration of the project design and budget was produced. A representative from the Finnish embassy and a delegation from the government visited the communities with the NGO, and discussed the project in a community meeting in Orinoco. The entire delegation was pleased with the project, and financing seemed imminent. However, disagreement over the technical appropriateness of several aspects of the project arose within the Finnish embassy. The Finnish embassy eventually decided against funding the project, leaving the UNDP discouraged from searching for another donor, and abandoning the project.

Yet the work that resulted from the initial workshops, funded with 10,000 USD, less than 0.5 % of the proposed project budget, spawned a number of policy insights related to increased energy access, carbon abatement, and climate policy, highlighting the importance of information uncovered through practice. Simple pilot projects can often provide illuminating insights not revealed by the simplified information and metrics used by 'experts' to construct policies. The project catalyzed several subsequent research projects that evolved to form the primary aspects of this dissertation.

Outline of the dissertation

Chapter 1 is centered upon analysis and policy insights that emerged from the energy efficiency campaign of the abandoned CDCC Clean Water and Energy project. The chapter begins with the observation that there are opportunities for global agendas, such as combating climate change, to increase the material wellbeing of many vulnerable communities while also mitigating emissions. Globally, increasing consequences of climate change will have severe outcomes for some of the poorest communities, and yet common planning and analysis tools for greenhouse gas mitigation fail to highlight the equity impacts of various mitigation choices. Augmenting metrics of cost and tons of emissions reduced to include several welfare measures increases the visibility of impacts on project stakeholders. While introducing equity into the policy level discussion creates a greater awareness of the possible project impacts, it does not reveal how certain projects may actually support stakeholder priorities.

During the project design stage for the CDCC Clean Energy and Water Project, budgets were drawn up and equipment was specified with the goal of meeting the project mandate of clean energy and water provision. Following several participatory workshops, energy services were linked to economic development projects within the village. However, the projects were planned without a deep understanding, by either the experts or the beneficiaries, regarding the causal chains linking the interventions to stakeholder benefit.

The remainder of the dissertation is dedicated to exploring the importance of various forms of information and communication for project designs and outcomes. Chapter 2 provides a brief history of political and economic trends that have shaped rural livelihoods on the Atlantic Coast. Chapter 3 details a novel participatory method that seeks to address the information gap between planners and beneficiaries and between desired outcomes and the necessary capabilities needed to reach those outcomes. The participatory process, referred to as participatory modeling, involves participants creating a simplified model of their fishing economy, in the form of a board game. Chapter 4 looks at the past and present challenges in the artisanal fishing economy on the coast, describing how the game playing process helped to reveal insights about fisher aspirations and values. The chapter provides circumstantial evidence regarding the value of the participatory modeling approach for uncovering new information that allows fishers to better evaluate the benefits of potential projects or policies.

Chapter 1 Practice informing policy: opportunities for global agendas to positively shape local livelihoods

Introduction

This chapter provides insights into the way in which policy makers collapse information into select metrics, leaving hidden the true impacts that policy recommendations can have upon the complex realities of various groups of stakeholders[6]. In addition, I will demonstrate how insights resulting from actual project implementation can feed back into the policy making process, highlighting the manners in which further aspects of local realities can be made visible.

The impacts of climate change will be most severe for billions of vulnerable populations, especially those whose livelihoods are based on agriculture and subsistence activities, and directly dependant on weather patterns. However, many tools that are helpful for evaluating greenhouse gas (GHG) mitigation measures, such as carbon abatement cost curves, focus exclusively on a monetary cost and tons of avoided GHG emissions, without quantifying how various stakeholders may be impacted by the proposed mitigation measures. Even though issues of poverty and equity have become common in climate change discourse related to adaptation, dominant policy tools lack metrics that highlight poverty and equity impacts of mitigation measures.

The first part of this chapter will describe how the carbon abatement cost curve, which has become popular for evaluating carbon mitigation strategies, remains blind to the equity impacts that can result from different policy choices. I will then describe how increasing electricity access to poor rural users has the potential to not only complement the global climate change agenda, but also impact other poverty metrics of rural users. This policy recommendation is based upon insights that emerged from the energy efficiency campaign in the two Nicaraguan villages, before the cancellation of the CDCC Clean Energy and Water Project, illustrating how practice can inform policy. Project results are quantified using an energy supply curve and a carbon abatement cost curve, which are typically aggregated over national or regional economies, rather than at the community level. The final part of this chapter then complements the limited metrics of the carbon abatement curve with several poverty metrics, increasing the visibility that project impacts might have on local realities, bringing people back into the picture. It is also discussed how this approach can be carried out in practice at the national or global level.

Climate change and the poor

There are many metrics that highlight the livelihood challenges that a large proportion of the global population faces. Almost a quarter of humanity does not have access to electricity, three billion people lack adequate sanitation, and one billion people don't have clean drinking water (UNDP, 2010b, p. 7). The daily struggle for survival of many of these marginalized communities will be made more difficult with environmental shocks resulting from climate change (Hertel & Rosch, 2010; Lobell et al., 2008).

The World Bank estimates that 75 to 80% of the costs and damages caused by future climate changes will be borne by the poorest countries (World Bank, 2010, p. xx). Communities

[6] A portion of the material in this chapter is drawn from (Casillas & Kammen, 2011, 2012a)

whose daily livelihoods are intimately tied to their natural resources will be most vulnerable to climate change (Hertel & Rosch, 2010; IPCC, 2007a; Ribot, 2010; World Bank, 2010). They will have the greatest exposure to change and the least capacity to adapt (Tol, Downing, Kuik, & Smith, 2004). Today, slightly less than half of the global population lives in rural areas. The livelihoods of 85% of this population are dependent on agriculture (World Bank, 2008, p. 3), and 70% of them live in extreme poverty (IFAD, 2010, p. 9). Studies show that as mean temperatures in tropical and mid-latitudes rise, there will be a decrease in average agricultural yields, with communities in Asia and Africa impacted the worst (World Bank, 2010, p. 146).

Poor communities in rural areas are not the only populations susceptible to climate change. Poor, elderly, and children all comprise urban populations vulnerable to climate change. Decreasing agricultural yields will affect food prices, impacting the welfare of the urban poor (M. E. Brown & Funk, 2008; Lobell et al., 2008). Heat waves in 2003 in Europe resulted in devastating increases in mortality, particularly among the elderly living in urban areas (Martiello & Giacchi, 2010). Warmer temperatures and increased concentrations of carbon dioxide in urban environments have already been seen to increase pollen counts, a primary contributor to asthma, the largest chronic disease among children (Bloomberg & Aggarwala, 2008, p. 1; Kinney, 2008, p. 461).

Dialogue over the connection between climate change and the poor has primarily focused upon aspects of equity in emissions (Baer et al., 2000) and adaptation (Paavola & Adger, 2006; Ribot, 2010; Smit & Pilifosova, 2003; Tol et al., 2004; Tompkins & Adger, 2004). Much of the adaptation literature addresses climate change and poverty, framed in terms of vulnerabilities, accounting for one's exposure and capacity to adapt to risk. Poverty can manifest as a lack of money, education, health care, housing, security, and social and political participation (Sen, 1999, p. 87; UNDP, 2010a, p. 94), all of which will affect one's ability to adapt to climate shocks.

The literature is limited with respect to the links between emissions mitigation and poverty, primarily focusing on the impacts on agriculture and forestry projects (Hertel & Rosch, 2010; Olsen, 2007; Pearson, 2007; Phelps, Webb, & Agrawal, 2010; Ribot, Agrawal, & Larson, 2006). Most of the studies that directly explore more general relationships between mitigation and poverty are within the context of clean development mechanism (CDM) projects (Lenzen, Schaeffer, & Matsuhashi, 2007; Olsen, 2007). Other, more general mitigation policy studies, focus on environmental effectiveness and costs, with little attention paid to poverty and equity (Heinrich Blechinger & Shah, 2011; Konidari & Mavrakis, 2007).

However, mitigation projects will have many direct and indirect impacts on the poor, and not just in agriculture and forestry sectors (Casillas & Kammen, 2010). The relationship between mitigation and poverty can be made more explicit in general climate policy and planning dialogue, at the local and national levels, through the use of welfare metrics, instead of just cost and GHG emissions.

Carbon mitigation and equity

Greenhouse gas mitigation claims to focus on politically, technically, and economically feasible emission reduction strategies. The Intergovernmental Panel on Climate Change's (IPCC's) fourth annual assessment report (AR4) classifies the areas with the greatest mitigation potential into the sectors of energy supply, transportation, buildings, industry, agriculture, forests and forestry, and waste management (IPCC, 2007b). The table below shows a breakdown, by economic sector, of GHG emission sources, as well as an estimation of the range of annual emission reductions that could be achieved for less than 100 USD/tCO_2-eq.

Sector	2004 GHG emissions (% of total)	Mitigation potential for less than 100 USD/tCO_2-eq (in GtCO_2-eq/yr)
Energy Supply	26	2.4-4.7
Industry	19	2.5-5.5
Forestry/Forests	17	1.3-4.2
Agriculture	14	2.3-6.4
Transport	13	1.6-2.5
Buildings	8	5.3-6.7
Waste Management	3	.4-1

Table 1: 2004 greenhouse gas emissions and estimated mitigation costs for various sectors (IPCC, 2007c)

There are many options that can be targeted for mitigating GHG emissions. Some involve reducing emissions from fossil fuel based technologies, while others involve management of carbon sinks, in sectors of forestry and agriculture. The table below shows instruments and policies, for different sectors, that have been implemented with various levels of effectiveness.

Sector	Potential instruments or policies
Energy Supply	Reduction of fossil fuel subsidies Taxes or carbon charges on fossil fuels Feed-in tariffs for renewable energy technologies Renewable energy quotas Generation subsidies
Industry	Provision of benchmark information Performance standards Subsidies, tax credits Tradable permits Voluntary agreements
Forestry/Forests	Financial incentives (national and international) to increase forest area, to reduce deforestation, and to maintain and manage forests Land use regulation and enforcement
Agriculture	Financial incentives and regulations for improved land management, maintaining soil carbon content, efficient use of fertilizers and irrigation
Transport	Mandatory fuel economy, biofuel blending and CO2 standards for road transport Taxes on vehicle purchase, registration, use and motor fuels, road and parking pricing Influence mobility needs through land use regulations, and infrastructure planning Investment in attractive public transport facilities and non-motorized forms of transport
Buildings	Appliance standards and labeling Building codes and certification Demand-side management programs Public sector leadership programs, including procurement Incentives for energy service companies (ESCOs)
Waste Management	Financial incentives for improved waste and wastewater management Renewable energy incentives or obligations Waste management regulations

Table 2: Sectors offering the potential for significant greenhouse gas mitigation. The policies and measures are those that have been found to be environmentally effective in national-level implementations (IPCC, 2007b).

The AR4 recommends four main criteria to evaluate carbon mitigation instruments and policies (IPCC, 2007b, p. 751). These include environmental effectiveness, cost effectiveness, distributional and equity effects, and institutional feasibility. While the IPCC reports and other discussions highlight the importance of equity issues, they are often presented at the qualitative level, and have yet to manifest in commonly used metrics for evaluating projects. The best example of climate policy measures that seek to take address equity issues in a structured analysis is the use of multi-criteria evaluations in CDM projects (Lenzen et al., 2007).

The more quantitative mitigation analysis tools, that are common among policy makers, focus on carbon costs and abatement potential without quantifying poverty impacts. The recent prevalence of carbon abatement cost curves provides a stark example[7]. A carbon abatement cost curve typically shows the average or marginal cost for reducing emissions relative to a given baseline, through the introduction of a new technology or policy (Klepper & Peterson, 2006). The curves provide approximations of mitigation supply curves, often for national or global economies, showing the approximate cost ($ /tCO_2-eq) for various measures and the total abatement potential. Within the last several years the management consulting firm, McKinsey and Company, and the World Bank, have begun constructing numerous carbon abatement cost curves for national economies. These studies focus on financial cost to society and carbon metrics, with little effort to quantify how the measures will impact diverse stakeholders (Ekins, Kesicki, & Smith, 2011, p. 27).

By way of illustration, in Figure 1 below, a modified version of an economy-wide carbon abatement cost curve for Mexico is presented, adapted from a World Bank report (Johnson, Alatorre, Romo, & Liu, 2009, p. 8). The report was produced in order to support the mitigation goals of Mexico's Special Climate Change Development Program. Both the climate change program and the report demonstrate the lack of quantitative analysis regarding the poverty or equity impacts of climate mitigation policy.

The authors of the World Bank report use three criteria to select the mitigation interventions: those that would result in reductions of over 50 million tons of CO_2-equivalent

[7] Carbon abatement cost curves share a close relationship to economic supply curves. In the economics literature, marginal abatement cost (MAC) curves follow from the production theory of firms (Klepper & Peterson, 2006; McKitrick, 1999). A firm-level supply curve shows the quantity of a product that the firm is willing to produce for a given price. In a competitive market a firm's decision to produce or not to produce is determined by its marginal costs. A profit maximizing firm will only be willing to operate where the marginal cost to produce an additional good is less than or equal to the price of the good. A sector wide supply curve shows the amount of goods that will be supplied to a market, for a given price. In recent years, a number of macro-level estimations of supply curves for carbon abatement have been created for national and global economies (Ekins, Kesicki, & Smith, 2011), where the firm is most likely a government or society. The supply curve is comprised of mitigation interventions over various sectors, such as electricity, transportation, or forest management. The costs are annualized costs to society, often net of taxes and subsidies, averaged across each given sector. Macro-level curves will have a different nature than micro-level curves (McKinsey & Company, 2009, p. 40), which may focus on a specific sector, under specific circumstances (such as a diesel micro-grid). Due to the disaggregated nature of the costs in a micro-level curve, it can be presented more easily from the perspective of either the consumers or providers of a service. There is some ambiguity in the direct analogy to the marginal cost curve of a single firm that is basing its production decisions on its marginal costs.

before 2030, have costs below 25 \$/ton CO_2-equivalent, and that would be technically and financially feasible in the near term. The closest that the report comes to addressing equity concerns is to mention potential health co-benefits from emission reductions.

In order to illustrate the inequalities embedded in the mitigation analysis, a number of the interventions have been highlighted, contrasting the differential social impacts that could result from the various measures. Each box in the curve represents a different mitigation measure, ordered from the cheapest to the most expensive. The x-axis shows an estimation of the total abatement potential for each measure over a 22 year time frame, and the y-axis represents the average cost to society, relative to a business as usual scenario. Measures that fall below the x-axis represent net savings. The original carbon abatement cost curve from Johnson et al. (2009, p. 8) has been modified so that light gray boxes represent measures that could have direct co-benefits to the poorest populations, through monetary savings, employment, or the local reduction of air pollution. Gray and white striped boxes represent measures that would primarily provide benefits to owners of industry, as well as a skilled labor force.

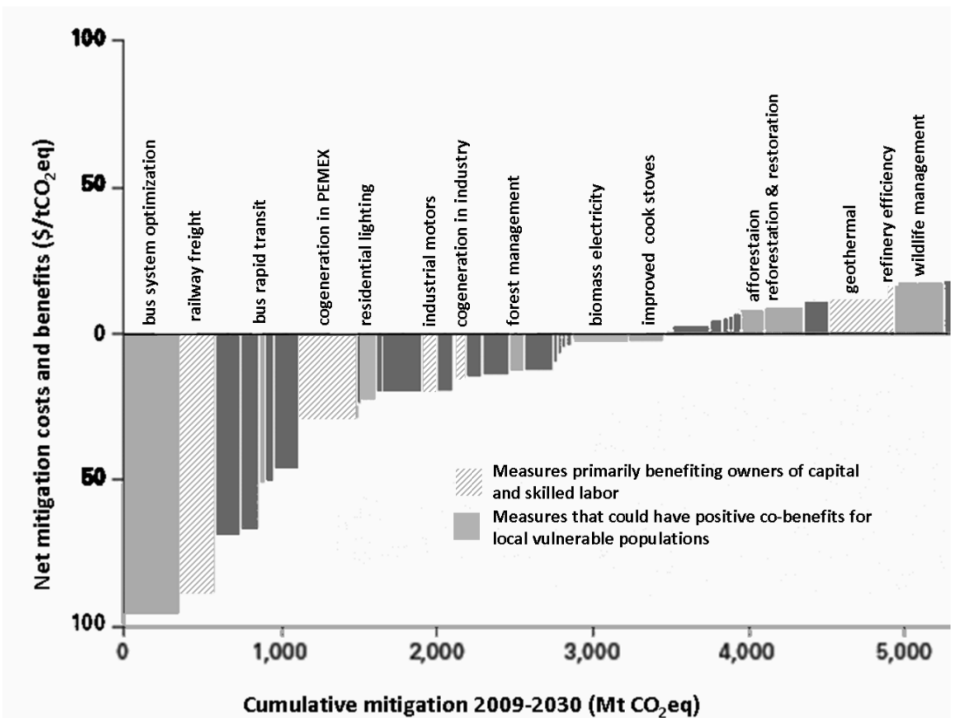

Figure 1: Carbon abatement cost curve for Mexico, adapted from Johnson et al (2009, p. 8). The width of each box represents the cumulative mitigation potential (Mt CO2-eq), and the height represents the net mitigation costs, relative to a business as usual baseline. Measures below the x-axis represent a net savings. The original figure has been modified, with only a portion of the interventions labeled, in order to highlight the differential social impacts between them. The interventions labeled with light grey boxes could provide direct co-benefits to poor urban and poor rural populations, through increased employment, savings, and improved air quality. The grey and white boxes represent measures that would likely benefit owners of industry and support job creation for skilled labor forces. Although not all the measures are highlighted, it is estimated that 40% of all mitigation measures in the curve could have positive co-benefits for poor populations, representing slightly more than 2,000 Mt CO2-eq.

The cheapest carbon mitigation option in the supply curve is optimization of the bus system, which would likely benefit many of the poorest urban populations. Improved public transportation in urban mega-cities can disproportionately benefit the poorest sectors, decreasing transportation times and reducing air pollution (INE, 2008).

Forestry and natural resource management is another sector that will have significant impacts on vulnerable communities. Almost 65% of global mitigation potential (up to 100 US$/t$CO_2$-eq) is located in the tropics and about 50% of the total could be met through the reduction of deforestation (IPCC, 2007c, p. 14). However, the manner in which deforestation projects are structured will be critical in terms of whether or not they will improve the livelihood of local stakeholders (Agrawal, Chhatre, & Hardin, 2008; Phelps et al., 2010). Mexico already has over a decade of experience with forest management used for carbon mitigation, providing conflicting evidence regarding the benefits to rural stakeholders (K. Brown & Corbera, 2003; Nelson & de Jong, 2003). Marginalized communities living primarily off the land could suffer if forests and other resources are only valued in terms of monetary or carbon metrics, especially when projects alter relationships of traditional resource access (Corbera, Brown, & Adger, 2007; Phelps et al., 2010; Ribot & Peluso, 2003).

It is necessary to understand how current challenges of poverty can be addressed while also responding to climate change, beyond measures of adaptation. This requires understanding the links between mitigation measures and the welfare of marginalized communities. Mitigation strategies will necessarily involve changes to environments and infrastructure and could very well induce structural changes to economies. This will create winners and losers, providing opportunities for reducing vulnerabilities of marginalized populations, depending on how the projects are implemented.

While issues of equity continue to be pervasive in climate discussions related to abatement and emissions rights, they are noticeably absent from mainstream analysis of mitigation. Carbon abatement cost curves have become ubiquitous because they have an intuitive logic and understandable interpretation that is attractive to policy planners. The very fact that carbon abatement cost curves are presented without highlighting stakeholder impacts creates the risk of implementing climate programs that could widen socio-economic inequalities, exacerbating conditions of climate vulnerability. By attempting to quantify, or at the very least, highlight, the potential poverty alleviation opportunities that coincide with carbon mitigation interventions, carbon abatement cost curves can keep issues of equity and poverty within climate mitigation discussions – the first step towards integrating them into planning and implementation.

Electricity's role in both poverty and climate change

The largest portion of anthropogenic greenhouse gas emissions results from electricity generation (IPCC, 2007d)[8]. The majority of emissions from the world's poorest countries come from agriculture and changes in land use (World Bank, 2010, p. 195). However, with 1.5 billion people without access to electricity, combustion-related emissions from the rural power sector will substantially increase.

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[8] In 2004, 26% of global anthropogenic emissions were from electricity generation, 19% from industry, and 13% from transportation (IPCC, 2007d).

Electricity provision facilitates access to energy services that can directly address the quality of life and economic opportunities for rural communities (Cabraal, Barnes, & Agarwal, 2005; Cecelski, 2000; Flavin & Aeck, 2005; Kirubi, Jacobson, Kammen, & Mills, 2009). Electricity needed for motive power, such as grinding and pumping, is not the only manner in which it can serve as a catalyst for economic activity. One study in Kenya documents the utilization of low power consumption for such economic activities as tailoring, hair salons, phone services, radio and television repair, and refrigeration for household businesses in rural Kenya (Kirubi et al., 2009). Access to electricity consistently increases the quality of services available to meet basic business and domestic needs for families, such as lighting, labor saving devices for kitchens, and information and leisure activities from TV and radio (IEG, 2008). Many of these services disproportionately benefit women and children, who are involved in domestic activities. While access to electricity services may not lessen work burdens, it improves the conditions in which domestic activities take place (Bose, 1993; Cecelski, 2000) and creates opportunities for economically productive tasks (Cabraal et al., 2005). The provision of high quality lighting can provide healthier conditions for domestic work and study, and increased security in public spaces and walkways (Cecelski, 2000; Jacobson & Kammen, 2007). Educated professionals, such as doctors, nurses, and teachers, are more willing to remain in a rural setting if they are able to access forms of modern energy (Modi, 2005). However, there are close to 1.4 billion people without access to electricity in the world, the majority them living in rural areas (IEA, 2010).

Cost is a primary barrier to the widespread delivery of electricity. Rural users live in remote areas and often have limited capacity to pay for services (IEG, 2008). This necessitates electricity providers to determine the lowest cost means of electrification, often having to subsidize the true cost of electricity delivery. However, as many authors have pointed out, it is not the delivery of electricity that matters, but rather the provision of energy services (Cabraal et al., 2005; Modi, 2005), which underscores the need for energy providers to pay close attention to demand side energy measures. A number of studies have examined the benefits of using distributed generation using renewable energy sources as a means for increasing access to areas where grid extension might not be feasible in the near term (Kaundinya, Balachandra, & Ravindranath, 2009). However, studies quantitatively comparing costs between supply and demand side measures for rural power systems are harder to find. In order to determine the most cost effective and appropriate rural energy system, both supply and demand side measures must be considered.

Demand side programs are fundamental for systems where the ongoing costs of electricity generation are high, as is the case with diesel microgrids. While grid extension is typically the most prevalent tool utilized by governments to rapidly increase electricity access, in many cases it is more cost effective to bring electricity to isolated communities through the development of microgrids that generate power at or near the village location (Kaundinya et al., 2009). Tens of thousands of village-scale microgrids exist worldwide, the majority in China, Nepal, and India (Flavin & Aeck, 2005). While there are a large number that utilize micro-hydro generation, those that are not located in areas with adequate river resources typically rely on diesel powered generators (Baring-Gould, Barley, & Drouilhet, 1997; IEG, 2008; Solano-Peralta, Moner-Girona, Van Sark, & Vallvè, 2009). Due to the low capital costs and ubiquitous diesel suppliers and service networks, diesel generators often become the technology of choice, without placing sufficient consideration on the long term volatility of fuel costs (World Bank, 2006).

Over the past eight years, the average price of diesel fuel has more than doubled leading to sharp rises in the cost of electricity generation from diesel engines. Diesel prices for rural users are further exacerbated by the costs needed to transport the diesel fuel to isolated rural areas, often resulting in the cost doubling or tripling[9]. Addressing adequate demand side measures can greatly reduce the costs of energy service provision in these contexts.

Every dollar spent on the transition to more efficient low-carbon energy systems in rural areas has the potential to produce greater human development, savings, and carbon mitigation returns than in more industrialized ones. However, debates about climate change and vulnerability have been slow to highlight the energy-poverty-climate nexus (Casillas & Kammen, 2010). This has been due, in part, to the lack of meaningful metrics that make visible welfare benefits between various mitigation measures.

In the following sections, I will first use traditional financial metrics to analyze the potential benefits of conservation and renewable energy measures at the village level, and then complement these measures with emissions metrics, highlighting the opportunities for cheaply increasing energy access and carbon mitigation at the local level. The analysis is based upon the insights from the energy efficiency campaign of the CDCC Clean Energy and Water project, carried out in Marshall Point and Orinoco.

In order to compare the economic benefits between different measures, an estimation of an energy supply curve is constructed that includes both supply costs and the cost of conserved energy. The curve provides insight into relative benefits of energy conservation measures, and may help encourage energy providers and policy makers to rethink conventional wisdom used for making investment decisions in both isolated and grid connected systems. The energy supply curve is complemented by a carbon abatement cost curve. Well documented examples of energy systems that jointly address low-cost and low-carbon objectives, particularly in rural areas of developing nations, are rare. In a context of global warming and emerging international policy strategies for the mitigation of carbon dioxide emissions, this analysis seeks to provide additional visibility to the manner in which the transition from diesel generation to carbon-free rural electricity systems can be done while also reducing costs and potentially improving local welfare aspects. In order to highlight how the carbon mitigation measures impact the poorest stakeholders, various poverty metrics are used to complement the carbon abatement cost curve, further bringing the local impacts of policy decisions into the field of view of policy makers and planners.

Village case study: the poverty impacts of carbon mitigation in the electricity sector

Nicaragua has one of the lowest electrification rates in Central America, and its generation portfolio is primarily composed of petroleum based fuels used in thermal power plants (Mostert, 2007). The government is currently embarking upon an ambitious project that will vastly increase electricity access throughout the country, and shift the generation portfolio

[9] Rural locations in many developing countries often require boat or air transport to carry fuels, resulting in fuel prices which can be as great as three times more expensive than urban areas (Personal communications in Colombia and Nicaragua, 2008/2009).

from fossil fuels to renewable energy sources. Community-level case studies can complement national implementation plans by providing insight into the micro-level equity impacts of these policy initiatives. This particular case study is at the community level, demonstrating how socio-economic data can be used to incorporate an understanding of local impacts from policy decisions, often made at the national level.

Communities on Nicaragua's Atlantic Coast remain some of the most impoverished in Central America when measured using metrics of monetary earnings and lack of access to public goods, such as education, health care, clean water, and electricity (UNDP, 2005). The communities on the Atlantic Coast have characteristics that are typical of the many vulnerable, rural communities throughout the global south. The coastal villagers depend on the marine and terrestrial ecosystems for their livelihoods, being both fishers and farmers, living at the crossroads of complex environmental, social, and economic systems .

The two neighboring villages of Orinoco and Marshall Point have populations of roughly 850 and 250 people, respectively (Casillas, Sobalvarro, & Valverde, 2010, p. 5). In the village of Orinoco there is a three-phase 110 kW diesel generator. Two of the phases are distributed within the village, with the third phase connecting to the village of Marshall Point, located 3 kilometers away. The distribution system provides power to a total of 186 clients, administered by the national electric company (ENEL). Prior to the installation of meters and an energy efficiency campaign in the summer of 2009, the grid operated for 10 hours each day, from 2 pm until midnight.

Over 90 % of the consumption is for residential use (lighting, TV, and refrigeration) and public illumination, with very little utilized by commercial or public buildings. The following table contains estimations of the loads within the community:

	Orinoco	Marshall Point	Total	kWh/month	%
Connected Houses	121	51	172	3839	66.8%
Public Lighting	29	25	54	1458	25.4%
Hotels	2	0	2	273	4.7%
Health Clinic	1	1	2	82	1.4%
Churches	4	2	6	41	0.7%
Schools	2	0	2	30	0.5%
Carpentry Shop	1	0	1	15	0.3%
Communal Building	0	1	1	11	0.2%
TOTAL	160	80	240	5749	100%

Table 3: Estimation of total electric loads by source, in Orinoco and Marshall Point. Consumption estimates are based on the meter readings for the month of August 2009. Public lighting estimation is based on the assumption that each light bulb is 150W and is turned on between 6pm and 12am every day. In reality, many of the automatic light sensors on the street lights do not function, and many of the lights remain on for 12 hours. The carpentry shop is fairly new and is not yet regularly utilized.

During the months from June to August, 2009, two demand side measures were implemented within the microgrid. During the month of June, ENEL installed conventional electric meters at each client connection. Prior to this intervention, clients were charged a fixed monthly tariff that was based upon an audit of their building, noting the power consumption of various appliances and estimated hours of usage. Due to the fixed nature of this tariff system, there was not any incentive for clients to conserve electricity.

In August, shortly after the meter installation, the Ministry of Energy and Mines supported a request from a local non-government organization to conduct an energy efficiency campaign in both Orinoco and Marshall Point, focused on replacing incandescent lights with compact fluorescent lights (CFLs).

The installation of the meters resulted in a 28% reduction in the electricity load, and the installation of CFLs resulted in an additional 17% load reduction. Measurements of the load profiles before and immediately after the meter installation, as well as following the installation of the CFLs, are shown in Figure 1. Following the diesel savings that resulted from the meter installation, grid operation was increased two more hours, to twelve hours per day. As of August 2009, the system received a monthly allotment of 4540 liters of diesel fuel, and the plant was operated 12 hours every day, running from 12 pm to 12 am.

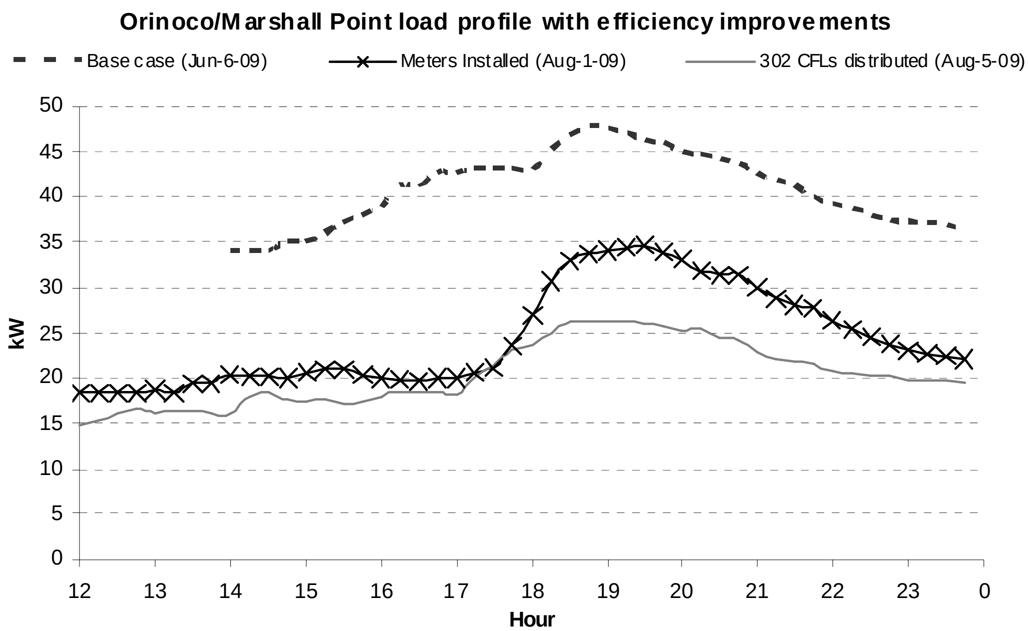

Figure 2: Load profile before and after demand side measures were implemented. Measurements were made by the author using a Hioki 3197 power quality analyzer.

In order to demonstrate the potential monetary benefits in addition to the installation of meters and CFLs, cost estimations were made for other supply and demand measures. Financial calculations typically produce the primary metrics used by project planners to evaluate energy projects. There are a number of common metrics used in order to compare the costs and benefits of the various measures, such as capital cost, the net present value, the internal rate of return, or the annualized energy cost. Akin to the annualized energy cost, the marginal cost of conserved energy (CCE) is useful for comparing conservation with energy supply measures (Blumstein & Stoft, 1995; Meier, 1982; Rosenfeld et al., 1993; Stoft, 1995). CCE may be defined as the total investment cost of conservation (TCC) for the intervention, divided by the total resultant energy savings[10]:

[10] See Stoft, 1995 for a detailed discussion of a more complete calculation of the cost of conserved energy, rather than the discretized, but commonly used, formula presented here.

cost of conserved energy (CCE) = $\frac{\text{total investment cost of conservation (TCC)}}{\text{total energy savings}}$.

The total cost of conservation includes the capital costs, operation, and maintenance costs over the lifetime of the measures. A more complete calculation accounts for the time value of money by using the levelized annual (annualized) costs, divided by the annual energy savings. The annualized costs (AC) can be calculated from the present value (PV) of the costs:

$$AC = \frac{PV \cdot r}{1-(1+r)^{-n}},$$

where *r* is the real discount rate and *n* is the lifetime of the intervention. This gives:

$$CCE = \frac{\text{annualized cost of conservation}}{\text{annual energy savings } (\Delta E)}.$$

CCE for various conservation measures can be compared with annualized energy supply costs. For example, in terms of energy services delivered, a kWh of electricity that supplies a quantity of lighting using inefficient technology would be equivalent to the reduction in demand by a kWh of electricity delivering the same lighting using more efficient technology. In both cases, a quantity of energy service is provided, one by supplying a kWh, and the other by conserving a kWh.

Table 2 summarizes various metrics for interventions to the Orinoco and Marshall Point electric system. The first two demand-side measures, meter and CFL installation, were implemented, and the energy savings are based on actual measurements of the load changes. All other activities in the table are based on estimations, which are discussed in detail in the Appendices.

	Capital cost	Lifetime (yrs)	Annualized cost ($/yr)	kWh/day saved or supplied	Liters/day of diesel saved	Estimated annual diesel savings	Internal rate of return	Annualized cost of cons. / supplied energy ($/kWh)
Meter installation	$4,350	10.0	$648	115	33	$12,726	293%	$0.02
CFL installation	$1,030	2.0	$577	50	14	$5,581	528%	$0.03
Smaller street lights	$3,240	7.0	$622	46	13	$5,101	157%	$0.04
Biogas	$13,500	10.0	$4,012	43	22	$8,690	49%	$0.26
Reduce diesel plant capacity	$23,000	5.0	$5,760	58	24	$9,157	28%	$0.27
Wind turbine (class 2)	$61,557	15.0	$7,767	54	22	$8,500	10%	$0.39
Replace street light sensors	$322	0.3	$1,352	9	4	$1,468	23%	$0.42
Solar PV	$92,300	20.0	$9,501	33	14	$5,579	2%	$0.78

Table 4: Summary table of demand and supply side measures in the Orinoco and Marshall Point electric grid. Meter and CFL installation were implemented. Detailed desriptions of each measure and values used in the estimations are discussed in the Appendices.

The measures are ordered by increasing values with respect to the cost of conserved energy (CCE), which were calculated using each previous measure as a baseline. The supply side measures are based on *additional costs* for integration into the existing grid. For example, the costs for reducing the diesel plant capacity to a 55 kW diesel generator are the additional investment costs (capital cost and installation) and do not include the cost of diesel fuel or ongoing labor and maintenance, since these costs are already being paid. The annual levelized costs were calculated using a discount rate of 8.0 %[11], and include both capital and operation and maintenance costs. The amount of total energy (kWh) and diesel fuel that is saved is based on the reduction in demand resulting from the intervention[12]. In the case of renewable generation, the energy supplied is based on the amount of renewable energy that can be generated to offset diesel fuel consumption. It is important to note that there is a drop in efficiency of diesel engines as the load decreases. The change in diesel efficiency was modeled using HOMER, a micro-power simulation tool. The annual savings are calculated from the number of liters of diesel fuel that are saved, using a constant diesel price of $1.06[13]. The internal rate of return demonstrates the comparative economic value of the various measures, as well as overall economic attractiveness of the specific measure[14]. However, it is important to note that the various metrics and savings shown in Table 4 say nothing about the resulting impacts on the various stakeholders (especially the utility versus the consumers). The following subsections will continue to present an analysis from the typical planner's perspective, which use a narrow range of financial metrics for evaluating the attractiveness of energy projects.

Community level energy supply curve

The figure below displays an estimation of a "supply curve"[15] for conserved and supplied energy for the Orinoco and Marshall Point microgrid. The vertical access displays the annualized production cost of energy for supply measures and the cost of conserved energy for conservation measures (the final column of Table 2). The width of each step in the curve represents the total possible kWhs conserved or supplied by each measure. For example, the first step on the left signifies that up to 115 kWh of electricity from diesel generation can be saved at an annualized cost of 0.02 $/kWh from the installation of meters, followed by another 50 kWh for 0.03 $/kWh with the installation of CFLs.

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[11] The discount rate accounts for market interest rate minus inflation (i.e. the real interest rate). In 2003, 14% was an average cost of capital in Nicaragua (World Bank, 2003), and the rates of interest between 2003 and 2009 were not dissimilar (see lending rates at the national bank: http://www.bcn.gob.ni/). However, due to the fact that many systems for rural electrification are subsidized by the government or supported by international lending institutions such as The World Bank and The Inter-American Development Bank, they would most likely have access to capital at interest rates lower than the typical market rates in the country, which is why 8.0% was chosen.

[12] Liters of diesel conserved/year = $\dfrac{365\frac{days}{year}}{LHV\frac{kWh}{liter}} \quad \dfrac{P_1\frac{kWh}{day}}{\eta_1} \quad \dfrac{P_2\frac{kWh}{day}}{\eta_2}$, is the equivalent amount of diesel fuel (in liters) that was conserved, either through the reduction in load, where η_1 is the diesel efficiency before the measure and η_2 is the efficiency following the measure, or replacement of supply. The lower heating value (LHV) used for the diesel fuel is 9.84 kWh/liter.

[13] This fuel price is based on the average retail diesel price for 2008 (derived from data from the Nicaragua Institute of Energy, http://www.ine.gob.ni/). The diesel prices in rural areas in 2009 remained at or above this price. I was not able to ascertain the true cost that the government pays for the diesel fuel. While this cost is surely much lower than the retail price, it is unlikely that it would remain constant for the demand or supply side measures that have lifetimes greater than 5 years.

[14] The internal rate of return (IRR) is calculated by finding the interest rate at which the net present value of investment is equal to zero (i.e., the lifetime costs and benefits are equal). Investments where the IRR is greater than the cost of capital are typically considered attractive.

[15] See Stoft, 1995 for an explanation why this curve is different from a classical economic supply curve.

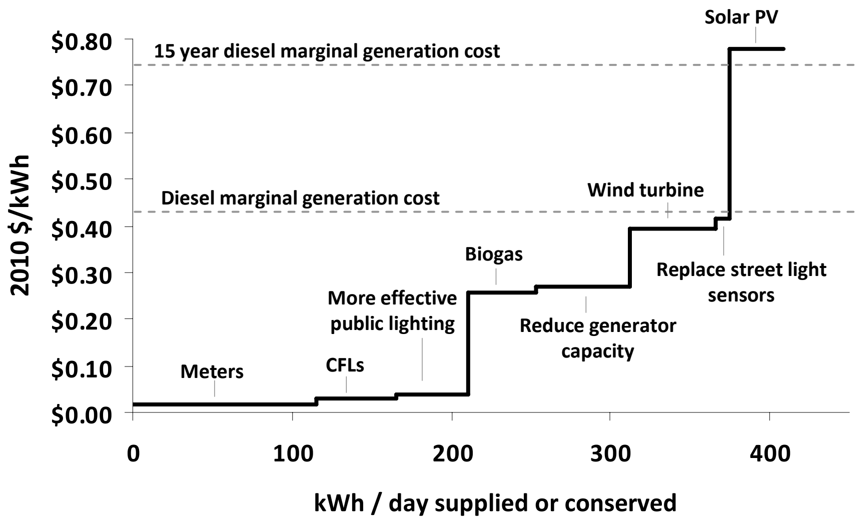

Figure 3: Rural energy supply curve for Orinoco and Marshall Point electric grid. The values displayed in the curve are taken from Table 4. Details of the calculations can be found in the Appendices 1 and 2.

The lower dotted line represents the estimated marginal production cost of 0.43 $/kW for a 110 kW diesel engine operating at 25% efficiency, and utilizing diesel fuel at a cost of 1.06 $/liter. Relative to this diesel cost, all measures that lie below this line could be implemented at cost savings. However, this may not be the most relevant comparison since it compares an estimate of today's marginal generation costs with the annualized production costs for other measures that have lifetimes ranging from 0.3 years to 20 years. Especially for the cases of wind and solar (with 20 and 15 year lifetimes, respectively) a more appropriate comparison price for these measures might therefore be the average marginal diesel generation cost over an equivalent lifetime.

Since there is no reliable way of estimating the average price of oil over the next 15 years, one rational method by which one can guarantee an average diesel price over this time frame would be to borrow money at a given interest rate (8% to remain consistent with the discount rate used for other calculations) and purchase 15 years worth of diesel fuel at today's diesel price. The resulting annual loan payments can be used to represent an attainable fuel price over the next 15 years[16]. At an initial diesel price of 1.06 $/liter and an 8% interest rate, the marginal diesel generation cost becomes 0.76 $/kWh, which is represented by the upper dotted line in the figure. While it might be argued that a more economically rational choice would be to wait until the current marginal diesel price (the lower dotted line) exceeds the annualized cost of a measure before investing in it, there may be other motivations for earlier investment, such as reducing carbon emissions as soon as possible.

After the equivalent of 408 kWh of diesel generation have been conserved or supplied, without any increase in demand, then the system would be running with 100% renewable

[16] If today's cost of fuel is *C*, then the annual fuel cost for a project of lifetime *n*, with a loan taken at an interest rate of *i* would be: Annual fuel price = $C \cdot n \cdot \frac{i}{1-(1+i)^{-n}}$

energies, resulting from the energy efficiency measures, resizing of the diesel system, supplementation of diesel fuel for biogas, as well as integration of wind and solar.

The distribution of financial benefits: utility versus client

It is important to recognize who will bear the costs and benefits of each supply or demand measure. Energy supply curves and carbon abatement curves typically assume that the costs will be borne by society, without explicitly determining how those costs will be allocated. In the case of a diesel microgrid for a rural area, who will reap financial benefits of supply and demand measures will vary, depending on electricity rate structure, government subsidies or incentives, and whether or not one is analyzing the benefits from the consumer perspective or the perspective of the electricity company.

It is well known that demand-side conservation measures are not attractive to utilities unless adequate regulation or financial incentives are provided (Kushler, York, & Witte, 2006). The electricity rate structure may need to be altered in order to compensate profit-making utilities, and encourage investment in conservation. In the case of a subsidized electric system, where the utility is *losing* money on each unit of energy generated, energy conservation results in savings to both the utility and the consumer.

Estimating a supply curve without displaying the values relative to a baseline has the advantage that it remains general by not relying on energy prices, and can be useful for various utilities and changing prices since the generation costs are not embedded in the calculations (Meier, 1982; Stoft, 1995). However, additional insight can be gained by calculating the values relative to the baseline from a particular stakeholder's perspective.

As an example, the new costs were calculated when the monetary savings to the utility were taken into account. The monetary savings resulting from both conservation and renewable energy supply measures are due to the avoided cost of diesel fuel, and can be estimated as the *marginal generation cost x saved energy*.

The table below shows how the investment values, from the utility perspective, changes with proper accounting for diesel savings and decreased revenue resulting from energy efficiency. The second to last column in the table is the annualized energy cost relative to the marginal generation cost of diesel (0.43 $/kWh). The negative values signify savings to the utility, assuming it paid for all measures. An ordered curve of the energy costs would appear the same as that shown in Figure 3, simply shifted down by 0.43 $/kWh. The last column is the annualized energy cost relative to baseline marginal generation cost *and* the marginal loss of revenue collection (0.26 $/kWh) resulting from energy efficiency (conservation) measures. This would be the cost seen by the utility.

	kWh/day saved or supplied	Annual tariff loss $/kWh	Liters/day of diesel saved	Estimated annual diesel savings	Annualized energy cost ($/kWh)	Annualized energy cost w/ diesel savings ($/kWh)	Annualized energy cost w/ diesel savings and tariff loss ($/kWh)
Meter installation	115	$10,894	33	$12,726	$0.02	-$0.41	-$0.15
CFL installation	50	$4,763	14	$5,581	$0.03	-$0.40	-$0.14
Smaller street lights	46	$4,382	13	$5,101	$0.04	-$0.39	-$0.13
Biogas	43	$0	22	$8,690	$0.26	-$0.17	-$0.17
Reduce diesel plant capacity	58	$5,525	24	$9,157	$0.27	-$0.16	$0.10
Wind turbine (class 2)	54	$0	22	$8,500	$0.39	-$0.03	-$0.03
Replace street light sensors	9	$846	4	$1,468	$0.42	-$0.01	$0.25
Solar PV	33	$0	14	$5,579	$0.78	$0.35	$0.35

Table 5: Summary table showing annualized energy costs relative to baseline diesel generation supply and tariff schedule for the Orinoco and Marshall Point electric grid. The second to last column in the table is the annualized energy cost relative to the marginal generation cost of diesel (0.43 $/kWh). Negative values signify savings. The last column is the annualized energy cost relative to baseline marginal generation cost *and* the marginal loss of revenue collection (0.26 $/kWh).

A conservation measure may or may not be attractive to a utility. This will depend on the value of the energy generation costs relative to the tariffs they charge, and any regulatory incentives that they may face. Where the utility is making a profit on each unit of energy (i.e., the tariff is priced above the marginal generation cost), the implementation of a conservation measure will result in revenue loss, unless appropriate regulatory incentives are provided to the utility (e.g., the lost revenue could be accounted for with a tariff increase). However, if the utility is actually losing money on each unit of electricity sold (which is often the case in subsidized rural electrification schemes), then energy conservation measures would result in cost savings to both consumers and the utility. The lost revenue can be approximated as the *marginal tariff rate x energy saved.*

Taking into account the tariff can shift the relative attractiveness of an investment in supply or conservation. Investment in renewable energy supply in a diesel grid results in savings from reduction in diesel fuel consumption, without any revenue loss from decreased demand. Investment in conservation, from the financial perspective of the utility, is only attractive when marginal generation costs exceed the tariff rate (i.e., the utility is producing at a loss).

In the case of the Orinoco and Marshall Point microgrid, the system is heavily subsidized. The system is a two-part tariff system in which the client pays a fixed rate for any consumption below 15 kWh, and a marginal rate of 0.26 $/kWh for consumption above 15 kWh. Therefore, with a marginal generation cost of 0.43 $/kWh, based on a diesel price of 1.06 $/liter, energy conservation is attractive to both utility and client.

The final column in Table 8 takes into account the loss in tariff revenue from the conservation measures. The price, as seen by the utility, for supply measures between the second to last and final column stay the same, while the conservation measures become more expensive due to the loss in revenue. It can be seen that reducing diesel plant capacity and replacing the street light sensors shift to become net costs with the utility's tariff schedule.

Community level carbon abatement cost curve

As discussed earlier, carbon abatement cost curves, typically calculated at the level of national or global economies, are used to evaluate the attractiveness of carbon mitigation measures, based on the metrics of cost and total quantity of GHGs that can be reduced. The community level energy supply curve can easily be transformed into a carbon abatement cost curve. The liters of diesel fuel that were conserved from the measures shown in Table 4 can be used to estimate the mass of abated CO_2, using the U.S. Environmental Protection Agency's carbon intensity value for diesel of 2.688 kg CO_2/liter. The unit abatement cost (UAC) of a carbon mitigation option can be calculated as:

$$UAC = \frac{\text{Annualized cost of the investment}}{\text{tCO}_2\text{/yr abated}} .$$

Unlike the energy supply curve, carbon abatement cost curves are typically displayed relative to a baseline, or business as usual (BAU) scenario, losing an aspect of generality since it now has the energy price embedded in the calculation. The abatement cost relative to a baseline scenario for a mitigation option is calculated as:

$$MAC = \frac{\text{Annualized cost of the investment}}{tCO_2 \text{ abated}} - \text{BAU}\,\$/tCO_2$$

Table 9 shows the carbon abatement costs that result from the reduction of diesel combustion in the Orinoco and Marshall Point microgrid. This is a first order approximation, and does not take into account the imbedded emissions associated with the lifetimes of the technologies. The second to last column shows the unit abatement costs relative to the baseline diesel generation scenario, and the final column takes into account the tariff loss from the conservation measures[17].

	Annualized cost ($/yr)	Liters/day of diesel saved	tCO2/yr abated	Unit Abatement Cost ($/tCO2)	UAC relative to BAU ($/tCO2)	UAC relative to BAU with tariff loss ($/tCO2)
Meter installation	$648	33	32	$20	-$377	-$135
CFL installation	$577	14	14	$41	-$356	-$114
Smaller street lights	$622	13	13	$48	-$349	-$107
Biogas	$4,012	22	22	$183	-$214	-$214
Reduce diesel plant capacity	$5,760	24	23	$250	-$147	$95
Wind turbine (class 2)	$7,767	22	21	$363	-$34	-$34
Replace street light sensors	$1,352	4	4	$366	-$32	$211
Solar PV	$9,501	14	14	$677	$279	$279

Table 6: Summary table of estimations of carbon mitigation impacts from demand and supply side measures in the Orinoco and Marshall Point electric grid (UAC = unit abatement cost, BAU = business as usual). Details of the calculations can be found in the Appendices.

Using the total annual abatement of tons CO_2, from the third column in Table 9, and the unit abatement costs relative to the business as usual case, the second to last column, a community level carbon abatement cost curve can be easily constructed, and is shown in Figure 4. The curve highlights the large financial savings that can be accrued while also mitigating CO_2, through the integration of both energy conservation and renewable energy generation measures, relative to diesel generation.

[17] $MAC = UAC - \frac{\text{marginal generation cost (\$/kWh)}}{\text{tonsCO2/kWh}} = UAC - 397\$/kWh$,

Tariff adjusted MAC for conservation measures: $= UAC - \frac{\text{marginal generation cost (\$/kWh)}}{\text{tonsCO2/kWh}} + \frac{\text{marginal tariff loss (\$/kWh)}}{\text{tonsCO2/kWh}}$

$= UAC - 397\$/kWh + 242\$/kWh$. Where $\$/kWh\ \text{electric} = \frac{\$}{liter}\frac{liter}{kwh}\frac{1}{\eta}$, and $tCO_2/kWh\ \text{electric} = \frac{tCO2}{liter}\frac{liter}{kwh}\frac{1}{\eta}$. Based upon a diesel cost of 1.06 $/liter, the U.S. Environmental Protection Agency carbon intensity value for diesel of 2.688 kg CO_2/liter, lower heating fuel value of 9.84 liter/kWh, diesel engine efficiency of 0.2525, and a marginal tariff price of 0.26 $/kWh electric.

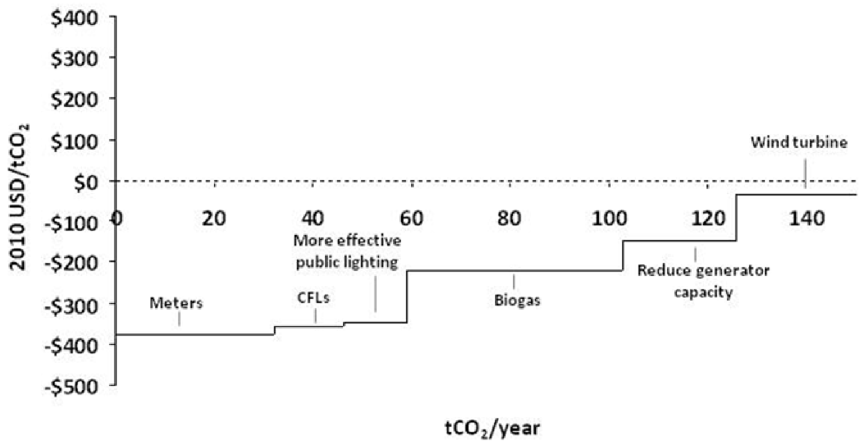

Figure 4: Carbon abatement cost curve: Abatement cost is with respect to a baseline diesel carbon price of 397 \$/tCO2. Abatement potential is due to the reduction of diesel use, relative to each previous measure. Multiplying abatement potential and abatement cost gives total annual costs (negative cost = savings) relative to the diesel baseline, assuming the previous measure was implemented. Details of the calculations can be found in Appendix 2.

It is worth noting that while the total magnitude of the emission mitigations is not significant relative to global emissions (over 100 liters of diesel per day are conserved), such opportunities represent low hanging fruit for mitigation investments, with the potential for improving aspects of local welfare for vulnerable communities. However, if the goal is increasing access to energy services, than the conserved diesel may be reinvested in additional hours of access, which may not represent a net reduction in CO_2, but rather a reduction in the carbon intensity of CO_2 per day of energy access.

Similar to the energy supply curve, the carbon abatement cost curve does not provide information regarding how the costs and savings will be distributed among the stakeholders. In a recent paper, Casillas and Kammen (2012b) provide a more detailed discussion regarding how financial costs and savings may be distributed between the utility and consumers, depending on how tariffs and subsidies are structured. However, the analysis embedded within both carbon abatement cost curves and energy supply curves are primarily financial in nature, using metrics that reveal little information about the potential welfare impacts that may result from different measures. The following sections introduce welfare metrics that begin to provide insights into how these planned implementations may affect various stakeholders within the communities. This is a first attempt to demonstrate how the egregious elimination of people from top-down planning can be improved.

However, these proposed metrics come with the acknowledged critique that they are imperfect at best, and do nothing to address the approach that this analysis epitomizes: namely experts making calculations and proposing technical solutions, without incorporating any information regarding the social, political, or cultural realities that they are targeting. The final two chapters of the dissertation will incorporate bottom-up perspectives.

Incorporating poverty and equity metrics

Using household socio-economic data from Marshall Point and Orinoco, several poverty metrics were calculated in order to quantify impacts from the carbon mitigation activities on income and equity. Poverty headcount ratio, income and energy Gini coefficients, and Kuznets ratios were computed for each of the interventions in the carbon abatement cost curve. The estimated impact of each intervention was determined using income data from household surveys as well as residential electricity bills. The poverty metrics were calculated for a random sample of 69 households from the village of Orinoco (which had 121 households connected to the grid). Because the suite of mitigation efforts included those that were actually implemented (meter and CFL installation) as well as estimations for additional interventions, the approach demonstrates the feasibility of estimating potential impacts of mitigation measures at the planning stages.

The metrics used in the study were chosen due to the availability of data. Both the United Nation's Human Development Report 2010 and the International Fund for Agricultural Development (IFAD) provide summaries of a number of more comprehensive metrics for assessing the many aspects of poverty (IFAD, 2010; UNDP, 2010a). Some of these metrics include aggregated indices such as the human development index, the gender equality index, and the multidimensional poverty index. While these measures incorporate more diverse aspects of poverty, they require more comprehensive data sets. Various poverty measures are listed in the table below.

Metric name	What it measures
*Poverty Headcount Ratio	Ratio of population below a poverty line
*Gini Coefficient	Level of income/consumption inequality
*Energy Gini	Level of energy consumption inequality in kWh
*Kuznet Ratio	Level of inequality between the wealthiest and poorest
Human Development Index	Index based on measures of life expectancy, income, and education (level and years of schooling)
Gender Inequality Index	Index comprised of reproductive health (childhood mortality rate and adolescent fertility rate), empowerment (gender equality in education and parliamentary seats), and labor (gender participation in the labor force).
Multidimensional Poverty Index	Index comprised of measures of health (childhood mortality and nutrition),education, depth and intensity of income poverty, and standard of living (cooking fuel, toilet, water, electricity, floor, assets)

Table 7: Various metrics for measuring aspects of human welfare. Mitigation measures could be evaluated based on its estimated impact on the various poverty or inequality measures. The metrics with the asterisks (*) were calculated in this study.

In order to determine the impacts of the mitigation measures on absolute poverty, changes to income were estimated following each intervention. The poverty headcount ratio is an absolute poverty measure that reveals the portion of a population below a certain income, or consumption cutoff, defined as: $p = \frac{q}{n}$, where *n* is the total population size and *q* is the number of people below the given cutoff. The headcount ratio is a simple measure, but allows one to see if a particular intervention significantly impacts income or consumption potential of the poor. Accounting for purchasing power parity among countries, the World Bank currently uses a value of 1.25 $/day to define the cutoff for poverty (Ravallion, Chen, & Sangraula, 2009). It is important to note that using this value for the villages is not very meaningful in assessing the consumption aspect of poverty, due to the higher cost of basic foods for these remote villages, as well as the subsistence livelihoods of many of the families. However, the value does provide insight into the potential that these families have for paying for goods and services, in comparison to other regions of the country.

Gini coefficients and Kuznets ratios were used in order to measure the impacts of the mitigation measures on inequality. The Gini coefficient is a commonly used measure of income inequality within a population (Ray, 1998). A Gini coefficient of zero denotes a community with perfect income equality, while a Gini coefficient of one means that all of the income is held by a single individual. Separate Gini coefficients were calculated from the income data as well as electricity consumption data from household bills. The income Gini coefficient indicates whether or not the mitigation intervention impacts distribution of wealth, while the energy Gini indicates distribution of electricity access (Jacobson, Milman, & Kammen, 2005).

The final metrics calculated were Kuznets ratios, which give the ratio of the share of income held by the poorest 20 percent to the income share held by richest 20 percent, as a measure of inequality between the tails of the income spectrum. The following table shows the resultant change to the poverty metrics following the actual or estimated implementation of each carbon mitigation measure.

	Mitigation measure	Poverty headcount	20/20 Kuznets ratio	Income share of bottom	Income share of top 20%	Gini	Energy Gini
	BASELINE	0.53	18.39	3.07	56.46	0.51	0.45
1	Meter installation	0.52	17.74	3.18	56.37	0.51	0.43
2	CFL installation	0.50	18.09	3.13	56.53	0.51	0.48
3	More effective street lights	0.50	17.22	3.27	56.28	0.51	0.45
4	Biogas	0.48	11.23	4.84	54.33	0.47	0.45
5	Reduce diesel plant capacity	0.48	11.23	4.84	54.33	0.47	0.45
6	Wind turbine (class 2)	0.48	11.23	4.84	54.33	0.47	0.45

Table 8: The change to various measures of poverty and inequality following the implementation of carbon mitigation measures. The metrics are calculated based upon earnings and electricity consumption data from 69 of the 121 households that have electricity service in the village of Orinoco. Details of the calculations are provided in Appendix 2.

The poverty headcount ratio is most impacted by the meter and CFL installation and biogas generation. Prior to meter installation, many households left appliances and lighting on, even when they weren't utilizing them. Due to the fixed tariff, they knew that they would be charged the same whether or not they turned off appliances. With the implementation of metering, they began only using their appliances at times when they valued the energy service, resulting in bills below the fixed tariff for many households. The improved efficiency of the CFL lights resulted in additional monetary savings for most households, without a decrease in illumination. The poverty headcount ratio would decrease even further except that there was a regressive, two-part tariff system in the community. The poorest clients who consume less than

15 kWh/month pay a fixed rate. Even though their consumption fell, they received no monetary savings.

In this case study, the demand changes were observed. However, at the planning stages estimating impacts that are based on demand elasticities can be unreliable. This strengthens the need for increased project implementation capacity and documentation to have sufficient empirical evidence to support assumptions. This effort could be facilitated by the multinational development community adopting reporting requirements for energy access data across socioeconomic groups, which are often done for income to build Gini curves (Jacobson et al., 2005)

In order to demonstrate the potential poverty and equity benefits that may be derived from creating a local diesel substitute, consider the example of the production of biogas from the anaerobic digestion of animal waste. Using a top-down planning approach, it was assumed that the operation of the plant would be carried out by four workers earning a yearly salary of 1000 $/year. In addition, the animal residues used for the digestion would be purchased from a cooperative of 16 farmers. The electric utility would purchase the biogas at its avoided fuel costs of 1.06 $/liter. Fifty percent of this payment would be passed on to the cooperative for the purchase of the animal waste, resulting in an annual earning of $542 per farmer. The 20 beneficiaries would be chosen from among the poorest households in the community. The reduction in poverty and inequality that could result from the estimated implementation of the biogas system is seen as poverty headcount ratio would fall from 0.50 to 0.48, and the income Gini would change from 0.51 to 0.47, shown in Table 4. However, it should be noted that increase in equity is due to the manner in which the project is planned. One could also imagine a biogas project that is privately owned by a wealthy community member, and could result in a decrease in income equality within the community.

In contrast to the local benefits from biogas generation, the installation of the wind turbine does not have any impacts on the chosen poverty metrics for the community. Whereas the majority of the lifetime costs for generation from an internal combustion engine are contained in the fuel costs, which can be captured by communities through local fuel production, the bulk of the lifetime costs for wind or solar generation are wrapped up in the capital cost of imported technologies.

It is worth noting that the energy Gini coefficient increases (i.e., consumption becomes more unequal) with the installation of the CFLs. This is most likely due to the fact that with the drop in demand resulting from increased lighting efficiency, household consumption becomes dominated by refrigeration in wealthier households, increasing consumption inequality. Thus, one must take care in interpreting changes in equality metrics in the case of energy efficiency. Energy services consumed (e.g., lighting or cooling) are the appropriate measure of consumption, since energy service consumption can increase while kWh consumption falls.

The figure below shows a plot of the change in the poverty headcount ratios and income Gini, matched to the carbon abatement cost curve. The plots show one possibility for complimenting the graphical simplicity of the carbon abatement cost curve with resulting poverty and equity impacts for a particular community, beginning to make visible the project impacts on local realities.

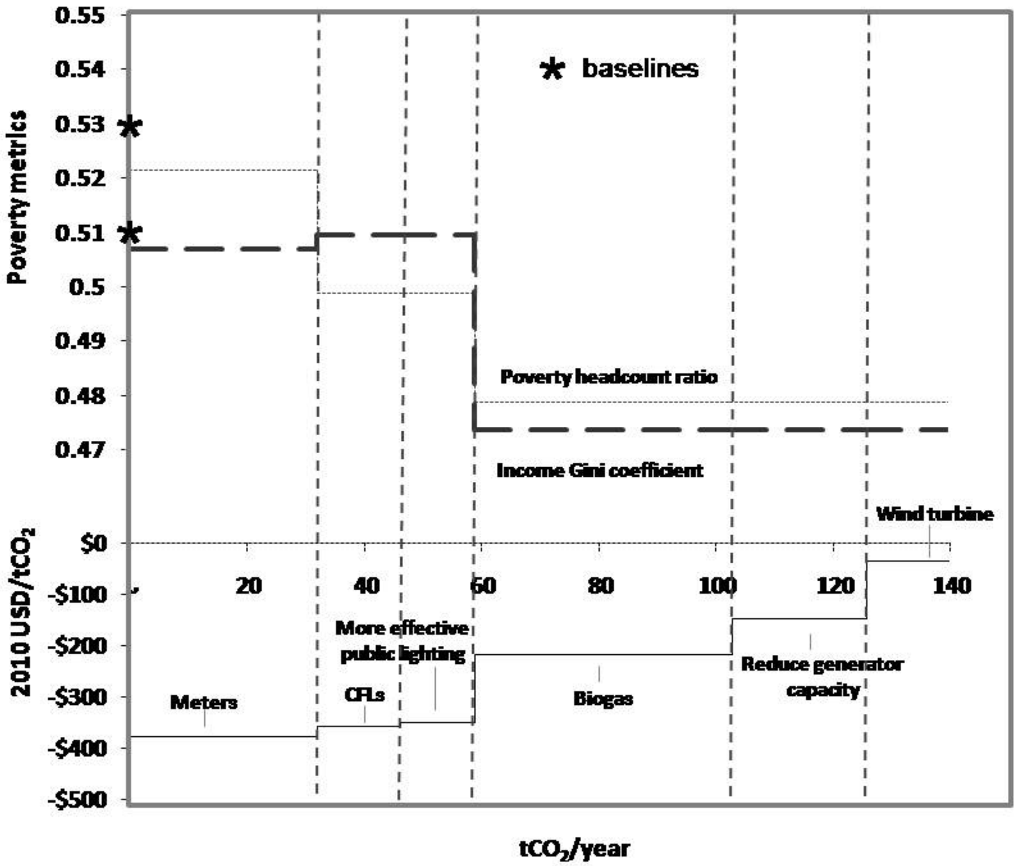

Figure 5: Carbon abatement cost curve with poverty metrics: Carbon abatement cost curve for diesel microgrid in rural Nicaraguan community (bottom), and the resultant change to the Gini coefficient and poverty headcount ratio for one of the rural villages (top). The Gini coefficient and poverty headcount ratio are derived from earnings and electricity consumption data from 57% of the houses having electricity service in one of the rural villages, summarized in Table 4.

Policy implications and areas for further study

Although the carbon abatement cost curve was limited to the electricity sector in a rural village, the methodology can be generalized across scales to the national level, and across most mitigation instruments and policies. The poverty and inequality measures will need to be augmented to capture the full impact of many mitigation measures. For example, changes to public transportation may not only reduce monetary expenditures, but could reduce opportunity costs through decreased commute times and drastically reduce air pollution, and improve health. Interventions such as improved cooking stoves will predominantly impact the health of women and children, who spend the most time in smoke-filled kitchens (Smith & Haigler, 2008). More comprehensive indices such as the Human Development Index, Multidimensional Poverty Index, and Gender Inequality Index are likely to be appropriate for quantifying many more impacts on vulnerable populations.

Implementing this methodology at the national level will necessarily be more complicated. Consider the many mitigation options in the carbon abatement cost curve for Mexico, presented earlier in this chapter. It will be challenging, but by no means impossible, to estimate the impacts of forest management projects or residential lighting, at the national scale. Empirical evidence from community level interventions will be crucial for estimating poverty and equity impacts of projects that may be implemented nationwide. For example, while there will certainly be heterogeneity in outcomes of similar projects among different communities, the results from several village case studies, similar to the one in this paper, would give a reasonable estimation of expected economic and distributional impacts of lighting efficiency campaigns carried out in all of the diesel microgrids on the Atlantic Coast of Nicaragua.

It remains to be seen how various nations will prioritize issues of equity. While the IPCC's fourth assessment report identifies distributional and equity effects as one of four criteria for assessing mitigation measures, it is hardly as common as environmental effectiveness, cost effectiveness, or institutional feasibility. The criteria used to prioritize mitigation choices will need to be compatible with national development strategies, unique to each country, especially when there are limited funds and economic growth is a priority. The benefits of mitigation criteria will vary between countries. In industrialized countries, inequality may be impacted more by policies affecting urban populations, whereas the impacts of agriculture and forestry will be more important in countries that still have significant rural populations.

Multi-criteria approaches set up an appropriate framework for carefully weighing the costs and benefits of mitigation options (Konidari & Mavrakis, 2007), but unless a pro-poor approach is taken, metrics that highlight livelihood aspects of the most vulnerable stakeholders may be absent. Complementing popular planning tools, such as carbon abatement cost curves, with poverty and equity metrics will increase the transparency of discussions and decisions to community stakeholders.

Conclusions

The research in the chapter highlights two primary themes within this dissertation. The first being that practice, the process of planning and project implementation, uncovers information and insights that can lead to better policy. The energy efficiency project and subsequent analysis that emerged from the cancelled CDCC Clean Energy and Water Project demonstrates that there are many available opportunities for rapidly and cost effectively transitioning to the delivery of low-carbon energy services in rural communities. The second point is that policy makers and planners simplify information down to select metrics that will inevitably obscure important aspects of local realities. By increasing project analysis beyond aggregated financial criteria, to include welfare metrics, can increase the visibility of the welfare implications that may result from top-down projects.

Energy supply curves and carbon abatement cost curves can provide simple graphical tools for planners to compare the relative financial benefits between conservation and supply measures for delivering energy services to rural users. Cheap capital costs and the prevalence of well developed supply chains make diesel generators a common choice for providing power to isolated communities. However, the long term volatility of diesel prices and the negative environmental externalities resulting from the production of carbon dioxide provide two important reasons for reducing diesel dependency in these electric systems. In order to make the persuasive case to policy makers, government officials, and funders, it is critical to present the costs and benefits of the decisions in consistent and rigorous manners. Several important metrics include capital cost, ongoing fuel costs, risk of future fuel price volatility, the internal rate of return, carbon mitigation benefits, and savings relative to the current baseline.

Prioritizing the use of efficient public and residential lighting, as well as installing meters in order to provide users with more accurate consumption information, can result in large monetary savings as well as carbon abatement, with low capital investment costs. When the revenue lost from tariff collection is accounted for, some supply measures look more favorable relative to conservation measures. It is clear that there is abundant, low-hanging fruit in the form of both conservation and renewable energy generation that government and private utilities could rapidly implement in order to increase energy access and decrease costs.

One shortcoming is that the curves obscure the capital costs and lifetime of the different measures. More importantly, these curves also are typically displayed in a manner that neglects to highlight the revenue loss between conservation and supply measures, and are not displayed with any metrics showing how costs and savings are distributed among stakeholders.

The embedded inequalities of many carbon mitigation interventions are rarely addressed in a systematic manner. In particular, carbon abatement cost curves create a policy framework in which cost and carbon reduction potential are the primary metrics, ignoring an analysis of who will be the primary beneficiaries from the interventions. Carbon mitigation strategies can have vastly different local impacts on various aspects of poverty, such as income, jobs, or energy and resource access. Even though some mitigation measures have the cheapest $/$tCO_2$-eq, they may have little co-benefits for the poorest stakeholders, many of whom will be most vulnerable to climate shocks. Measures with local co-benefits should be prioritized. Simple metrics such as poverty headcount ratio, Gini coefficient, or Kuznets ratios can help illuminate social impacts of carbon abatement interventions, highlighting how the poorest will be impacted by specific mitigation decisions.

The case study finds that energy efficiency interventions that result in a decrease in energy consumption, without a loss of utility, can provide savings to the poorest consumers, increasing their spending potential and decreasing income poverty. In addition, renewable energy supply measures such as biomass-based generation, which involve local labor and resources, can have greater local benefits than wind and solar, whose lifetime costs are tied up in the capital costs, captured by industry.

There are an increasing number of studies emerging on the local impact of carbon mitigation policies, primarily in the arena of forestry and agriculture, as well as case studies from CDM projects. However, there is a lack of methodologies that tie the national level planning tools (such as carbon abatement cost curves) to stakeholder impacts at the sub-national level. The approach presented in this chapter provides an example of a method that can be used to integrate empirical evidence found at the project level, back into the planning process.

Poverty metrics such as poverty headcount ratio, Gini coefficient, or Kuznets ratios are fairly easy to calculate with available data, but they provide limited insight into the diverse impacts that mitigation measures may have on the local vulnerabilities and deprivations. There needs to be a consolidated effort in the research and policy arena to begin to analyze how mitigation measures affect various poverty indices, such as the Human Development Index, Multidimensional Poverty Index, and Gender Inequality Index. As this research demonstrates, poverty impacts can complement simple graphical tools, such as carbon abatement cost curves, that are becoming common to policy planners. However, policies designed in a top-down manner by policy ‘experts’, will inevitably only be able to include limited information about the local realities where projects will be implemented. Even by attempting to increase the visibility of local realities through the inclusion of more diverse metrics, important social, political, and cultural information will inevitably be left out, increasing the probability of unexpected consequences and project failure.

Chapter 2 The political economy of Nicaragua's Atlantic Coast

Introduction

In Chapter One I described how simple policy tools, such as carbon abatement cost curves and energy supply curves, can be complemented with welfare metrics, adding greater visibility to the way in which development projects might impact local livelihoods. However, forecasting how project outcomes may impact select metrics gives little insight into the suitability, longevity, or implementation challenges of a given endeavor. Even if a project is desirable by planners and potential beneficiaries, the actual implementation of the project may unfold in a manner that is very different than it was envisioned. Both governments and development institutions operate within political and social contexts that can drive the way in which planned projects unfold.

During the early and middle part of the last century, economic projects were implemented by foreign firms, maximizing profits through the exploitation of natural resources and local labor. In the 1980s, the Sandinista government implemented projects that attempted to integrate coastal communities and resources into the national economy. Since the 1990s, there has been an increased emphasis on the integration of local communities into regional and national markets. Economic development endeavors implemented in these different eras had different challenges and opportunities, defined by the economic and political paradigms in operation.

The transition from rural electrification to economy was the natural evolution that followed from the participatory workshops of the CDCC Clean Energy and Water Project. The participatory workshops that were carried out during the initial stages of the project highlighted the long history of failed, top-down projects, as well as the interest of community members in economic development projects. One of the primary goals of the CDCC project had been to improve electricity access, but, based on community input, it became clear that tying the electricity projects to income generation was fundamental. The last iteration of the project budget included plans for electricity to power an ice machine, a computer lab, and increased hours of operation for a carpentry shop. However, it remained unclear whether or not an ice machine, or more electricity, equipment, and training for a carpentry shop, were fundamental for overcoming the primary barriers to income generation within these economic sectors. A carbon abatement cost curve, energy supply curve, and poverty metrics can highlight how certain projects can provide financial savings for rural community members, but they do not provide insight into how they fit into the greater socio-economic context that have created conditions of material poverty or the inability for greater success in a given sector.

This chapter provides an overview of dominant political and economic forces that have impacted the livelihoods of communities along Nicaragua's Atlantic Coast. The purpose of this chapter is to provide details of the local and historical context surrounding current development projects on the coast, providing a background for further exploration of the role that local information plays in economic development projects, which will be explored in the final chapters.

Current economies

The Atlantic Coast region is divided into two political areas, the North Atlantic Autonomous Region (RAAN) and the South Atlantic Autonomous Region (RAAS), which have a combined population of over 700 000 people, seventy percent of whom live in rural areas (INEC, 2006a, p. 30). The territory of the RAAN and RAAS comprise close to half of the total surface area of Nicaragua, yet contain less than 15% of the total population (INEC, 2006a, p. 27).The majority of the populations live close to the coast, with the inland forests more sparsely populated. The populations can be divided among a number of different ethnicities. The Spanish speaking Mestizo communities, originally from the Pacific coast, have grown to an estimated 50% of the coastal population (Jamieson, 1999, p. 7). The largest indigenous population is that of the Miskito, comprising over 100 000 of the total coastal population, primarily in the RAAN (INEC, 2006b, p. 188). The small number of Rama, less than 1 500, lives primarily within a few communities in the RAAS. African descended Creole populations number over 20 000 on the coast, primarily living in the more urban areas in the RAAS. A small population, less than 1 500, of Garifuna live in the RAAS, and are of Amerindian and African descent. About half of the Atlantic populations have languages and cultural identities that are distinct from the Spanish speaking majority of the country, who make up about 97% of the total population of Nicaragua (INEC, 2006a, p. 40). However, these ethnic classifications only give a general sense of the diversity of communities in the Atlantic Coast region. Ethnic identities are often political products, and none of these rural communities live completely isolated from one another.

In the RAAN, along the more densely populated Rio Coco, which comprises the northern border between Honduras and Nicaragua, there are mostly Miskitu communities, which are dependent on harvests of rice and beans. They also grow plantains and fish and hunt. Commerce between different villages occurs along the Rio Coco (Jamieson, 1999, p. 13). Further south of the Rio Coco are a number of Miskitu communities living in savannahs and pine forests. The land is not ideal for agriculture. Many of the farmers depend on cassava, and aren't able to grow many marketable products, and therefore remain peripheral to any market economies (Jamieson, 1999, p. 15).

There are many Miskitu fisherman along the northern coast, and Miskitu, Rama, Creole, and Garifuna fishers live in the southern RAAS. The majority of people fish in the lagoons and coastal waters with nets and sell their catches to some of the larger communities, such as Bluefields. There are also a number of the indigenous communities that live along the rivers in the RAAS and RAAN regions and practice different types of horticulture and fishing but have poor access to markets and urban centers. Although many of the rural populations have their own means of production, they have varying access to goods and services.

There are a number of barriers that limit villagers from being the primary beneficiaries of their natural resources. These include a lack of access to credit and technical assistance, high transportation costs, and poor infrastructure. Most communities don't currently have the economic, technical, legal, or managerial skills needed to develop small scale industrial processing that could add value to their products or store surpluses. In the case of some products that may not require sophisticated processing, the communities lack the social networks and financial assistance needed to sell their products to buyers who may be higher up in the distribution chain. For many of the products, especially in the markets for seafood, there are a small number of buyers on the coast and rural fishers are often unable to effectively negotiate better prices for their goods.

Throughout most of the 20th century, coastal community members have worked sporadically as contract laborers to large foreign firms. From the seventies until the present time, community members have mainly sold their primary products to smaller private firms. The following sections will outline the dynamics of these historical economic positions.

Early extractive economies

Since the Spanish first began colonizing Nicaragua in the early 1500s, the populations of the eastern coast have remained largely isolated, primarily due to the poorer agricultural lands, more oppressive tropical climate, and vast tropical forests and river networks separating the central highlands from the Atlantic Coast. It is believed that before British traders first began interacting with the indigenous communities on the Atlantic Coast in the 1600s, the different populations along the rivers and ocean were separated by different kin relations and language dialects (Noveck, 1988, p. 19). After the arrival of British traders, the coastal groups gained access to foreign commodities, including muskets, from which the name "Miskitu" may be derived (Noveck, 1988, p. 20). The Miskitus eventually came to dominate the coastal region, as well as the other inland groups.

The Miskitu populations were supported as the ruling population through a system of indirect rule by the British in the mid 1800s, establishing a kingdom of Mosquitia. The departure of the British at the end of the 18th century left a vacuum of power that was quickly exploited by U.S. capitalists. The status of the Miskitu declined and the populations of the indigenous communities have since to often fallen into the roles of cheap wage labor or small producers at the bottom of the economic hierarchy (Noveck, 1988, p. 26). The Creole populations excelled as merchants and traders, and Mestizos immigrating from the western half of Nicaragua filled the highest levels of the power hierarchy. Over the course of the next hundred years, there were periods of economic booms and busts, with companies focused on short term accumulation of profits through the exploitation of natural resources and the cheap labor pool among the indigenous communities.

The economies of the Atlantic Coast, from the end of the 1800s until the period of the Sandinista revolution in 1979, have been defined by the largely unregulated extraction of primary goods by private firms[18]. Apart from the first period of governance by the Sandinista

[18] The dynamics of the economies on the Atlantic Coast is well represented by dependency theorists. For example see (Amin, 1976; Cardoso & Faletto, 1979; Chilcote, 1974). The industrial revolution catalyzed the growth of economic systems based on the enormous productivity of factory manufacturing. The advanced technology led to substantial comparative advantages for the production of manufactured goods in globalizing and urbanizing economic systems. The expanding economies of northern countries not only required substantial amounts of primary materials for inputs into their industrial processes, such as wood and minerals, but also manufactured and primary goods to meet growing patterns of consumption, as well as new markets for cheap manufactured goods. The advanced industrialization of northern nations created unequal dynamics between their economies and those of the less industrialized southern nations. The economic liberalism of the 1820-1930 period led to Latin America being integrated into a global capitalist system in which Latin American countries functioned primarily as agricultural exporters, and consumers of cheap manufactured imports (de Janvry, 1975)

party in the 1980s[19], government control and regulation on the Atlantic Coast has been minimal, leaving coastal labor and natural resources open for exploitation. The environment of the northern coast is dominated by pine savannah and mineral deposits, while the south is primarily tropical evergreens (Vilas, 1989, p. 2). The abundant rainfall and clay soils make the Atlantic Coast's environment suitable for agroforestry crops such as lumber, cacao, coconut, banana, and African palm. The table below highlights four different economic periods between 1880 and the present.

Time Period	Market	State	Society	Environment
1880-1930	Enclave economy – U.S. firms extract timber, bananas, minerals	Little regulation or presence – slight taxation	Contract laborers and subsistence farmers/fishers	Unregulated extraction of natural resources
1930-1979	Continued extractive economies with U.S. and Somoza owned firms – timber, fish, minerals	Successive Somozas protect financial interests of private firms	Unrest – resistance in RAAN to Somoza regime	Continued extraction and degradation of natural resources
1979-1990	Retreat of foreign capital, attempt at planned economy. Formation of cooperatives – minerals, fishing, coconut	Greater regulation, nationalization of foreign and Somoza owned firms. Legislation of Coastal Autonomous regions (1987)	Greater dominance of Spanish speaking government. Counter revolution, primarily in RAAN among Miskitu	Depleted resources, destruction of natural resources by hurricane Joan
1990-present	Neoliberalism. Reduced role of state. Privatization of state firms. Diversified livelihoods	Retreat of state and its provision of services	Increased dominance of Mestizo presence, pressure for enforcement of indigenous rights	Decline of fisheries, eastward expansion of agricultural frontier

Table 9: Key periods of economic development on the Atlantic Coast

Resource exhaustion, crop plagues, natural disasters, and political instability led to boom and bust cycles of the extractive economies that typified the coast until the Sandinista revolution in 1979 (Sollis, 1989; Vilas, 1989). Resource exploitation was not limited to land resources. Coastal lobster, fish, and shrimp were also capitalized upon by both U.S. and Somoza owned companies (Sollis, 1989, p. 492; Vilas, 1989, p. 76).

The economies on the coast were focused on exporting primary products to external markets. In the northern regions, where most of the lumbering took place, the majority of the laborers were Miskitu, typically signing one year labor contracts and living at or near the production facilities (Nietschmann, 1979, p. 6). This resulted in increased labor demands on their families as the subsistence level production at home was maintained by their wives and children. The jobs provided the rural families access to cash in order to buy manufactured goods, often imported and sold in company commissaries. Due to the Miskitu family's ability to maintain themselves through subsistence level production, firms could attract contract labor for wages below those needed to meet labor's livelihood needs, and the desire to minimize

[19] The Sandinista party under the leadership of Daniel Ortega was democratically elected in 2006. However, the party's ideals are now much more aligned with neoliberal policies rather than Marxist ones.

wages was further rationalized by the disarticulation between the labor force and the purchase of the firms' products. The fundamental power imbalances of large firms with access to external markets, coupled with little accountability to local labor or the environment, marginalized indigenous labor forces and destroyed much of their natural resources. However, several accounts state that some of the communities viewed these times positively, since it provided them access to a monetary economy and imported manufactured goods (Nietschmann, 1979, p. 6; Sollis, 1989, p. 495).

Following the Sandinista revolution, the new government made a determined effort to integrate the Atlantic Coast labor and resources into the national economy, nationalizing many foreign and Somoza owned firms (Vilas, 1989, p. 101). However, the coastal populations had become accustomed to the intermittent presence of foreign firms and accessibility of imported goods, regardless of the exploitive terms. Many populations resented the government's imposition and the departure of private firms (Sollis, 1989, pp. 501–503; Vilas, 1989, pp. 97–140).

Mixed economies of the Sandinista period 1979 - 1990

Historically the Atlantic Coast populations, for better or worse, were neglected by successive national governments until the Sandinista government in the 1980s attempted to integrate the coast into the national economy of Nicaragua. The Sandinista government came to power in 1979, following a popularly supported military campaign which overthrew the Somoza dictatorship. One of the goals of the government was to create a more egalitarian and unified economy, reconciling many of the economic and social inequalities manifested during 43 years of Somoza family rule. The government focused on forming a mixed economy of state, private, and cooperative holdings, while conducting a massive health and education campaign throughout the country (Harris, 1993; Wall, 1993). The government viewed the Atlantic Coast as a critical component for economic growth, underestimating the extensive resource degradation wrought by over a century of unregulated resource extraction, as well as the resistance of indigenous communities to being incorporated into a national framework dominated by Spanish-speaking leaders from the Pacific coast (Sollis, 1989, pp. 501–503; Vilas, 1989, pp. 97–140). By focusing on the industrialization of agricultural exports, the government hoped to increase economic productivity and modernization of the coastal economy (Vernooy, 1992). Through the nationalization of land confiscated from Somoza holdings the government focused on the development of products for export, such as African palm, coconut, mining, fishing, and ranching (Sollis, 1989, p. 500). The government organized and managed many projects, based on the import of technology and division of labor, including the organization of labor into cooperatives (Wall, 1993).

A number of Sandinista policies catalyzed immediate negative consequences for some of the coastal populations. U.S. inflow of aid and capital halted, and many capitalists fled, fearing loss of ownership and future economic downturns (Jamieson, 1999, p. 5). The flight of capital on the Atlantic Coast led to unemployment, inflation, and a loss of access to cheap imports. Many members of indigenous populations felt that this exemplified the central government's poor understanding of their conditions, which were unique from those in the western part of the country (Jamieson, 1999, p. 5). At the same time, the U.S. government began illicitly training and supporting counter-revolutionaries (the Contras) who opposed the Sandinista government. The perceived lack of understanding was magnified by forced resettlements by the Sandinista government, in an attempt to isolate many of the indigenous populations from the fighting between the government and the Contras (Vilas, 1989, p. 150). A large portion of the Contras on the Atlantic Coast came from the Miskitu populations, supporting the idea that they felt the state's efforts to integrate them into the national sphere revealed a lack of understanding of their identity (Bourgois, 1986).

Through an analysis of a number of large scale industrial projects in other parts of the country, Wall concludes that the Sandista regime remained too focused on technology intensive production, necessitating well paid managers and technicians, leaving the small scale producers excluded (Wall, 1993). Instead of focusing on labor intensive, low-tech processing facilities, the emphasis was on sophistication in the processing plant, leaving the primary producers of inputs without any technical advances, and often receiving low prices for their goods.

The Sandinistas also tried to organize the fishing communities into cooperatives, providing them with access to ice and equipment, and established an institute to buy the fish, leaving the processing of the fish in the hands of state or private enterprises (Jentoft, 1986a, p. 354). During the 1980s, the Sandinista government took control of private land outside of Kukra Hill, previously held by the Somoza regime, and redistributed it to 1000 individuals. The government allocated land and training to 200 of these new land-holders in order to produce African palm oil for export. A satellite of BANADES, the national development bank, was established to provide the farmers with financial and technical support, and a small processing plant was developed. The palm fruit was purchased by the manufacturing plant and then processed and sold externally.

The Sandinista policies increased support for small producers, encouraging primary production to remain in the hands of the rural communities. However, a faltering economy, combined with top-down organization and an emphasis on sophisticated technology, resulted in the sellers of the primary products being no better off than under the previous governments.

Neo-liberalism 1990 - present

In 1990 the Sandinista government was voted out of power, in no small part due to the failing economy, affected by the expensive Contra war and the U.S. embargo and lack of foreign aid (Dijkstra, 1999, pp. 297–299).The new government heralded the implementation of U.S. and World Bank mandated neoliberal policies (Enríquez, 2010; González, Jackson, & Zapata, 2002). These consisted of structural adjustments to the economy, aimed at decreasing foreign debt through the liberalization of trade, devaluation of the currency, privatization of state entities, and the reduction or elimination of costly social programs. On the Atlantic Coast, the neoliberal policies resulted in decreased access to credit and technical assistance, and the reduction of subsidized social programs, resulting in increases in poverty (Hegg, 2005). The rate of unemployment in the 1990s was estimated at levels of near 60% nationwide, with poverty concentrated in rural areas (Dijkstra, 1999, p. 306). In addition, the elimination of protective tariffs exposed rural producers to volatile prices as well as cheap food imports supported by agricultural subsidies and economies of scale present in U.S. agricultural systems (e.g., see

McMichael (2008)[20]). The drastic increase in nationwide unemployment contributed to landless farmers from the Pacific clear cutting and expanding the agricultural frontier eastward, resulting in the encroachment upon lands traditionally inhabited by indigenous groups on the Atlantic Coast (Glomsrod, Monge, & Vennemo, 1999, p. 20).

Economic activity in the RAAS since the 1990s has primarily consisted of villagers maintaining control of their means of production, selling agriculture and fishing products to privately owned secondary buyers or processers[21]. The continued shift from the sale of labor to the sale of primary resources has catalyzed greater reliance on the market and more rapid abandonment of subsistence production[22] [23]. An inability to negotiate prices or access better markets creates ongoing conditions in which rural producers accept low prices. In an attempt to maximize income, small scale producers, especially fishers, exert increasing pressures on natural resources, contributing to their gradual degradation (Christie et al., 2000).

In the southern Atlantic region (RAAS), the coastal livelihoods tend to consist of subsistence production from fishing and agriculture, with monetary income primarily generated through the sale of fish, government jobs, small enterprises, remittances, and agriculture (Casillas et al., 2010; Christie et al., 2000; González et al., 2002; Lapoutre, 2002; Schmitt & Kramer, 2010). Although the majority of the community members continue to remain involved in subsistence production, the largest portion of household budgets is typically spent on the purchase of food[24].

In 2006, 64% of Nicaraguan fishing production came from the Atlantic Coast, where 90% of the fishers are indigenous community members, primarily fishing at the artisanal level[25]. There are currently only three commercial processing companies, two located in Bluefields, and

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[20] Research by Enríquez on the Pacific coast found that overall, small scale farmers seemed to be adversely affected by the neoliberal policies implemented in the 1990s. However, due to favorable market prices in the dairy industry, some producers benefited from expanded export markets (Enríquez, 2010)

[21] Over the last century, especially in the fishing sector in the RAAS, the existence of small firms buying products from village fishers was not uncommon (e.g., see Christie et al. (2000)). Following the ‘80s, the disappearance of large foreign firms hiring laborers meant that small firms as purchasers of primary goods became more dominant.

[22] Over a period of 10 years, during the ‘70s, Nietschmann observed that with the disappearance of the large foreign firms that had hired the Miskitu as contract laborers, they increasingly turned to selling their local resources on the market in order to access money (Nietschmann, 1979). The arrival of a private turtle meat processing plant rapidly led to the over-hunting of turtles by the Miskitu of Tasbapauni. In addition, the increased focus on hunting turtles for profits led to the erosion of subsistence production and sharing. Nietschmann observed that the villagers ended up working more to earn money primarily to meet their food needs, which used to be met through subsistence production.

[23] In addition to the many direct barriers that are hindering the evolution of competitive agriculture and fishing industries, there are also strong perversions in the local markets due to remittances and other cash income resulting from interactions with drug traffickers moving cocaine from Columbia up to Mexico and the US. These large infusions of money have hindered youth, especially men, from investing in education or farming, both of which have longer term returns than fishing, finding drugs, or waiting for the next remittance check (Dennis, 2003; Lapoutre, 2002; Towns, 2006).

[24] In Orinoco, surveys showed that 51% of the households were economically active in the fishing industry, and 37% received some form of income from agriculture, although it only amounted to 2% of the gross product of the village in 2009 (Casillas et al., 2010, pp. 8–11). However, 64% of these villagers were involved in agriculture, primarily at the subsistence level. Nonetheless 60% of household budgets went for the purchase of food, demonstrating that even with subsistence production their livelihoods are heavily dependent on the market.

[25] See http://www.fao.org/fi/oldsite/FCP/es/NIC/profile.htm

another on nearby Corn Island. These businesses are medium size and purchase the bulk of their fish from the local communities, process the fish, and sell it on the Pacific coast and in foreign markets, primarily to the US[26]. There are a number of variables which impede the ability of most fishers to extract greater wealth from their labors. Some of these include a lack of local ice production, high transportation costs[27], limited access to credit to purchase equipment such as nets and boats. In addition, an inability to enforce the regulation of net size, and the increased use of nets, have contributed to a steady decline in productivity (Christie et al., 2000, pp. 60, 66). While there are several different cooperatives, they have low membership and little coordination capacity among the different villages, resulting in negligible bargaining power over their selling prices.

In the case of agriculture, the situation is more complicated. The agroforestal climate necessitates different farming practices than the more fertile commercial farms on the Pacific coast. The high cost of transport in several villages limits access to markets, while in others there are only intermittent opportunities for transport. A study in 2008 found that in the community of Pearl Lagoon, the arrival of a tar road from Managua resulted in an increase of imported goods, with little impact on the selling price for local farmers, whose prices were not competitive with external markets (Schmitt & Kramer, 2010). Most communities lack access to facilities that would be able to add value to goods for local markets or store surplus, such as a rice mills or canning facilities. With the exception of occasional projects from NGOs or the government, most communities lack access to technical training as well as credit for the purchase of higher yield seed varieties or synthetic inputs[28].

Without adequate options for insurance, there is substantial risk due to the frequency of hurricanes and flooding, deterring large capital investments. In addition, the challenge with the production of produce for the external market is that small farmers will be competing against large scale, private industries in other regions of Nicaragua, Latin America, and the U.S. For example, it is unlikely that a small farmer cooperative would be able to produce bananas at a price competitive to an industrial scale plantation that is using synthetic fertilizers and pesticides, and which may also control several levels of the value chain, such as marketing and distribution. While specialty markets such as Fair Trade and eco-labels provide guaranteed minimum prices to ensure sustainable practices and protect producers against market fluctuations (Bacon, 2005), rural producers on the Atlantic Coast have limited access to these markets. Many small farmers remain in production due to their willingness to accept a razor thin profit margin. The subsistence nature of most small farmers leaves them exposed to exploitation in the market, as they don’t need to earn enough income to cover their food needs.

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[26] In 2006 80% of revenues from seafood were from sales to the United States. (http://www.fao.org/fi/oldsite/FCP/es/NIC/profile.htm)

[27] Schmitt and Kramer showed that in the Pearl Lagoon area there was a correlation between selling price and distance to roads. With the arrival of a road connecting Pearl Lagoon to Managua, fishers were able to access better prices, although local farmers were less competitive with imported goods (Schmitt & Kramer, 2010).

[28] The Nicaraguan NGO FADCANIC provides technical assistance on sustainable agricultural techniques to farmers, as well as selling high yield varieties of seeds. The rural development institute, IDR, has recently provided technical assistance and funding for projects, but the capacity of this government organization is limited.

The monopolistic relationships that now exist between the buyers and local producers leave the producers without any ability to negotiate prices. In order to access external markets, producers typically need to guarantee minimum volumes of their product, which isn't feasible for individual fishers or farmers. The ability of rural producers to organize into coherent cooperatives can therefore be critical when attempting to sell fish or agricultural goods to external buyers (Bacon, 2005).

The case of an African palm plantation in the RAAS exemplifies the still present power imbalances resulting from the privatization of land. Following the 1990 elections and the privatization of state businesses, the Sandinista's African palm processing plant was purchased by a multinational firm called Rio Escondido Industrial. Shortly thereafter, the parent company, Cukra Development Corporation, bought the crops and land from the small holders. Today, the plantation encompasses more than 7 000 hectares and employs over 2 000 people, the majority of whom are temporary laborers (Potosme, 2010). While the plantation is the largest employer in the municipality, many of the employees are transients from the Pacific coast, and come to live in the work camps during the harvests as contract labor. There have been ongoing conflicts regarding environmental pollution from the processing plant, and local communities worry about the impact that the chemical runoffs from the fertilizers and pesticides may be having on fish in Pearl Lagoon[29]. In addition, the plant falls under certain free-trade agreements, making it exempt from a large number of taxes. It ships the raw oil to its processing plant in Costa Rica to avoid paying tax on any value-added processing. Free market policies have created the conditions that allow for the existence of plantations very similar to those of the enclave economies of the last century. While the plantation provides 60% of the income in the community of Kukra Hill (Potosme, 2010), it comes at a the expense of responsible environmental management and fair labor practices.

Autonomy and its role in negotiating prosperity

In a region where the livelihoods of community members are tied to their natural resources, maintaining access and protection of these resources is critical. There has been a growing trend of land disputes due to the eastward expansion of the agricultural frontier, along with entrepreneurial speculation on land values. There are a number of conflicting demarcations of land tenure in the Atlantic Coast region, including national land, private ownership with legal titles, and land that has been traditionally occupied by indigenous groups and is legally protected but poorly demarcated and untitled. In the past, separate agencies have given titles, with no centralized body verifying whether there are existing claims to land before administering new titles (Jamieson, 1999, p. 18). The expansion of the agricultural frontier is partially driven by Mestizo farmers who have lost access to land and employment in the more fertile central highlands (Glomsrod et al., 1999, p. 20). Due to the low fertility of the land in the RAAN and RAAS, and the slash and burn agricultural techniques of the farmers, the farmers are only able to produce on the land for 2-3 years (Glomsrod et al., 1999, pp. 20–26). If the Mestizo migrants are able to attain a title to the land, they can then resell the cleared and fallow land to

[29] In June 2011, a large number of fish in Pearl Lagoon died, causing the government to restrict the buying and selling of fish for a week. The government performed tests on the dead fish, but the results were not well distributed. Many of the community members in Pearl Lagoon speculated that the fish deaths were linked to run-off of poisons from the African palm plantation.

ranchers (Jamieson, 1999, p. 18). The lack of a transparent and efficient system for maintaining authority over the land has created conflict between the indigenous communities, migrants, and the government. Although the indigenous communities have constitutional rights to their historical lands, they are not able to defend these rights without an integration with, and understanding of, the state legal system needed to enforce protection.

Increased economic opportunity may reside in the ability of community members to mobilize and leverage the rights to their land and resources, under a more unified front. However, the heterogeneous and disparate communities have become increasingly polarized by a market driven emphasis on individualism and the slow but steady abandonment of subsistence livelihoods. The greatest hope for unified alignment and rectifying the historical imbalances of power between the indigenous communities and the state and markets may lie in the successful implementation and evolution of the autonomy laws.

Negotiations between indigenous organizations and the first Sandinista government led to the incorporation of the Autonomy Statute in the constitution in 1987. This statute guarantees the rights to land, culture, language, and administration for the indigenous populations of the coast (Goett, 2004; Rinne, 2006, p. 44; Sollis, 1989, p. 514). However, these rights have not been effectively upheld. Between 1989 and 2005, no communal land titles were issued (Rinne, 2006, p. 50). This was due primarily to the lack of a defined process, limited funds for implementing demarcation, and the disincentives of the national government to support autonomy (Goett, 2004). In 2002 the law of land demarcation was passed, Law 445, defining procedures and governing institutions for demarcating indigenous lands, resolving conflicts, and managing resources (National Assembly of Nicaragua, 2002). Law 445 seeks to address some of these issues by outlining the roles of indigenous administrative bodies, state financing, and legal processes. For example, the law specifies that negotiations for concessions for rights to resource use must be done through communal, municipal and national agreement. Tax revenue from granted concessions will be divided in quarters between the community, municipality, regional, and national authorities. The management of natural resources will be carried out by the indigenous communities in collaboration with the national Ministry of the Environment and Natural Resources (MARENA).

On paper, these laws begin to delineate the necessary rights and specifications which, if protected and implemented, would provide a framework for beginning to compensate for some of the power imbalances between the communities and the state and market. However, there continue to be discourses by the national government that undermine the indigenous land rights set out in the constitution. Specifically, there is ongoing dialogue regarding the exploration of a trans-isthmus railroad, an oil pipeline, off-shore petroleum production, lumber concessions, and biofuel production (Goett, 2004; Hidalgo, 2007). Despite the fact that the current Sandinista government has increased financial support, the communities are still struggling to cover the logistical and legal costs of demarcation, and the reconciliation of conflicting land claims. There also continues to be violent conflict as landless Mestizo farmers look for farmland on indigenous lands, with little or no intervention by the national government.

In addition, rural communities have little experience negotiating concessions with transnational companies. In 2011 a Chinese firm received government and community permission to extract lumber from forests near the community of Kakabila, in the Pearl Lagoon municipality. Community members were hired as day-laborers, receiving minimal compensation for the extracted timber (Personal communication, December 2011).

The administrative bodies, empowered by the Autonomy law of 1987 as well as Law 445, should play critical roles in mobilizing communal decision making and governance of the coastal resources. Instead, they have been weakened by the process of state decentralization that began with the neoliberal policies in the 1990s, with the goal of distributing more power to municipalities. These mayoral districts implement policy and communications from the national government, bypassing the communal and regional governments. In 9 of the 12 municipalities in the RAAS, there is a Mestizo majority, whose welfare and priorities may be contradictory to the land rights of the indigenous populations (Goett, 2004, p. 11). In addition, many of these municipalities are often weak, corrupt, and continue to be underfunded.

It is stated in Law 445 that the communities will work with MARENA for the development of land management plans, but strict resource metrics need to be developed, as well as the appropriate means to incentivize or enforce the protection of resources. As outlined in the law, indigenous as well as state governments have stakes in negotiating concessions to resources. Having equal stakes with the national government could create conflict due to different viewpoints about those resources. The costs of environmental degradation, as demonstrated in the decline of fishing and lumber resources, are often not felt immediately, and may not impact near-term profits. In addition, the costs of the environmentally destructive agricultural practices, such as mono-cultivations using large amounts of synthetic inputs, often have negative externalities borne by neighboring communities.

While Law 445 specifies that communal governments have rights to negotiate concessions, there is nothing that mandates transparency or sets checks for corruption. Concession rights can be sold for a song, especially if the communal members aren't aware of the true value of an enterprise, or if corruption is present among government and community leaders. Additional statutes need to be established that set minimal standards for negotiations, providing professional legal representation and specifying minimum wage and labor conditions for concession rights, as well as baseline values for leasing land.

Conclusions

The political and economic history on the Atlantic Coast has been dominated by the exploitation of local labor and natural resources. The economic development processes up until the 1980s primarily took the form of extractive economies, providing significant financial returns to foreign and national firms, denuding local resources. A greater emphasis on the development of local economies, administered by the government in the '80s, had only marginal benefits for local economies. There is still a dearth of infrastructure, effective laws, and institutions that support local communities as the primary beneficiaries of their natural resources. Many communities remain in marginalized positions in relation to the market, either as sellers of their labor or their primary goods.

From the failure of the Sandinista development projects of the '80s to the more recent neoliberal, market-based approaches, most of the projects, planned from the top-down, have not met expectations. Utilizing welfare and financial metrics can bring greater visibility to various aspects of local realities, but they often reveal nothing about the dominant political and economic inertia that may be driving development projects.

Effective development projects will need to take into account technical, economic, political, *and* social and cultural conditions. Taking a macro-level view of the structures and trends of economic and political processes may not provide insights about why community members make the choices that they do in particular contexts, or how they view ongoing economic and political processes. A micro-level analysis is needed to understand if, within existing political and economic constraints, there is room for greater agency of groups or individuals, and how participatory processes may provide local benefit. In particular, it may be important to have effective methods of knowledge sharing among community members, as well as with development actors. For example, what level of cognition do community members have regarding their land rights, as well as access and understanding of mechanisms to claim those rights? How do they understand the opportunities and consequences for the exploitation of various natural resources? In the final chapters I will describe a participatory process that seeks to provide a framework in which community members can explore and expand their understanding of the complex network of relationships that impact their local livelihoods.

Chapter 3 Communicating between developers and beneficiaries

Introduction

In Chapter 1, an energy supply curve, carbon abatement cost curve, and several poverty metrics were constructed at the village level, showing how projects designed from the top-down might translate into local benefit. However, the calculated metrics involve a number of assumptions regarding how the projects would be implemented, and what might be the actual value to the targeted communities. The projects were not necessarily inclusive of the priorities of the community stakeholders, or revealing of what other capabilities must be present so that the targeted outcome actually has impact. As an intervention moves from policy to practice, from the imaginary to reality, the importance of politics, culture, and society will make their presence known.

Chapter 2 provided an overview of the historical and contemporary political and economic context on the Atlantic Coast, motivated by the interest of community members in strengthening their local economies. In order to better understand some of the challenges and promises for rural farmers and fishers on the coast, I visited various different projects and communities in August of 2009. I interviewed artisanal fishers, fish processors, buyers, coconut farmers, and spent time with both a cacao and lumber cooperative. It became clear that most farmers and fishers were struggling to make ends meet, with varying levels of success in local, national, and global markets. Most of the communities suffered from typical disadvantages of rural producers, lacking access to complete markets such as credit or insurance (e.g., see Bardhan (1989)), and having only marginal infrastructure and mobility to connect to existing buyers. However, the conversations with various producers in different commodity markets revealed certain themes. Often they had conflicting opinions about what were the greatest challenges to income generation. Some of the producers felt that they were at the mercy of the government, waiting for it to provide infrastructure and credit institutions, while other felt that they needed private firms to develop markets[30].

The capture of fish, lobster, and shrimp make up the largest sector of the coastal economy, of which the majority of fishery exports go to the U.S. Although over 85% of the fish are captured by artisanal fishers (INPESCA, 2011), they may only receive between 25-40% of the export price of the fish[31]. Fishers complain that the processing companies that buy their fish control the distribution of ice, which they need to keep their fish from spoiling; they also suspect price collusion. However, the technical barrier of access to ice is just one of many

[30] The reasons that farmers give are often convincing. Several coconut farmers explained that there is significant capital investment needed to begin a plantation, with a seed costing 2-4 USD, depending on the variety, and 150 trees per hectare. While there are some government programs that give small loans to farmers, most of them have payback times of three years. The farmers say that the coconuts need at least five years before they become productive enough to be able to use the income to pay down the loans. One of the largest coconut farmers remained skeptical that better credit would lead to increased production, explaining that coconuts require a lot of care during their first years, and he observed that a typical farmer will leave the young trees to compete against weeds and pests. He believes that the industry will never mature without significant investment, either from the government or the private sector.

[31] The average declared (FOB) price for fish in 2008 was 1.98 USD/lb (http://www.inpesca.gob.ni/). In 2011, fishers in the community of Orinoco were receiving 0.59 USD/lb (30% of FOB price) and 0.85 USD/lb in Bluefields (44% of FOB) for snook (Prices based on author's own investigation, 2011).

challenges. Fish processors are skeptical that ice is limiting the financial prospects of fishers, suggesting that even if there were ice production in the villages, it would only have a marginal impact until the fishers had better functioning cooperatives. Many fishers shared that they have individualistic mentalities and lack the trust and leadership skills needed to organize into large cooperatives that could give them greater market access. In addition, their own inability to restrict unsustainable fishing practices has led to a steady decline in the productivity of their lagoons and coastal waters over the past several decades (Christie et al., 2000). Similar to farmers, fishers feel that they have little agency to improve their economic prospects without changes made by outside actors, such as the government or large companies.

I developed the idea to work with groups of farmers or fishers in order to facilitate a more quantitative analysis of their economy, explore different challenges to economic growth, and try to understand what solutions were within reach given current capabilities, and what challenges were due to external economic and political forces. It seemed plausible that with more complete or accurate information, local producers might make different decisions, increasing their ability to take greater command of their financial livelihoods, as well as demand different types of economic development projects.

This chapter reviews the role of participatory processes in development and describes how a participatory modeling process differs from many commonly used techniques, which focus on eliciting information from targeted beneficiaries rather than challenging and sharing information between targeted beneficiaries and project implementers. I will then detail how the process was designed and utilized with groups of fishers in three communities in the Pearl Lagoon basin. Chapter 4 will go on to analyze how the methodology provides insights related to challenges and promises within the context of current and past development projects in the artisanal fishing sector.

A need for better communication tools

After almost sixty years of international, institution-led development, we still find a world of vast inequality, with over a quarter of the global population living in states of extreme material poverty (IFAD, 2010, p. 16). In a world with limited funds, dollar allocation is critical. There is an ever-growing amount of research seeking to explain why development money often leads to poor outcomes (e.g., see Riddell (2007)). This chapter seeks to contribute to discussions of community-scale development interventions that are planned and implemented by non-community actors. Decisions taken with incomplete or inaccurate information will likely lead to sub-optimal results. Development actors often have a poor understanding of the true goals and rationale underlying behaviors observed within a community. On the receiving end, target beneficiaries frequently lack an accurate conception of the likely benefits that may result from a proposed technology or policy intervention. In this chapter I focus on the introduction of a participatory method for planners and beneficiaries that facilitates the discovery and exchange of information.

The multitude of failed development projects has led to the main-streaming of participatory planning processes by development institutions (Aycrigg, 1998; Cornwall, 2006; White, 1996). There are a number of well utilized participatory methods that can be used to elicit information from a community. Many of these methods use information revealed in focus-group settings, in which the facilitator primarily plays the role of passive observer. Such methods allow the facilitator to gain insight into the *perceived* reality of specific community members. However, individual perceptions may be biased and often need to be further explored in order to understand how common the perceptions are among other groups. In contrast to focus groups, field observation allows the observer to gain intuition about the realities of community behavior, although time constraints and partial information may limit a thorough understanding of the underlying rationale guiding observed behavior.

The most popular participatory methods focus on eliciting information from community groups without resolving communication barriers between planners and beneficiaries. There are often misperceptions by community members regarding the outcomes of a proposed development intervention. Whether the development project is electrification, the construction of a health center, or agricultural extension work, community members are usually not privy to the implementation and operation details of the project, often designed by external specialists. This may lead to beneficiaries being surprised or disappointed with project outcomes. There is a need for greater utilization of methods that effectively facilitate communication between planners and target beneficiaries.

The neoliberal development paradigm and the co-option of participation

During the 1980s, neoliberal economic policies[32] took the form of economic structural adjustments in many developing countries, as a criterion for receiving funds from the largest development lenders, such as the World Bank and IMF (Easterly, 2005). The dominant structural adjustment policies included the privatization and deregulation of state firms, the devaluation of currency, repayment of debt, reduction in the size of government, and transition from free social services to fee for service. Such measures were meant to stabilize economies as a prerequisite for future economic growth, supporting the belief that these policies would, in the long run, be beneficial for national economies and all sectors of the population. However, the short term consequences of structural adjustment policies, which frequently led to the reduction of social services, likely exacerbated the vulnerable conditions of many marginalized communities (Cornia, Jolly, & Stewart, 1989; Jolly, 1991).

The social consequences of the neoliberal policies of the ‘80s and ‘90s created sharp reactions from civil society. The harsh outcries resulting from structural adjustment policies necessitated a response from development institutions to show that they were both serious about the welfare of the individual (Lockwood, 2005, p. 778), and sensitive to the diverse constituencies that comprise a nation. In addition to the restructuring of markets, new policies focusing on social development and institutional reform were developed (Mohan & Stokke, 2000, p. 248). By the turn of the millennium, there was a shift in neoliberal policies towards the inclusion of local communities in the planning and implementation of many of the institution-led economic development projects. The revised neoliberal policies that currently dominate institution-led development place an emphasis on decentralization, local participation, and attempt to understand project effects across ethnic and gender lines, as well as target the involvement of local NGOs and other community-focused practices during the implementation of projects.

[32] Neoliberal economic policies, notably championed by economists Frederick Hayek and Milton Friedman following World War II (Tickell & Peck, 2003, p. 8), posit that markets tend to be the most economically efficient mechanisms for allocating goods and services in a society.

Many of the most commonly used forms of participatory fields practices had their origins in the late ‘60s and early ‘70s, evolving through the ‘80s (Brisolara, 1998; Chambers, 1994; Cornwall, 2006; Hall, 1992). A number of the participatory practices that emerged during these decades sought to value the knowledge and capabilities of the poor, founded on the view that the poor are capable and can be empowered, and that outsiders have roles as coordinators or facilitators (Chambers, 1994, p. 954). In contrast, the adoption of participatory methods by large development institutions reflected a realization that the efficient and sustainable implementation of any development project, carried out at a localized level, would be enhanced with local buy-in and participation (Aycrigg, 1998, p. 1).

Several World Bank documents outline the logic of participation as an instrument that can contribute to economically efficient outcomes of the delivery of goods and services (Picciotto, 1992; Vieira da Cunha & Junho Pena, 1997). World Bank economist Picciotto notes that project evaluations saw higher failure rates when there was low beneficiary involvement (1992, p. 3). He argues that participation is an instrument that has the potential to deliver decisions that meet the demands of a group in a more efficient manner than centralized planning. However, there is much debate regarding the quantifiable impacts of participation on development outcomes (Almeida, Hamerschlag, LeFrancois, & McEllinny, 2008; Aycrigg, 1998).

Participation can be seen as a critical tool for implementing a market-based agenda. This agenda includes the integration of rural communities into a global economic system, based on market mechanisms that respond to demands, rather than perceived needs (Vieira da Cunha & Junho Pena, 1997, pp. 6–8). When externally planned agendas are inconsistent with local priorities, a lack of local buy-in can lead to increased failure rates. Since the needs of a population are subjective and unique, under specific conditions, markets can do a more efficient job of determining and meeting the demands of individuals. However, in order for markets to efficiently meet demands, they must be competitive and complete, and consumers must have full information (Bardhan, 1989, p. 1391). In the absence of such conditions, or in the case of public goods, institutions are needed to correct for market inefficiencies. In rural communities, where public goods are often important and markets are missing or poorly functioning, the design and implementation of institutions in order to meet demands is important (Bardhan, 1989), and community decision making is critical.

Yet, strong critique is leveled against the mainstreaming of participatory practices by dominant development institutions such as the World Bank (Cooke & Kothari, 2001; Cornwall, 2006; Hickey & Mohan, 2004; White, 1996). It can be argued that institutions like the World Bank create development blueprints that serve to legitimize external development agendas, leaving a narrow space for authentic contributions from community members (Cornwall, 2006). The unequal power relations created by the facilitators from these institutions strongly impact participatory decisions, and their pre-formulated agendas co-opt local development processes (Cooke & Kothari, 2001; Cornwall, 2006; Hickey & Mohan, 2004).

Cooke has a harsher critique of participatory development, suggesting that it might best be abandoned altogether (Cooke, 2004). He argues that participatory practices have become mandated by institutions, with their foreign field agents embodying their own culture and class structures, making some form of co-option of local agendas inevitable (Cooke & Kothari, 2001). Though extreme, Cooke’s critiques force the practitioner to take a sharp look at her methods and the role that she may be implicitly playing in oppressive power structures.

In addition, participatory practices that don't account for the heterogeneity within communities will likely be dominated by the local elite. Communities are often composed of biased relations, founded on differences of race, ethnicity, gender, or economic class (Cornwall & Jewkes, 1995, p. 1673). There must be some form of corrective mechanism to insure that the marginalized have influence in decisions (Cooke & Kothari, 2001, p. 69).

Wherever there is a hierarchy of power, it is logical that groups who have the most to lose will seek to co-opt any methods that threaten their advantage. With this simple observation in mind, participatory methods will be vulnerable to co-option in order to maintain existing power structures. While participatory methods have the potential to bring agency and voice to marginalized populations, they must be implemented in manners that maintain awareness of power relations between facilitators and participants, as well as among participants.

Empowerment through games as participatory learning tools

Many of the participatory methods commonly used by development experts, especially those of rapid rural appraisal (RRA), focus on compartmentalizing and eliciting information from community members to inform top-down planning or implementation of a pre-conceived project. Rarely do the processes create frameworks through which the participants can come to a detailed understanding of a proposed project and the many variables and complex dynamics that define their local livelihoods. There is, however, a history of participatory methods used as tools for local empowerment, primarily focusing on learning.

The late Orlando Fals Borda is considered to be one of the seminal contributors to the field of participatory action research (PAR). The basis of PAR is to support 'people's power', which Fals Borda describes as the capacity for grassroots organizations to articulate and systematize knowledge in ways that allow them to control, or at least affect, development (Fals-Borda, 1987). In contrast to conventional research and teaching, in which there is quite often a subject (the researcher or teacher) and an object (the student or community member), Fals Borda believed that PAR could create learning systems composed solely of subjects.

Fals Borda's work resonates closely with Paulo Freire's pedagogy for adult education (Freire, 1970). Freire's influential work was motivated by the desire to empower rural community members through dialogue, reflection, and action, with the goal of gaining a deeper awareness of structures of oppression. The heart of his work was an examination of the role that knowledge creation plays in structures of power. He argued that liberation from oppression must begin with a critical examination of one's own reality (Freire, 1970, pp. 54–55).

Freire saw dialogue as the primary tool for an authentic learning process, outlining a method that he called problem-posing education (Freire, 1970, pp. 79–80). This practice might be compared to the Socratic Method, in the sense that it involves challenging others' perceptions of reality through a series of questions that are explored with dialogue. The role of facilitators or educators is to discover the dominant cultural, societal, and economic themes that challenge individuals, and re-present topics in ways that are more readily understood. The problem-posing approach to education turns the teacher into a co-learner. Through dialogue, education is transformed into a subject-subject relationship: teachers become students and vice versa, all having the goal of trying to learn more than they already know. This can be contrasted with typical educational practices where the teacher is the expert and the student acts as a passive vessel in which information is deposited, what Freire calls the 'banking system' of education (Freire, 1970, p. 72).

In stark contrast to most forms of classroom learning, in which the student often plays the part of Freire's passive vessel, games require participants to apply their knowledge, challenging them to evaluate information and develop decision-making skills to attain desired goals. Game playing can also serve as a vehicle for introducing problem-posing methods into learning environments. Simulation games are activities in which participants interact with an environment that represents reality (Dorn, 1989, pp. 2–3), immersed in attaining a goal, often through collecting information and making decisions. Role-playing games are a type of simulation game in which individuals are given sets of rules and goals in order to explore system relationships from particular viewpoints.

There have been several notable role-playing games developed over the last thirty years that emphasize system relationships, whose target audience has primarily been development workers, students, and political actors. In the 1980s, Dennis Meadows and others were commissioned to develop the role-playing game STRATEGEM, with the objective of providing a pedagogic tool for leaders in Latin American governments to gain intuition about the relationships between energy systems, the environment, population growth, and the economy (D. Meadows, 2007; D. L. Meadows, 1999). Meadows went on to develop other games, including Fish Banks, which explores decisions for managing fish resources (D. L. Meadows, Fiddaman, & Shannon, 1986). These games have been played in many educational environments around the world, as well as in institutional environments such as the World Bank and governments (D. L. Meadows, 1999). Also, in the 1980s the World Bank commissioned "The Green Revolution Game" and "Exaction", which challenge players to make resource use decisions for rural farmers, industrialists, and governments (Chapman, 1983; McNeill, 1990; Park, English, Gray, & Cleland, 1995). These games and derivatives have also been used in university curriculums for agricultural economics and geography (Fox, 2005; Park et al., 1995). Notable among these examples is the lack of games developed and played by the rural community members themselves.

There are, however, recent examples of the utilization of role-playing games developed with rural stakeholders. A group of researchers at a French institute focusing on agricultural research and development, CIRAD, developed a methodology that they call companion modeling (Barreteau et al., 2003)[33], which has a similar approach to group modeling, utilized in the business sector (Vennix, 1999). Their approach has evolved over a number of years, with the goal to "facilitate dialogue, shared learning, and collective decision-making through interdisciplinary and "implicated" action-oriented research to strengthen the adaptive management capacity of local communities" (Barreteau et al., 2003, p. 7).

Researchers using the companion modeling approach typically begin by working with community members to create a simplified role-playing game that models the decision rules of various stakeholders, focusing on a specific problem identified by the community. Upon development and validation of the decision rules, stakeholders can then play the game, running through various scenarios. The role-playing game can also be translated into a computer model,

[33] The website: http://cormas.cirad.fr/ComMod/en/, provides access to information, publications, and software related to the companion modeling approach.

allowing for the rapid exploration of almost unlimited scenarios. Community stakeholders play lead roles in the development of both the role-playing game and the computer model. The technique has been used primarily in rural communities in eastern Asia to explore issues related to the management of irrigation systems, various land use decisions, commodity value chains (Barreteau, Le Page, & Perez, 2007; Bousquet, Trébuil, & Hardy, 2005), and fishery management (Castillo, Bousquet, Janssen, Worrapimphong, & Cardenas, 2011; Worrapimphong, Gajaseni, Le Page, & Bousquet, 2010).

While many of the case studies in East Asia are focused on resource management, the approach can also be used more generally to facilitate the exploration of various dynamics of local economies or societies. The adoption and adaptation of the companion modeling approach offers a novel methodology for working with various stakeholder groups to explore development projects. Designing the games creates a forum in which developers and targeted beneficiaries can work together using a problem-posing approach to come to a shared understanding of local realities and the costs and benefits of future projects or policies. Over the course of six months, I explored such a process with fishers on Nicaragua's Atlantic Coast.

Case study: exploring an artisanal fishing economy through gaming

Description of the context

The research focused on three communities in the municipality of Pearl Lagoon, which is situated around a large lagoon with the same name, shown in the map in the figure below.

Figure 6: Map of Pearl Lagoon, in the southern autonomous region of Nicaragua, and the three communities where the investigation was conducted (Orinoco, Marshall Point, and Pearl Lagoon).

The Pearl Lagoon municipality consists of twelve communities and varying ethnicities, though primarily English-Creole speakers. The project focused on the three communities of Pearl Lagoon, Orinoco, and Marshall Point, looking at the artisanal fishing sector. The motivation for choosing both the communities and topic came from several years of working within the communities of Orinoco and Marshall Point. There is a strong local interest in developing strategies to strengthen their local economies, with particular emphasis on the fishing industry. My prior work within these communities laid the groundwork for both a basic knowledge of the dynamics within the community, as well as familiarity with many of the community members.

The third community, Pearl Lagoon, was chosen in order to provide contrast to the more isolated communities of Orinoco and Marshall Point, as well as to facilitate potential insights into benefits realized from improved infrastructure and better access to markets, since Pearl Lagoon is the capital of the municipality head and has road access and twenty-four hour electricity service.

	Pearl Lagoon*	Orinoco**	Marshall Point**
Ethnic majority	Creole	Garifuna (82%)	Creole (83%)
Number of houses	384	130	54
Population	2200	830	199
Number of households that fish	NA	67 (51%)	30 (48%)
% of community income from fishing	NA	45%	62%
Ave USD/household/day	NA	$10.30	$10.50
Road access	Yes	No	No
Hours of electricity access	24 hours	12 hours	12 hours

Table 10: Characteristics of the three communities involved in the participatory modeling. Sources: * (INIDE, 2010), ** (Casillas et al., 2010).

The fishing economy for communities located in the Pearl Lagoon basin consists of a combination of scale fish, shrimp, lobster, and crab. Fishing comprises a critical part of both the monetary and subsistence economy. Depending on the time of year and the species, fish are sold to both intermediaries and fish processors, or simply consumed in the house or shared among community members.

The lagoon itself is home to a wide variety of scale fish and shrimp, many of which migrate from the ocean during different times of year. During the rainy months, the scale fish tend to be most populous and active, and gill nets are the most effective equipment.

Fishers typically fish with one to two partners. While some fishers have fiberglass boats with outboard motors, the majority use small wooden canoes, paddling and sailing. A boat will typically have from one to fifteen gill nets, with a typical net measuring 100 meters in length, and several meters in depth. The fishers set their nets in the early morning or evening, and then pull fish from the nets after six to eight hours. Catch sizes can range from zero to several hundred pounds of fish.

The best market prices are paid for snook and catfish. Fishers usually sell to middlemen within their communities, who then sell to one of several fish processors located in the nearby city of Bluefields. There is a large diversity of other fish that are caught, which tend to be sold or shared within the communities, rather than sold to middlemen or fish processing plants. Depending on the season, shrimp can be abundant, and typically are caught close to shore with a single cast net, reducing the barriers for both women and children to participate. In contrast, lobster fishing is done at sea, and requires large investments in equipment and weeks away from home, limiting the number of community members who are able to participate.

There are a number of fishing cooperatives, both within communities and across multiple communities. The primary motivation for most fishermen to join is to gain access to loans or grants that can be used to buy equipment. The cooperatives, almost universally, tend to suffer from poor management, abuse of funds, and very little collaboration between members.

The recurrent themes among fishers in almost all of the communities tend to be the lack of access to financing to buy equipment, the desire for local ice production, and a general trend of declining fish productivity. Most fishers from the communities cannot access loans from any of the local banks, because they live on communal lands and therefore do not have a land title needed for collateral.

Many fishers view the lack of local ice production as a primary impediment to developing local fishing economies. Ice allows fishers to stay in the lagoon multiple days without having to pay transportation costs to deliver fresh caught-fish, or aggregate catches within the community before delivering to a better market. Most of the main fish processors provide free ice to fishers, provided that they sell them their fish. Ice is transported up to the rural communities in large coolers, primarily by middlemen. Due to the high capital cost, ongoing maintenance, and technical complexity of ice machines, some argue that local ice production is not a feasible technical solution for rural communities.

The ongoing decline of fish productivity is another critical issue. During the formal interviews, every fisher proclaimed that fishing in the lagoon will become worse due to overfishing from increased use of gill nets, unless some form of regulation is implemented. In particular, there was universal consensus among the participants that a closed season for the use of gill nets needs to be enforced[34]. Most participants agreed that the implementation of a closed season would require the input of fishers from all of the communities, but needed to be carried out and enforced by the government[35].

Process development

The goal of the investigation was to work with small groups of fishers in order to facilitate a more quantitative understanding of their fishing economy and a deeper analysis of the logic behind their decisions, as well as to explore a number of common themes that had emerged during conversations, observations, interviews, and participatory workshops. These themes included understanding the benefits of ice production, the need for financing, the management of cooperatives, and the perceived decline in fish productivity.

I chose not to offer any incentives for participation, with the intention of working with community members who had greater initiative or curiosity about the process. However, gathering the participants for the game playing was often a challenge. Many of these communities have a long history of government, universities, and NGOs giving workshops, doing surveys, and organizing meetings, often with no benefits perceived by the community members. This has led to the practice of organizations providing a stipend or food in order to

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[34] There currently exist several fishing regulations applicable to Pearl Lagoon, yet they are not followed or enforced. There is a law that prohibits the use of gill nets during two months of the year, as well as limits the minimum size of the net openings, allowing young fish to escape. A representative of INPESCA, the national government's ministry for fishing, explained that they don't have the resources to enforce the laws, and the laws were created without participation or consensus from the local communities, and are, therefore, ignored.

[35] A representative of INPESCA said that in order to design a closed season, the municipality would need to create a commission composed of members from the government, as well as community members, and a majority consensus within each community would be needed (personal communication, September 12, 2011).

motivate participation. In the smaller community of Marshall Point, leaders of the cooperative were able to gather the same group of about eight cooperative members each time. In Pearl Lagoon, the largest community, the president of the cooperative had a difficult time organizing the members. He said that part of the reason was that they were still waiting on their government funds, and members were tired of meetings related to a non-functioning cooperative. The game-playing workshops therefore typically consisted of around five fishers who were family members or friends. Orinoco proved to be the community where it was most challenging to gather the same group of fishers for each meeting. One of the most active participants of the process often ended up helping to gathering fishers, and the workshops ranged in size from six to ten participants.

The initial plan was for the participatory modeling process to begin with a series of focus group meetings, leading to a multi-day modeling workshop. The focus group meetings were planned to act as forums where the dominant themes of the fishing economy could be critically discussed, allowing participants to pinpoint areas of disagreement or where there was a lack of information. The intention was for participants to plan and carry out small investigations in order to fill in the information gaps. The initial plan is outlined in the table below.

Visit	Purpose	Rationale
1	Meeting	Group meeting with fishers in each community. Explain the goals of the participatory modeling process. Provide a sign-up sheet for up to 12 fishers interested in participating in the process.
2	Interviews	Provide a baseline of each fisher's behavior, knowledge, and opinions regarding the fishing economy. The information would be used to help formulate the game as well as to evaluate changes in knowledge.
3	1st Focus group	Carry out a discussion around the dominant themes that surfaced within the interviews and informal conversations, and organize participants to collect information where knowledge was lacking or participants had differing opinions.
4	2nd Focus group	Evaluate the information collected by the fishermen and discuss if there was convergence of opinions
5	Game workshop	Multiple-day workshop in which the rules of the fishing game are discussed and several completed simulations are played. The simulation would allow fishers to try out new strategies and gain intuition regarding possible pros/cons.
6	Post interviews	In order to determine fishers' opinions of the process and see if there are any lasting impressions from the game playing

Table 11: Initial process plan for the participatory modeling process

During the third visit, which was to be the first focus group meeting, it became clear that diverse group dynamics between villages called for a more organic process, tailored to the personalities and evolving interests and views of each distinct participant group. For example, in the village of Marshall Point, the focus group meeting went well, and participants agreed to investigate information on a number of subjects, such as the cost of maintaining an ice machine, the procedures needed for the government to take a more active approach in regulating laws, and the various buying prices that fish processors offered in the town of Bluefields.

However, in the village of Orinoco the debate centered upon the concept of the game and misunderstandings of what it might entail. One of the participants thought that the game was an experiment that would be carried out in the lagoon, and didn't understand why fishers would want to invest their own precious resources in an experiment. In the rural villages there is not a shared experience of playing different types of board games, as is common in other cultures, especially in urban communities. Game playing is a popular afternoon leisure activity in many of the rural coastal communities, but usually takes the form of either cards or dominoes. Neither of these games provides intuition about the creation and playing of role-playing games that are meant to provide a characterization of real life. Therefore, it became clear that participants needed to experience a prototype of the game, which would also help them decide whether they wanted to continue participating in the project. Since a good understanding of the general dynamics of the fishing economy had been developed from group discussions, formal and informal interviews, observations, and going fishing with community members, the decision was made to introduce a prototype of the game, rather than continue with the focus groups.

A chronogram of the process that was realized in the communities is shown in the figure below. The primary difference between the planned and realized process was the iteration of multiple game playing sessions, rather than having one multiple-day workshop dedicated to modifying and playing the game. One could envision having multiple sessions over the course of several days, condensing the process into a much shorter timeline. The timeline was spread out over a longer period in order to decrease the strain on the participants' personal time, as well as integrate feedback into the game design. Many participants preferred to play near the end of the week, or on Sundays, providing opportunity for only one or two sessions in a week.

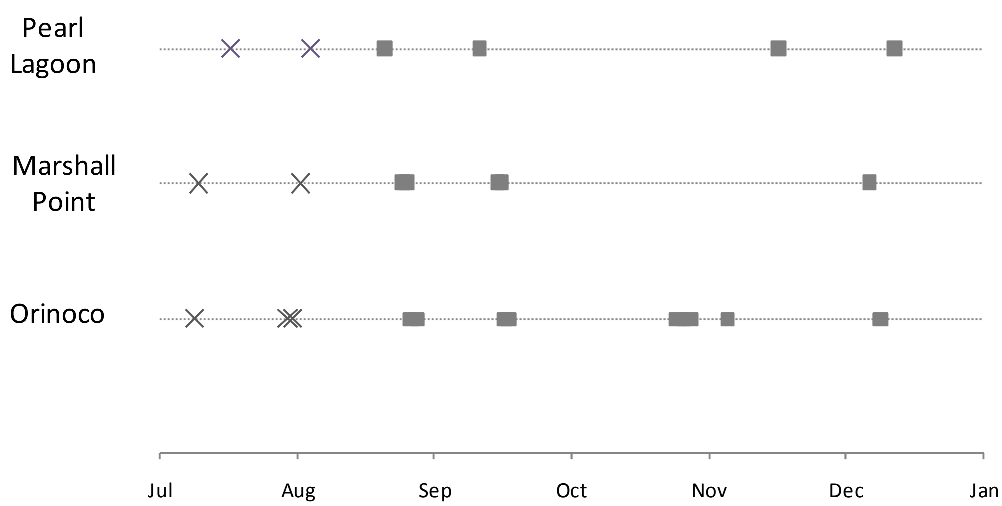

Figure 7: Realized process timeline for the participatory modeling, 2011. The square boxes represent game playing sessions, and the crosses represent meetings and interviews.

Game design

The goal of the game prototype was to design a basic framework through which the participants could express their decision behavior, as well as to explore the dominant themes that had emerged during the first several meetings. The initial prototype consisted of a large map of the area of the lagoon where villagers fished. The first meetings with the game involved emphasizing that the goal was for the villagers to work through the decisions that they actually take in their daily lives. In addition to the map, the prototype included cards, with pictures of different equipment that fishers might need, and dice for determining fish catches. The prototype provided a simulated reality where participants could 'act out' the manner in which they fish, with their real-world constraints, such as how much fish they catch, how often they fish, where they fish, and what equipment they use, forming the rules within the game. One of the original versions of the game is shown in the figure below.

Figure 8: Game prototype (left) and group of fishermen playing the game (right) (Author's photographs).

In the final evolutions of the game, each fisher was given a small token, which represented his or her nets, and options for the acquisition of equipment. Various versions of the game were played, some in which fishers were randomly given various equipment, others in which they could only play with equipment that they owned in real life, and others in which they were able to take out a loan to buy additional equipment. The equipment available in the game included nets, ice coolers, boats, and motors. The equipment and costs are shown in the table below.

Equipment	Cost (USD)
Fishing net	$70
300 pound cooler	$270
Canoe	$450
1 000 pound cooler	$1 140
15 horsepower motor	$2 500
Fiberglass boat	$4 540

Table 12: Equipment and costs used in the fishing game

During the games that players were allowed to take out loans, they were allowed a total loan amount of $ 2 700, which is close to the amount that many fishers receive through the cooperatives. If they didn't have any equipment, a common choice was to buy a canoe, ten nets, and two 300 pound coolers. If they wanted a motor, then they would need to collaborate with another fisher in order to double the total loan size, so that they could also purchase a boat, nets, and coolers.

Almost all fishers in the villages fish in pairs. Sometimes the partnership is strategic. If one fisher has a boat and motor and the other has some quantity of nets, then they combine their equipment. Many partners are family members. In the case of partnerships, they often divide the profits equally. Other fishers have all of their own equipment and pay another community member, a sailor, to help them, often paying him ten percent of the profits.

I created a pair of game dice in order to simulate the uncertainty of catching fish. The numbers on the dice were chosen so that the sum of the two dice represented the expected catch, in pounds, that a fisher might make with one net during a particular month[36]. For example, if a fisher had ten nets and the values on the two thrown dice were a 3 and a 12, then the fisher would record a catch of 150 pounds (15 pounds/net x 10 nets = 150 pounds). Many fishers in Orinoco set their nets and then retrieve the fish from the nets six to eight hours later. They typically haul in their nets two times each day, in the late evening and early morning. When the fish are abundant, fishers haul in fish as often as three times a day.

The highest operational cost for fishers who have boats with motors is the gasoline. During November of 2011, gasoline was sold in the village of Orinoco for $7.50 per gallon, and in Pearl Lagoon for $6 per gallon. The typical round trip gasoline consumption for a single fishing trip from Orinoco or Marshall Point is between one and three gallons, depending on the fishing spot, and assuming that fishers are returning to sell their fish to an intermediary buyer in Orinoco. Thus, with two trips per day, they may spend between $15 and $45 in gasoline. If fishers have ice and coolers, then they can sleep in their small boats, or nearby on the shore, without having to return immediately to sell their fish. This is done in order to save on fuel costs, as well as to keep an eye on their nets to prevent theft of both the nets and caught fish. In order for fish to remain salable, they need to be placed on ice within hours after taking them from the nets. Fish can remain as long as one week on ice, and still be sold to the buyers. During a two to three day trip, fishers from Orinoco reported that they may consume four to five gallons of gasoline. If fishers had coolers in the game, they could remain with their nets until their catch exceeded the capacity of their coolers.

The three buyers in Bluefields, as well as the one processor near Pearl Lagoon[37], have ice machines. Most of them give ice to fishers or intermediaries for free, with the understanding that all of the fish caught will then be sold to that same provider of ice.

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[36] A researcher from another university was studying fishing behavior and had been recording the catches that fishers were making in various villages throughout the year. Based on this data, numbers on a pair of dice were made to approximate the distribution of per net catches. Representing catches for the months of June and July, the numbers on the two dice were: (3,3,3,3,8,13) and (2,2,2,2,7,12).

[37] The processor in Pearl Lagoon is located on the piece of land known as Bar Point. The product is then brought to a processing plant on Corn Island. The other buyer in Pearl Lagoon, Alan Downs, is an intermediary that sells exclusively to the processing company of Caribesa, located in Bluefields.

An important aspect of the fishing economy involves determining where the fish are sold. There are two intermediary buyers in Orinoco who offer $0.59 per pound for snook, which is the most valuable market fish. In the town of Pearl Lagoon, there is one intermediary buyer and one processor, who both offer $0.73 per pound. In the town of Bluefields, there are two processors and an intermediary, who each offer $0.86 per pound[38]. The table below provides an example of the travel costs for a fisher leaving from Orinoco or Marshall Point, based solely on consumption of gasoline, the fish prices offered, and the minimum pounds of snook that would need to be sold to the different vendors in order to break even. The amount of fish represents a minimum, since there would be additional variable costs, such as the salary or opportunity cost of the driver, as well as food. A round trip from Orinoco to Pearl Lagoon could be done in an afternoon, whereas the trip to Bluefields, including waiting time at the processor, could take more than a day.

	Gallons gas	Gas Cost	Price/lb	Min Catch (lbs)
Orinoco/Marshall Pt	--	--	$0.59	--
Pearl Lagoon	18	$98	$0.73	135
Bluefields	46	$251	$0.86	291

Table 13: Minimum catch needed to break even with transportation costs for fishers from Orinoco or Marshall Point. The gallons of gas represent round-trip consumption using a boat with an outboard motor of 15 horsepower. The gasoline cost is based upon a price of $5.45 per gallon. The fish price is for snook. The minimum catch is the minimum amount of snook that a boat will need to sell in order to pay for the gasoline costs, and does not include any other costs, such as salary or food. All prices are in USD.

In addition to the uncertainty in the amount of fish that might be caught, "chance" cards were introduced in order to provide for the many other random events that occur in the lives of the fishers, and impact their livelihoods. The fishers would draw one of the cards every other turn during the game. The cards represented random events that were not uncommon in the lives of many of the fishers. Some of the cards introduced positive events, such as earning extra money from the harvest of a small crop, receiving money from a relative living abroad, or having an unexpectedly large fishing catch. Other cards had negative events, such as having one of their nets stolen, paying to send a family member to Bluefields, buying a cell phone, having to make repairs to their equipment, or getting sick and being unable to fish for a day.

In order to keep track of earnings during the course of the game, which would usually simulate the profits and losses for a week of fishing, each fisher, or pair if they were playing with a partner, received an accounting sheet. The accounting sheet allowed the players to record their daily catches, earnings, and costs, as well as the equipment that they were using. At the end of the game, gross and net earnings were calculated, leading to a discussion of how the participants faired during the game.

The role of facilitator

The game proved to be a rich catalyst for discussions of fishing behavior and strategies. In fact, the game revealed itself to be a more enjoyable and stimulating medium for discussion

[38] The buyers pay in Cordobas, which is the national currency of Nicaragua. In November of 2011, 22 Cordobas were equal to 1 USD. The buyers in Bluefields all claim to pay 19 Cordobas per pound for snook, as there appears to be price collusion among the buyers. Some of the fishers told me that one buyer will often pay 1 Cordoba more than the others, unofficially.

than the initial focus groups. The participants initially familiarized themselves with the scaled map that was centered on their dominant fishing locations. They often processed the information together, pointing out the various landmarks and fishing holes to new participants. As they made different choices during the game, opportunities were created whereby the facilitator could pose questions. For example, as participants decided where to fish, or what gear to use, questions could be asked, such as why they made certain choices, was it a common decision, and what alternative choices might there be. The game was a cross between informal interviews and participant observation. In the span of a few hours, the facilitator could witness a wide range of behaviors while gathering explanations for the choices that were made.

The role of the facilitator as both observer and questioner was critical. The game-playing exercise provides the opportunity for both the participants and the facilitator to deepen their understandings of the fishing economy, very much in the spirit of Freire's vision of the dissolved boundaries between teacher and learner (Freire, 1970). In the first few iterations of the game, acting as the facilitator, I tended to ask questions that didn't necessarily increase the fishers' knowledge, but rather helped me come to a better understanding of the behavior of the fishers. During this initial process I was able to deepen my own knowledge of the context of the fishing economy while helping to determine what fishing behaviors lend themselves easily to rules that could be implemented within the game. This was the game creation stage.

The initial questioning process also provided a forum in which other participants could discuss or provide contrary opinions regarding the reason why a decision was made, or share variations of decisions. If a point of debate couldn't be adequately resolved, it highlighted an area in which I could encourage several of the participants to collect information that would help to resolve the dispute for the next meeting.

It was important for me, as the facilitator, to gain an understanding of the dynamics of the economy without creating too many digressions that would inhibit the flow of the game, causing participants to lose interest. Some examples of questions that I asked during the initial stages of the game included:

- *How many boats can fish in this spot at the same time?*
- *Does everyone agree that a boat can carry this many coolers?*
- *Do you know of anyone in your village who owns as many nets as you are using in this game?*
- *What time of year can you catch that many pounds of fish?*
- *How many gallons of gas does it take to travel that far?*
- *How do you normally choose your fishing partner?*
- *How does the amount of fish that you caught in this turn compare to what you caught this past week?*

Once the game prototype was designed and the participants agreed that it was a good representation of their economy, we were able to use the game to present new scenarios, challenging participant knowledge and aspirations and stimulating discussions. Many questions emerged simply from observing that an alternative behavior could be valuable, or by introducing new information to the participants. Some example questions that I asked during this stage were:

- *Can you explain why it may be more profitable to sell your fish in location A than location B?*
- *Can you think of some advantages of buying a large boat that can carry ice from Bluefields, instead of getting an ice machine?*
- *Did you know that some companies pay a better price to catches greater than 3 000 pounds?*
- *If the loan from the government does not come through, is there any other way that you can get enough money to buy a bigger cooler?*
- *How many fishing boats are needed to catch enough fish to fill up the bigger cooler?*
- *How many pounds of fish do you need to make the trip to location B profitable?*

It is important to acknowledge the difficulty of maintaining a neutral role. As individuals, our actions are guided by our experiences, habits, and desires, all of which work together to numb a more objective awareness of our reality. During a number of the game sessions, I had an observer present. The observer's role was to remain in silence, outside the perimeter of the game, and take note of the observed dynamics and power relations among the participants, and between the participants and myself, in the role of facilitator. I provided the observer with a sheet with specific questions relating to player interest, understanding, and dominance, and the facilitator's ability to be respectful, stimulate discussion, maintain focus and interest, and try to remain external to the process, as much as possible. Later, during the game-playing process, a number of the players who had participated in many of the games spontaneously took over the role of facilitator, explaining the game to new players and managing the playing, transforming my role to that of observer.

Goals and constraints in the game-playing process

During the initial few game sessions the fishers replicated their usual behaviors, fishing with the same number of gill nets that they were accustomed to and selling to the same buyers, even when presented with the opportunity to acquire more fishing gear or make different choices. While this meant that the initial games provided good opportunities for understanding the behavior and strategies of fishers, it became apparent that various constraints or incentives would need to be introduced in order to stimulate the exploration of new strategies. After several sessions, the game was organized as a competition in which participants could choose to join with others or fish alone. Each person had the option of acquiring a loan, and the group that had the greatest net income would be declared the winner.

This introduced an atmosphere of competition, increasing the energy, focus, and interest of the participants. The introduction of competition catalyzed many of the fishers to make choices that they wouldn't generally make in real life. For example, many participants began maximizing the number of fishing nets that they could buy. Following several discussions, most fishers agreed that it was not realistic for a pair of fishers to handle more than twenty to twenty-five nets. They also discussed the role that a preponderance of nets could have on resource decline. The fishers decided that they would set limits on the number of nets that they could have in the game, taking into consideration the need for resource regulation as well as the feasibility of implementing such a rule in the real world.

Competition also created a dynamic whereby teams began challenging the realism of choices made by other groups. This typically led to lively discussions and explanations, based on experience, as to why or why not such an action was possible. The discussions tended to be constructive, fleshing out the details of various fishing strategies. For example, one group had maximized the amount of fish that they could store in their cooler, so they decided to fish in the morning, travel to a vender to sell the product at midday, and then return to set their nets again in the evening. This incited a discussion of travel times, costs, and transaction times, resulting in an agreement that while the strategy was possible in real life, it would leave the fishers exhausted, making it unlikely that anyone would carry out the strategy in practice.

It became apparent that the behavior of fishers was not based solely on income maximization. In daily life, fishers did not fish every day, even when there was opportunity. Clearly their decisions were based on other aspects of wellbeing, with rest and leisure time appearing to be important components. Thus, one could attempt to introduce additional aspects into the game that would make it closer to reality, such as maximizing income subject to the constraint of having a minimum number of hours of leisure time, or first investing profits in household durables, such as TVs or radios, before investing in more fishing nets.

Power relations

The outcomes of the participatory process can easily be influenced by power relations among the participants. These power relations may manifest along axes of social, racial, educational, or economic differences. Many of the game participants tended to play leadership roles in the community, some had greater economic advantage, and likely had above-average interests in educational activities. In each of the three villages, the group of participants included various members of local fishing cooperatives, including the presidents.

The initial group of participants influenced the evolution of the game, providing feedback about the aspects that they liked and found useful. This led to the use of accounting sheets, necessitating ease with reading and basic math calculations. If the target audience for the game had been a group with low levels of literacy, then it would have been critical to have non-literate participants involved in the early stages of the game creation.

In later games, in which more fishers were involved, it was clear that some participants were less comfortable with the accounting, and maybe even dissuaded from participating because it looked like too much work. However, once the games began, which often included quite a bit of laughing and animated discussion, onlookers often wanted to participate, and the players took on the role of teachers, showing them how to use the accounting sheets. In fact, when asked about the aspects that they most enjoyed about the game, many of the participants explained that they enjoyed the accounting sheets. One participant described their fishing practice as “brutal” since they don’t keep track of how much they catch or how much money they make, rarely save, and typically spend the money as it comes and goes. He explained that the accounting sheets allowed him to see the importance of keeping track of income flows.

However, not everyone appreciated the accounting sheets. An older fisherman, who had participated in almost all of the initial workshops, mentioned that he preferred the earlier versions of the game, in which the accounting was done by counting piles of beans, rather than using the accounting sheets, but he never expressed this in the group setting.

Using the game in other settings

While the participatory modeling process can be a useful mechanism for coming to a shared understanding of the benefits of potential development interventions, the process can easily be manipulated by development actors or other self-interested groups, both in positive and negative ways. Several community members in Orinoco expressed interest in using the game to explore the potential effectiveness of a well-run cooperative, acting as a buyer and seller of fish. Accounting sheets were designed to highlight the rules outlined by Nicaragua's cooperative guidelines and policies[39]. The wife of the intermediary buyer came to the first session to play the role of accountant. One of the main benefits that can come from a cooperative is the dividend that is paid to cooperative members, based upon their participation. During the first game, the participants discussed how the dividend could be divided, and how revenue would be used to pay for an accountant and workers to care for the ice, weigh fish, and deliver fish to processors. The most surprising outcome for the participants was the extra income that could be received as a dividend. Nicaraguan law for an official cooperative states that at most 58% of profits from the cooperative should be returned to each member, based upon the percentage of total fish that the member contributes. The fishers, the majority of whom were members of a local cooperative, were surprised to learn that the cooperative rules in the game were based upon the actual bylaws that all cooperatives are supposed to follow[40]. The game acted as a tool in which the participants seemed to come to a new understanding of the manner in which a properly run cooperative could benefit them.

In the methodology described in this paper, the facilitator plays a neutral role, supporting and challenging the information and ideas of the participants. However, one can easily imagine a situation where the facilitator might have a specific technology or policy that is being advanced. The facilitator can provide biased information, or easily focus the modeling process on targeted solutions. In addition, the participatory process could become truncated into a much shorter time period, increasing the probability that information discovery and recurring themes are not given adequate time to emerge. In order for the participatory modeling method to facilitate the discovery of long-term solutions, it is critical that the facilitator plays a conscientious, honest, and self-critical role, posing questions that facilitate a co-learning process.

The participatory modeling process results in a game that models a particular aspect of a community or group's reality. The game can serve as a learning or training tool for other groups, or in school settings. Over the course of the modeling workshops, several versions of the game were introduced to students in a number of settings, listed in the following table.

Institution	Context
URUCCAN University	Research methodologies course
URUCCAN University	Technical diploma in fisheries, taught within the community
BICU University	Administration course
Wawashang Agroforestry School	High school students
Kahka Creek Nature Reserve	A camp for at-risk elementary/high school students

[39]Nicaragua Law 449 outlines many of the mandates for operating a cooperative, including the payment of dividends: http://www.infocoop.gob.ni/

[40] The fact the cooperative members were not currently receiving dividends was not due to the fact that the dividends were being withheld, but that the cooperative was in a such a poor state of organization that it was not currently functioning as an intermediary buyer, purchasing fish from cooperative members and reselling to the fish processors, with a percent of the profits returned to the fishers as a dividend.

Table 14: List of various educational institutions where the game was played. BICU and URUCCAN are two universities based in Bluefields. Wawashang Agroforestry School and the Kahka Creek Nature Reserve are both run by a local NGO named FADCANIC.

At one university, the methodology was introduced to a class focused on research methods to students, preparing students for their final year research projects. The instructor thought that the process could be useful for students who were investigating decision-making processes and alternative strategies of rural farmers. The process was also shared with the manager of the largest fish processing plant in the city of Bluefields, who also taught natural resource administration courses at both universities. The game was played in two of his classes. Both instructors viewed the game-playing process as an innovative tool for understanding the details of local economies, and for helping students think more critically about various important issues for income generation using natural resources, ranging from sustainable resource management, to thinking through the different equipment costs and benefits.

I was also invited to spend two days with a group of adult students who were in the process of finishing a multi-year program to obtain a technical diploma in fishing. The students completed a survey before the game on the first day, and then completed the same survey on the second day, after playing the game for the second time. Although many of the students were from Orinoco and came from families with fishers, most were not active fishers themselves. The students' written feedback about the game was overwhelmingly positive, with one student replying that it was the most active class in his career, allowing him to get a good understanding of what occurs in real life[41]. However, their responses to quantitative questions regarding estimations of weekly or monthly income had very little variation before and after the game, suggesting that insufficient time may have been spent on the debriefing process[42].

The game was also played with a group of high school students at an agroforestry boarding school, as well as with a group of younger at-risk students who were participating in a multiple-week environmental education program in a nature reserve[43]. The younger students didn't have any difficulty understanding the rules or performing the calculations needed to complete the player accounting sheets. In both cases, many of the participants were not familiar with the fishing economy and reported that they enjoyed learning how the fishers catch fish, and the importance of sustainably managing resources.

The potential for computer simulation

Inspired by the companion modeling approach developed in France (Bousquet et al., 2005), I created an agent-based computer model of the game, using the freely available and user-friendly NetLogo programming environment. One of the attractive aspects of the computer model is that it allows for participants to quickly gain intuition about the sensitivity of outcomes, such as income, to a range of variables like fuel and fish prices, as well as household-level parameters like weekly expenditures or the number of fishing nets or partners in a boat.

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[41] The students are trained to read and write in Spanish, but their daily conversations are in English Creole. The student's written response was: "What I like that this game is the best active class that I ever get in my carier. And it make we see tha what realy happen in real life."

[42] See Peters and Vissers for a discussion of the importance of debriefing on learning (2004).

[43] Both the agroforestry school and the nature reserve are run by FADCANIC, a coastal NGO (http://www.fadcanic.org.ni)

Rather than spending several hours playing the board game in order to determine the effect of parameter changes, parameters can be varied with the click of a button, quickly revealing the sensitivities. The model creation was straightforward since it was an implementation of the game already developed by the participants, where rules constraining behavior became constraints within the model.

Whereas groups that are implementing the companion modeling process emphasize the importance of model creation with the participants, a deliberate choice was made to continue to focus on the evolution and playing of the board game, rather than complicate the process with the computer simulation. Instead, the intention was to demonstrate the model during the final meetings, in order to stimulate discussions. However, due to time constraints, the simulation was not shown to all groups.

A graphic of the user interface is shown in the figure below.

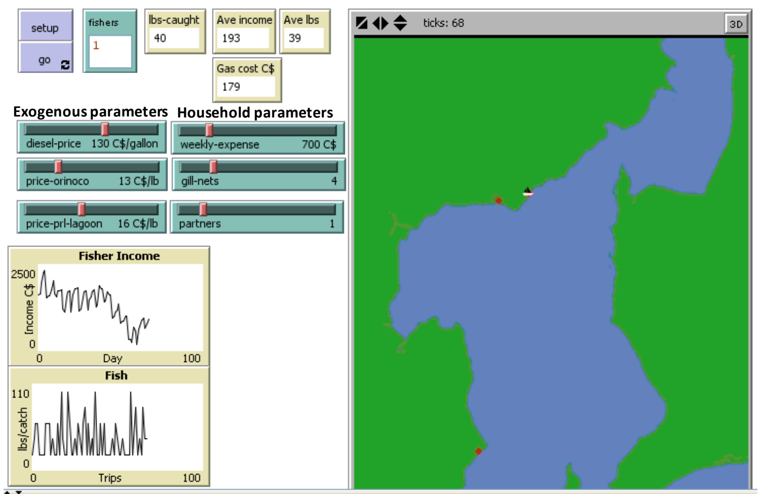

Figure 9: Agent-based simulation of the fishing game, using NetLogo

Even if the computer model is not introduced to the community members, it can play a valuable role for the facilitator during the process of the game creation. It can help the facilitator quickly gain an understanding of the impact of the primary game variables on participant goals, such as income gain. For example, the facilitator can quickly determine the sensitivity to the number of nets, gas prices, and weekly household expenses. From these insights the facilitator can then introduce appropriate scenarios into the board game simulations, helping participants develop similar intuition regarding the most important variable sensitivities.

Keeping it simple

In addition to fishing, catching shrimp also plays an important part of family income, and often coincides during the times when the snook fishing is less productive. Shrimp fishing also provides an opportunity for greater participation from both women and children, since it often takes place closer to shore and only requires a single throw-net. A number of participants suggested including shrimp fishing in the game because of the importance that it plays for household income, especially in the community of Pearl Lagoon.

Several of the gaming sessions focused on maximizing income, which naturally led to the purchase of more nets. However, it became clear that most fishermen were not just focused on maximizing income, supported by the fact that they didn't fish every day, and they placed importance on leisure time. Other aspects of community wellbeing could also be explored within the confines of the game. While the game creation and playing focused primarily on income (which was motivated by the participants), the game could also be used to explore other aspects of their society or culture that correlates to their wellbeing. For example, players could play to maximize income, subject to the constraint of maintaining some chosen amount of leisure time, or earning enough money to buy a television or a refrigerator.

In order to highlight annual earnings, and the potential for savings, a calculation sheet was introduced during the last game playing session in two of the communities. The idea was that, based upon the weekly earnings calculated during the game, the participants could then estimate monthly earnings, and then scale these to different months, based on historical records of seasonal fish catches. However, the additional calculations proved to be more than the participants were prepared to undertake, suggesting that more time was needed, or a prior conversation to motivate the calculation.

It is important to maintain a certain level of simplicity in the game, so that it can be easily learned by a range of ages and abilities, be fun to play, and still allow participants to gain insights. The facilitator must also evaluate the target group of the game. If one group of participants will be playing the game for a number of sessions, this introduces the opportunity to introduce additional complications into the game each time. However, if the game is intended to be played only once or twice, with a wide range of participants, then simplicity is important.

Conclusions

We live in an era of persistent material poverty, deepening inequality, and limited capital earmarked for institution-led development projects. Development agendas are heavily influenced by neoliberal paradigms, emphasizing decentralization and (limited) forms of participatory involvement in the design of projects. Development actors frequently target funding for interventions that can have a measureable impact, rarely providing funds for exploratory studies or capacity training. Project design is often left to local or foreign experts, almost always external to the beneficiary communities. This dominant development paradigm hampers the potential for the design of technically, culturally, and economically sustainable projects.

Participatory modeling provides a medium through which development actors can play the role of a neutral facilitator, learning alongside stakeholders in order to come to a shared understanding of what interventions meet the interests of stakeholders and are culturally viable. Participatory modeling appears to be a valuable learning method that can be implemented by instructors or various workshop facilitators, allowing participants to challenge and expand their perceptions of their reality, and gain intuition regarding the potential impacts that may result from a policy or technology intervention. Participatory modeling focuses on the creation and playing of a game, resulting in a focus on relationships and processes. The greater space there is to allow for the stages of the game creation to follow an organic evolution, the greater likelihood there will be for learning. Early on, I discovered that different groups had different interests and dynamics, calling for a modification of my initial timeline. The process must be appropriate for the interest, capacity, and timeline of the target group. Based on the experiences in Nicaragua, I have summarized the primary process steps:

1. The participatory modeling process may be helpful for a community that wants to better understand potential solutions to a problem, or outcomes to a proposed project. Problems or projects that lend themselves best to a participatory modeling process are those that contain a certain level of complexity, with dynamics evolving over time and space. In order for community members to have a better idea of what the game creation and playing may entail, it will be helpful to introduce simple visual examples during initial meetings. These could be photographs, or a first attempt at a prototype, which could be nothing more than a simple map and some playing pieces.
2. The bulk of the meetings will be focused on game development. This will entail the facilitator playing a key role as questioner, and working with community members to determine the important parameters and constraints that define the problem of interest. Investigation will go beyond the game sessions, and could take the form of participant observation, formal and informal interviews, or surveys.
3. Once the framework of the game has become well-defined and participants are comfortable with its representation of their reality, the facilitator can begin to introduce new levels of complication into the game, or change constraints that will push the participants to think critically about alternative decisions or realities. This provides the opportunity for participants to explore the costs and benefits of proposals for new development policies or projects.
4. Depending on the goals of the modeling process and interest of the participants, there may be additional benefit by introducing a computer simulation of the game, as commonly used with the companion modeling process.
5. After the game has been created, the potential exists for it to be used as a training or teaching tool in various contexts, allowing students, policy makers, or community groups the opportunity to come to a more detailed understanding of aspects of another group's reality.

It is clear that the participants of the research enjoyed the participatory modeling process and gained some insights into the pros and cons of several technology interventions, as well as planning benefits derived from keeping track of their costs and earning potential. However, it will be useful to conduct future investigations that attempt a more quantitative understanding of how the game impacts knowledge and perceptions. This will likely require surveys or tests, before and following the intervention, in comparison to a control group that uses more conventional learning approaches.

Understanding whether or not insights from the game process led to behavior changes in the participants was beyond the scope of the study. As both Freire and Fals Borda argue, transformative learning requires both reflection and action. It is clear that game playing provides a natural medium for facilitating problem-posing learning, but longer-term observation and a controlled study would be needed to determine whether or not participatory learning may actually catalyze community members to change behaviors in their daily lives.

It also remains to be seen whether or not NGOs, governments, and development institutions can acquire time and funding to embark on agenda-neutral learning processes. The benefit would be the formation of interventions that support a locally informed development agenda with the potential to meet expectations of community stakeholders, leading to the creation of more economically, socially, and environmentally sustainable projects.

The participatory modeling approach would certainly have benefited the project designs that were included within the aborted CDCC Clean Energy and Water Project, described in the introduction to the dissertation. The modeling of the fishing economy could have been complemented with another model related to the carpentry project, modeling the lumbering, production of furniture, and sales. Such a process would almost certainly have resulted in the conclusion that providing more hours of electricity to the workshop would help, but many other factors would be necessary for such an intervention to result in increased income and improved livelihoods. In the next chapter, the insights from the game will be placed within the context of development projects that have targeted the artisanal fishing economy.

Li describes the indefatigable will of development agents to improve their processes, and improve on improvements (Li, 2007, p. 274). She remains skeptical of the potential of such impetuses, when external marginalizing forces, especially political ones, are left unattended. In the next chapter I will place the participatory modeling process within local and non-local political frameworks, and see if and how a tool might provide local benefit, given political and social constraints, trying to understand how the tool may function as a means of moderating between policy and practice.

Chapter 4 The role of information and communication in development

Introduction

In this chapter I will explore the link between the discovery and communication of information, development, and participatory modeling, in the context of the artisanal fishing economy. The artisanal fishing sector on Nicaragua's southern Atlantic Coast has been the focus of decades of ineffective development projects, aimed primarily at increasing fisher income. Most of these projects emphasized improving catch capacity of fishers through increased access to finance and equipment, organizing fishers into groups or cooperatives, as well as focusing on resource management. These projects have been primarily top-down, driven by non-local political and economic agendas, with few of the projects resulting in lasting impacts.

While there are many new and evolving methods and best practices for incorporating decentralized planning and participant input, the non-linear nature of social and economic development tends to produce outcomes that are not readily foreseen (Rihani, 2002). Many methods are ineffective at incorporating aspects of social, economic, or political complexity. I will show how particular areas of knowledge, methods of discovery, and manners for incorporating new information into ongoing projects, may help improve process outcomes.

An underlying theme throughout this dissertation has been the role of communicating information in relation to policies and practice of institution-led development. In Chapter 1 I demonstrated how metrics create a simplified representation of local realities that can lead to projects which may have inequitable outcomes. Metrics, however, can be important in project planning and evaluation. In the planning stages, they are often used to simplify problems so that straightforward projects can be designed that will impact the chosen metric (though not necessarily resolving the underlying problem).

Simplifying the information content of complicated problems into something that can be addressed directly through the organization or construction of physical, social, or economic structures is the typical manner in which institution-led development is planned. This manner of technical deconstruction has the potential to bracket processes into mechanistic forms that often ignore social or political aspects fundamental to project sustainability (Li, 2007, p. 7). The planning process often leads to technical solutions that emerge from a black box controlled by experts, with the details of the black box often remaining opaque to the stakeholders.

However, Li stops short of exploring the benefits of technical rendering, especially when it is put in the hands of the targeted beneficiaries themselves. In this chapter I demonstrate that technical simplifications can be an empowering form of learning, providing insight into development projects. When the detailed logistics and implications of a proposed project are made visible to a group of stakeholders, they are in a better position to evaluate its desirability, as well as its strengths and weaknesses. Detailing causal processes can help those without power develop new aspirations, alter decisions, and uncover processes of control.

While the investigation was not of sufficient duration or scope to begin to understand whether information discovery during the modeling process led to behavior change, it opened the possibility for the development of new aspirations. Appadurai (2004) and Ray (2006) argue that aspirations can play key roles in catalyzing change within marginalized communities. Appadurai describes the "capacity to aspire" as a navigational capacity, based on personal or shared experiences, to move towards a desired end (Appadurai, 2004, p. 69). Ray hypothesizes that once an "aspiration window" has been opened, in which a group can envision an alternative reality with feasible steps to get there, there is greater potential for action to be taken (Ray, 2006, p. 412). Depending on lived experiences to form the basis of a range of alternative, imagined, futures will necessarily be limiting, especially in small, rural populations where the range of life experiences may not be diverse. Participatory modeling allows the potential for participants to develop detailed, shared visions, creating a medium to open many new aspiration windows.

Participatory modeling creates a process for stakeholders to not only peer inside the expert's black box, but explore their own ideas and potential solutions, looking at processes as well as potential outcomes. Technical rendering is done by the potential beneficiaries, as they attempt to simplify reality in order to understand the most critical dynamics of a particular problem. The process can also focus on political and social aspects of a problem and help participants better understand inter-relationships of the modeled system. More nuanced metrics, such as wellbeing, can be explored, making explicit the necessary capabilities that may be needed for projects to produce locally desired outcomes. New aspirations may motivate participants to demand better project designs. Development interventions tend to be outcome oriented, focusing on potential technical projects and what they *should* produce. In contrast, participatory modeling focuses on processes, uncovering insights related to the causal mechanisms that may lead to particular outcomes, embedded within a complex system. It is through the process of simplifying reality that it also becomes more intelligible.

Fishing and local livelihoods

As already highlighted in Chapters 2 and 3, fishing plays an important part in livelihood and identity for a number of communities on the Atlantic Coast. Many households participate in fishing or catching shrimp, either at the subsistence or monetary level. In the communities of Orinoco and Marshall Point, artisanal fishing comprises the largest single source of income in the community, followed by nursing and teaching, and sales from small shops, remittances, and agriculture (Casillas et al., 2010, p. 8). Over 50% of community members in Orinoco receive some form of income from fishing. However, due to the capital cost of nets, motors, and boats, there are likely closer to 30% of households that are actively involved in the monetary economy of the fishing sector[44]. Among the households involved in fishing, fishers often participate in other economic sectors, such as farming, operating small stores, or even being pastors.

Within the past several decades, communities have become increasingly dependent on the need for income. In Marshall Point and Orinoco, over 90% of households currently have electricity access and pay monthly bills that range from 5 to 25 USD[45]. Most households have a cell phone, TV, and an increasing number of houses have small satellites for their TVs, which require a monthly payment of close to 20 USD. While 64% of households in Orinoco have some level of agricultural production, over half of the average household budget is devoted to the purchase of food, followed by energy and transportation (Casillas et al., 2010, p. 11). Having some form of monetary income plays a necessary role for almost all households.

[44] This is based on the estimation of about 20 households that have gill nets, and each boat typically having 2 fishers, which may, at most comprise 40 households if no two fishers come from the same household. 40 out of 130 households is 30%.

[45] Based on the author's analysis of monthly electricity bills in Orinoco and Marshall Point, 2009-2010.

During the rainy months, between May and January, the scale fish tend to be most populous and active, and gill nets are the most effective equipment. During the peak months from June to August, a pair of fishers with sufficient equipment can earn as much as several hundred dollars in a single day, in a region where a typical wage for a day of labor is 5 USD. While fishing plays an important part of the livelihoods in the twelve communities in the Pearl Lagoon basin, data from 1997 imply that 25% of the population may be involved part-time, and as little as 1.5% full time[46].

There is an abundance of published work documenting the perception of the decline of productivity in Pearl Lagoon (Christie, 1999; Christie et al., 2000; Hostetler, 2006) and other coastal communities, confirmed by the author's own interviews. However, the fish sold to national markets has remained steady over the past decade (INPESCA, 2011, p. 12), likely resulting from increased catch per unit of effort. This is most likely due to increased use of nets, offsetting declining fish populations[47].

Rendering technical and the capacity to aspire: the case of cooperatives

Fishers often argue that they are constrained by difficulties accessing finance, equipment, and better fish prices. Each of these constraints is, of course, a technical solution meant to address the metric of increased income. In order to better understand the social and political contexts as well as their interdependencies, I will describe the role of fishing cooperatives, and the insights gained through participatory modeling by many cooperative members.

A well managed fishing cooperative has the potential to alleviate several of the main challenges that are identified by fishers. There are currently nine registered fishing cooperatives[48] in the Pearl Lagoon municipality. The primary motivation for most fishermen to join a cooperative is to gain access to loans or equipment from the government. Many cooperatives tend to suffer from poor organization and mismanagement of funds, and rarely function as an actual member-owned business. A cooperative-owned business would open the possibility for members to receive better prices, in addition to a dividend. However, my research indicates that many fishers aren't even aware of the forms of management and potential benefits that could result from a cooperative-owned business, which is primarily a result of inadequate communication. Before reviewing how the participatory modeling process helped fishers explore the dynamics of their fishing economy and the costs and benefits of proposed projects, I will briefly describe the development trends that have impacted fishers in Pearl Lagoon, since the 1980s.

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[46] The Pearl Lagoon municipality was comprised of 12 villages with an estimated population of 8,800 in 2005 (Beer & Vanegas, 2007). Christie (2000, p. 33) cites several sources estimating 100 full-time fishers (closer to 500 part time) in 1997. Tax information from the mayor's office of Pearl Lagoon, between May 2010 to May 2011 indicate 224,829 lbs (163,511 USD at 0.72 USD/lb) of snook and 33,451 lbs (10,643 USD at 0.31 USD/lb) of catfish were sold. Assuming this was spread among 100 fishers (or 7% of the total households assuming an average of 6 persons per household (1,467 households in Pearl Lagoon)), it would give an annual income of 1,741 USD/year, or 4.80 $/day. If it were spread among 500 fishers (households) it would provide 0.95 $/day for 35% of the households.

[47] This is supported by unpublished fish catch data collected by a researcher from the University of Michigan (K. Stevens, personal communication, April2012).

[48] Documentation on the registration of artisanal fishing cooperatives can be found on the government's website: http://www.inpesca.gob.ni.

Recent history of fishing cooperatives

The seafood industry, primarily run by Somoza enterprises, focusing on shrimp and lobster, collapsed following the Sandinista revolution[49]. The Sandinistas nationalized Somoza and foreign owned companies, focusing on domestic consumption of fish as well as exports. Most of their efforts targeted industry, with Jentoft noting that in the early 1980s, 90% of expenditures on equipment imports for fisheries were used for industry (1986a, p. 354).

During the early years of the Sandinista government, many economic development projects were state managed, based on the import of technology and division of labor. Instead of using labor intensive low-tech processing facilities, the emphasis was on sophistication in the processing plant, leaving the primary producers of input with little technical advances, and often receiving low prices for their goods (Wall, 1993, p. 11).

The goal of organizing fishing cooperatives was to improve the livelihoods of rural producers, as well as increase fish sold on domestic markets (Jentoft, 1986a, p. 354). Rural fishers lacked modern equipment, which was primarily channeled through cooperatives. In the Pearl Lagoon basin, the Sandinistas needed to send boats to purchase the catches from the rural cooperatives, as well as provide ice, because the cost of transportation, relative to fish prices, made delivery to processors in the larger towns unprofitable (Christie et al., 2000, pp. 46–47). The scale of the impact of cooperatives was also limited. In the early 1980s, Jentoft (1986a, p. 354) estimated that 500 fishers were participating nationwide, among an estimated population of 10 000 fishers, which amounts to only 5% of the total fishing population[50]. When the Sandinistas left office in 1990, the artisanal fishing economy on the Atlantic Coast was still in a state of dysfunction[51], likely hindered by a top-down approach and weak markets, amidst a faltering economy.

The departure of the Sandinista government in the 1990s led to the privatization of the state owned fishing companies. The neoliberal government granted concessions to foreign companies as it sold its national holdings[52], resulting in increasing rates of extraction, with capital concentrating in fewer pockets. The privatization of one fishing company resulted in a 90% drop in employment as workers were reduced from 600 to 60 (Hostetler, 1998, p. 47). However, nationwide revenue from fishing exports increased from 10 million USD in 1990 to 80 million USD by 1995 (Hostetler, 1998, p. 47). The penetration of markets into communities in the Pearl Lagoon municipality resulted in a number of consequences (Hostetler, 1998). An increased focus on fishing came at the expense of farming, leading to a decline in fish stocks,

[49] Records indicate 3.3 million pounds of shrimp were exported in 1975, compared to 0.5 million pounds in 1981 (Jentoft, 1986a, p. 353).

[50] A Creole speaker who ran one of the biggest cooperatives out of Bluefields during the 1980s said that there is an inherent mistrust among 'his people' and that they have an individual mentality, which doesn't lend itself to the well functioning of cooperatives (Personal communication, August 2010).

[51] Jentoft presents a case study of an anonymous community in which INPESCA, in cooperation with a Norwegian development agency, collaborated and developed a well funded "experiment" in the mid 1980s in Nicaragua. They focused on organizing and equipping several cooperatives, and building a fish processing plant with its own fleet of fishing boats. With optimism that the economic development project would attract a new populace, they also had designs for a housing project. He notes that is was seen as an experiment in terms of organization and management. Due to the anonymity of the project, the outcome is unknown.

[52] In 2007 there were 8 fish processors on the Atlantic Coast, 4 in the RAAN and 4 in the RAAS (INPESCA, 2007, p. 31).

fish being sold within communities as opposed to being given away or shared, and a decreased participation by women due to the use of more expensive equipment.

Between 1994 and 2001, the Dutch and Nicaraguan governments partnered to run a fisheries development program in the Pearl Lagoon basin, referred to by its acronym, DIPAL[53]. The stated focus of the project was to help artisanal fishers with participatory resource management and increase access to national and international markets (Perez Moreno & Eijs, 2002). Its implementation was perceived by fishers as top-down (Christie, 1999, p. 403). DIPAL organized "serious" fishers into solidarity groups and provided them with small amounts of funding (González, 2011b, p. 301). DIPAL also gave loans to processing companies to be used to purchase and then lease equipment to the fishers (Christie, 1999, p. 406). Fishers would then be obligated to sell their catch to the lending company, with 30-40% of their earnings going towards the equipment charges (Christie, 1999, p. 406). The project ended in 2001, resulting in the disbandment of the solidarity groups and the end of the equipment leasing programs. One fisher from Pearl Lagoon said the DIPAL project was significant only for its million dollar budget, most of which went into administration and research, with nothing more than some equipment finding its way to the fishers (S. McCoy, personal communication, August 4, 2011)[54].

In 2006, the Sandinista government was voted back into power. While the government has increased funding to social programs and maintained a populist rhetoric, its policies remain in line with the global neoliberal agenda, continuing to focus on decentralization of governance and an increased role of markets. However, the government renewed its project of forming small producer cooperatives. The Sandinista's current program for fishing cooperatives on the Atlantic Coast is based on "re-activating" rural fishing economies. The project is focused on registering and providing equipment to cooperatives[55]. After a group of community members has fulfilled the registration requirements for a cooperative, it eventually receives start-up capital from the government, typically on the order of 100,000 USD, which is then distributed among as many as forty cooperative members, in the form of equipment[56]. According to the promoter of the cooperative program, the distributed funds do not need to be repaid, and are meant to serve as activation capital (E. Wilshire, personal communication, November 24, 2011). The program has the viewpoint that most rural community members are fishers, even if they aren't currently involved in the monetary economy, and deserve the opportunity to access equipment that can improve their opportunities.

[53] 3 year pilot stage for DIPAL received 1,852,486 USD (1994 dollars) from the Dutch government and 152,000 from Nicaraguan government (Christie, 1999, p. 407)

[54] See Sequeira (2002) for a more optimistic view of the DIPAL project.

[55] At the close of 2011, according to statistics found on http://www.inpesca.gob.ni, there were 49 registered fishing cooperatives, 34 on the Atlantic Coast. The total number of members includes 1258 males (74%), and 448 females (26%).

[56] Early in the process funds were distributed directly to cooperatives. Due to mismanagement, cooperative members now select equipment from pre-approved vendors and then receive funds to purchase equipment. The funds are given by the government to CARUNA, the financial organization that has distributed development funds originating within the Bolivarian Alternatives for the Americas (ALBA)

The cooperative model and government intent

The government is not allocating its available resources in a manner that is likely to support the successful emergence of well run cooperatives[57]. In the years 2010 and 2011, the government allocated a budget of 3.9 million USD for artisanal fishing, 70% of which was focused in the southern autonomous region (E. Wilshire, personal communication, November 24, 2011)[58]. However, even with a budget in the millions, the promoter of the program stated that he alone was in charge of organizing the cooperatives, administering the funds, and providing the cooperative members with forty hours of training on topics ranging from financial management to value-added activities and sustainable resource management[59]. Over the past several decades, many community members have accumulated stacks of workbooks and participated in numerous workshops on managing their resources or running a cooperative. However, there is a clear lack of knowledge transfer, as evidenced by confusion over management of finances or a shared understanding of running a cooperative as a member-owned business that pays dividends to its members.

Some community members suspect that organizing the cooperatives may have more to do with political payback than actually strengthening local economies. The head of the cooperative in Marshall Point explained that his group has been waiting for the disbursement of their loan for three years, while other groups, organized much later, but having stronger affiliations to the Sandinista party, have already received their funds. He believes that being a member of the opposing political party has slowed the bureaucratic process of delivering funds to his community's cooperative. It is possible that the cooperative project serves the government as a vehicle for diverting equipment and funds towards rural communities, cultivating and rewarding political support.

The motivation and logic of the current project approach remains opaque, both to observers and project beneficiaries. There is poor communication regarding the financial loans, the time needed for processing the loan, and the benefits of organizing the cooperative as a buyer and seller of fish. Even the terms of the disbursed funds and equipment are not well understood within the communities. There is still widespread confusion among the cooperative

[57] Further north of Pearl Lagoon, there is a cacao cooperative, UNCRISPROCA, composed of about 150 farmers on the Rio Grande River. The project is supported by the NGO called FADCANIC, as well as a multilateral donor. FADCANIC has been working with the cooperative for ten years, and has taken an integrated approach, which includes adult education classes in the communities of the cooperative members. The director of the cooperative, a community member who benefitted from the adult education classes, has also been running the cooperative for ten years. Most of the cooperative farmers have been certified organic, and the cooperative sells cacao to an international fair trade market. However, the cooperative still requires external funding, demonstrating the time and resources that may be needed to create a sustainable cooperative.

[58] The promoter for the cooperative development mentioned that in 2010, a total budget of 76.5 million USD was allocated to development on the Atlantic Coast. 17.5 million USD was initially requested for development of the artisanal fishing , but wasn't approved in the national assembly (E. Wilshire, personal communication, November 24, 2011).

[59] According to the government's website on cooperatives (http://www.infocoop.gob.ni), among a total of 45 staff members at the national level for cooperatives in all economic sectors, 16 are dedicated to registration, 15 to financial administration, and only 3 related to education and capacity training.

members and leaders as to whether or not distributed money needs to be paid back[60]. The possibility for free equipment has resulted in membership ballooning beyond the most active fishers and resentment towards some cooperative members who received equipment, yet do not utilize the equipment or have sold it.

However, the technical approach of merely providing equipment to fishers certainly provides benefit. In contrast to the Pacific Coast, there are very few financing options for rural communities on the Atlantic Coast. To make matters worse, the land in most of the villages is communal and can't be used as collateral for bank loans. It is very difficult for fishers to access loans from traditional banks to buy equipment, making equipment received through the cooperatives a boon.

If the policy of the government is to re-activate village fishers through the creation of cooperative-owned fishing businesses that are competitive on local markets, providing access to equipment and increasing prices received for fish, then there is a large gap between policy and practice, which hasn't been overcome with 30 years of projects. However, the primary motivation for the government may be to disburse equipment to politically relevant constituencies at strategic times, in which case, its approach may be an adequate technical solution.

Although participatory modeling with fisher groups didn't provide insights into the government's motivation for its current projects, it did provide fishers the opportunity to access new information and take a more quantitative look at the costs and benefits of various technical approaches, creating incentives for members to demand greater accountability from development projects.

Cooperatives and participatory modeling

Several months into the participatory modeling process, one of the intermediary buyers in Orinoco expressed interest in using the game to explore how a cooperative could function as a buyer and seller of fish[61]. He mentioned that he would welcome the opportunity to move out of the buying and selling business, and instead concentrate on fishing. He believed that having a core group of the "more serious fishers" as members would be necessary for the success of a cooperatively run business, and wanted to organize a small group of fishers to participate in the game playing.

I designed accounting sheets to comply with the financial management rules stipulated by Nicaragua's policies for cooperatives[62]. The wife of the intermediary came to the first session to play the role of accountant, with a group of six fishers. The most surprising outcome for the participants was the extra income received in the form of a dividend. Nicaraguan law for a registered cooperative states that at most 58% of profits from the cooperative should be

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[60] One cooperative member in Orinoco mentioned that at the beginning recipients were willing to repay their loans to the cooperative, but due to clear mismanagement of the funds they lost faith in making payments to the local organizing board and have since ceased to repay the loan (Personal communication, 2011).

[61] When asked if he was bothered by the prospect that a cooperative that was actively purchasing fish would compete with his business, he said that he would rather devote his time to fishing instead of managing the buying (Personal communication, 2011).

[62] Nicaragua Law 449 outlines many of the mandates for operating a cooperative, including the payment of dividends: http://www.infocoop.gob.ni/

returned to each member, based upon the percentage of total fish that each member contributes. The fishers, the majority of whom were members of a local cooperative, were surprised to learn that the cooperative rules in the game were based upon the actual bylaws that all cooperative-run businesses are supposed to follow. This was due to the fact that none of the recent fishing cooperatives had functioned as businesses. Instead the cooperatives had only served to distribute equipment or loans.

Through the game, the fishers gained insight into the details of fiscal and organizational management, which decades of experience with dysfunctional cooperatives had not provided. In the community of Pearl Lagoon, the head of one of the cooperatives was excited to learn how accounting for a cooperative-owned business could be done, and a second session was arranged to reinforce how to calculate the payback of the dividend to the members.

The participatory modeling provided fishers with a better understanding of how their relationship with the cooperative might be impacted if it were run as a buyer and seller of fish. There has been a lot of experience, much of it unsuccessful, regarding the operation of fishing cooperatives, both in the developed and developing world (Jentoft, 1986b). A strong sense of individualism has been shown to be prevalent among small-scale fishers. Poggie cites a number of case studies from around the world in which fishers place a high importance on individualism and self reliance (1980). In one case study of a successful cooperative, it was found to be critical that the cooperative managers didn't place any constraints on fisher behavior (Poggie Jr, 1980). The system of dividends is an appropriate solution for individuals who place a high value on free time and labor independence, allowing them to maintain their own work schedule, but rewarding them with additional incentives to fish.

At the end of the final participatory modeling workshop, participants filled out surveys relating to a number of subjectively defined aspects of wellbeing. They completed a satisfaction with life survey[63], as well as questions about other aspects of their lives, priorities, personal relations, environment, leisure activities, and autonomy. Of note were the results that working for oneself and maintaining good neighbor relations were prioritized above increased income by most participants in Orinoco and Marshall Point, suggesting that any constraints that a cooperative business might place upon independence, leisure time, and neighbor relations would be quite important. The game provided the possibility for fishers to see that the cooperative could be run in a way that wouldn't constrain their behavior, and could provide them with extra income if it were well managed and had a sufficient number of members.

Due to the need to limit the scope of the game, participatory modeling can only focus on some attributes within the game and necessarily needs to discard others. Fully understanding the viability of a cooperative business would require investigation into a number of additional

[63] There were a number of methodological problems, primarily deriving from the challenge of keeping the participants focused following the game playing, resulting in the surveys filled out without any privacy in a group atmosphere. The questionnaires were administered to the communities of Orinoco, Marshall Point, and Pearl Lagoon, resulting in the completion of 8, 8, and 3, forms, respectively. The Satisfaction With Life Scale (SWLS) measures overall happiness (Diener, Emmons, Larsen, & Griffin, 1985).The average satisfaction with life scores for the three communities were 24, 28, and 28, respectively. A score of 25-29 reflects a high score (http://internal.psychology.illinois.edu/~ediener/Documents/Understanding%20SWLS%20Scores.pdf). Due to the limited number of respondents and group format used to complete the forms, the answers can, at most, be viewed as qualitative indications regarding general preferences.

technical details, besides just understanding the mechanism by which the dividend is paid. The operation of a successful cooperative, just like an intermediary's business, requires administrators with logistical and accounting skills. The manager of the largest fish processer in Bluefields explained that intermediaries are actually in the transport business. Success involves owning capital assets to store and transport fish. If one wants to turn a reasonable profit, this requires figuring out how to have those assets constantly productive, even when the fish aren't in season. As a point of evidence, the one intermediary in Pearl Lagoon used to be exclusively in the transport business.

The government's provision of equipment seems to have satisfied fishers' expectations, as they have tacitly accepted its approach to organizing cooperatives. However, participatory modeling facilitated an increased understanding of specific details regarding how a cooperatively-owned fishing business can be run. The game provided a framework for helping fishers develop intuition regarding how a dividend is sensitive to price, quantity of fish caught, and the number of cooperative members[64]. As well, the game could allow fishers to discuss what impacts a successful cooperative may have on the other intermediary buyers within the community[65]. Hirschman argues that when constituents of an institution's services, whether customers or citizens, deem its service unsatisfactory, they may be motivated to leave, protest, or simply hope for change; exit, voice, and loyalty, in his words (Hirschman, 1970). Without an understanding of viable alternatives, a constituency may be satisfied with the status quo, but as Li points out, hegemony can be a "a terrain of struggle" (1999, p. 316). If new information inspires a viable and accessible alternative, the possibility for change becomes greater, and could lead to fishers demanding more training and investment in the creation of cooperatively-run businesses.

Ice production: exploring the parameters of technical solutions

Ice plays a fundamental role in the artisanal fishing economy, keeping fish from deteriorating. Ice also allows fishers to stay in the lagoon multiple days, saving on daily costs of gasoline for transportation, as well as allowing middlemen to aggregate catches within the community before delivering to the producers. Most of the main fish processors in Bluefields provide ice freely to fishers, with the understanding that all fish will be sold to them in return, giving them a significant amount of control over the fishers. Local ice production within the communities would reduce the logistics and planning needed to store ice, as well as provide fishers the opportunity to sell to whomever they choose.

However, local ice production is neither a necessary nor sufficient condition for increased income, and is dependent on a number of additional capabilities. It would simplify logistics and planning for both the middlemen and fishers, which doesn't necessarily translate into increased income. The primary monetary benefit from ice production would likely come when catches

[64] While these relationships could easily be determined analytically, and this may be appropriate for a given group of participants, an important aspect of the game is that understanding can be developed through experience of changing parameters within the game, making it more accessible to participants who may not be as familiar with the use of mathematical equations.

[65] During the game playing process, the two intermediaries within Orinoco were invited to participate in the game. While one of them never joined the game, the other one only participated after proposing the game be used to model a well-run cooperative.

from multiple fishers are aggregated and sold to buyers who are paying a better price. This requires a certain level of organization among the fishers, or a well-functioning cooperative. If there were a well organized and managed cooperative, then it seems much more likely that the ice machine would be maintained and managed with increased potential for selling to better-paying buyers.

In the artisanal fishing sector, there is, perhaps, no better embodiment of the allure of technical solutions than the local production of ice. The outcome is easy to envision, imagining a building where one walks in, receives ice, and goes fishing. In contrast, a well-functioning cooperative is more abstract, raising questions regarding how it might be organized, restrict autonomy, or lead to monetary benefits. The conceptualization of an ice machine by most fishers seems to focus on *outcome*, leaving the devil in the details regarding capacities and processes needed to maintain local ice production. The capabilities required to upkeep technical solutions are often overlooked or misunderstood. In addition, ice production would likely become the object of both local and non-local struggle, with the most marginalized fighting for access and the more powerful fighting for control. As the intermediary in Pearl Lagoon stated, "Ice is the weapon."

The aspiration for local ice production has manifested in overwhelming demand by local fishers. The government and NGOs have responded by putting ice plants into economic development projects, both unwittingly and willfully ignoring the management and financial capabilities necessary to maintain an ice plant over the long term[66]. In 2011, despite disappearing funds and management troubles, a small ice machine was installed in the community of Orinoco, under the management of one of the cooperatives. The machine had the capacity to produce 1 000 kg of ice in 24 hours, half the capacity that the fishers wanted. While they have not yet had any technical problems, social and financial problems are already emerging. Orinoco's diesel powered electric grid, which only operates for 12 hours each day, allows the ice machine to produce a maximum of only 500 kg of ice per day. The cooperative has already had trouble paying the electricity bill, which is three times more expensive than electricity from the central grid in Bluefields[67]. The manager of the ice machine, who is also a cooperative member and a middleman, said that the machine does not produce sufficient ice to meet the fisher demands; they still need to bring ice from Bluefields[68]. One of the fishers complained that the manager prioritizes his family fishing business and has not made the ice accessible to cooperative members.

[66] The CDCC Clean Energy and Water Project proposed having renewable energy generation capacity to support ice generation. In 2011 a local NGO proposed ice production in the community of Monkey Point to meet the demands of leaders within the community. In 2012 the government committed to providing a diesel generator and ice plant to the same community, as part of the re-activation of fisher cooperatives (Various sources, personal communication, 2011).

[67] The cooperative just recently petitioned the electric company for a more favorable tariff, and was given a special tariff below that of any other paying customers in the community, which signifies that the electric company is now heavily subsidizing ice production, from which only a small number of fishers benefit (ENEL staff, personal communication, August 2011).

[68] The middleman and cooperative member who is managing the ice machine thought having two ice machines that produce 2,500 kg perday would be sufficient for all of the neighboring communities in the Lagoon (E. Gonzalez, personal communication, August 4, 2011).

There are a number of aspects that are needed for an ice machine to lead to successful outcomes for a community. These include the financial and technical challenges of maintaining an ice machine, managing access to the ice, and understanding how ice actually links to greater income capture for local fishers. Participatory modeling provides an excellent framework for exploring interactions between people, technology, and environments. In the fishing game, as in real life, fishers had the opportunity to purchase plastic ice boxes that could be used in their boats to store fish. In most of the sessions, the game was played with the assumption that ice was made available by the processors or intermediaries, reflecting reality. In the game, fishers purchased coolers if they had the capital, and spent multiple days in the lagoon. The intermediaries are left to deal with the logistics for ensuring that a sufficient supply of ice received from the processors meets fishers demand. Although not carried out, it would have been an informative session to restrict ice supply and calculate lost revenue due to spoiled fish and increased transport costs needed to bring daily catches to buyers.

During the participatory modeling process, the participants discussed estimations of the capital and operation costs for running an ice machine. One of the challenges is that the invested capital does not remain productive throughout the year, since peak demand for ice only occurs with the seasonal productivity of the fish. The fishers discussed the advantage of owning a large boat with a built-in cooler that could transport sufficient ice between the community and the buyers, and would be owned by the cooperative. Such a solution has existed at several times in the past (Hostetler, 1998, p. 66), and companies and entrepreneurs bring bigger boats up during times of peak catches. During the low season the boat would be able to continue to earn revenue in the transport business, which is the same solution used by the middleman in Pearl Lagoon. The success of such an operation would be dependent upon sufficient financial management and logistic skills, as well as having capital for maintaining the boat, necessitating a well managed cooperative.

Playing the fishing game allows for exploring how the use of ice can reduce transportation costs or provides greater access to buyers, but it doesn't necessarily reveal the details of owning and operating the ice machine. Fishers may underestimate the logistical and technical challenges needed to maintain local ice production, emphasizing the need for these costs to be researched and discussed among participants. The manager of Caribesa, the largest fish processor in Bluefields, was confident that an ice machine would have a short lifetime in any rural community, mentioning that time and again he has seen ice machines become the Achilles heels for small companies, requiring capital for parts and expertise for maintenance. He felt certain that ice production, by necessity, should be left in the hands of bigger companies (J. Montoya, personal communication, September 20, 2011). The middleman in Pearl Lagoon thought that ice machines could be quite robust and had investigated buying one, but due to cost and technical complication he decided against it. Of course, one could be skeptical of the intentions of both the middleman and buyer for arguing against the feasibility of installing an ice machine in the communities. Having a monopoly on ice production gives them control over the artisanal fishers. There are now buyers coming from Managua to Pearl Lagoon, as well as buyers in nearby Rama. Some of them offer better prices than the processors in Bluefields, and the price per pound increases when catch sizes reach several thousand pounds, which would be impossible to meet without having ice for aggregating catches from numerous fishers over several days.

In cases where information is lacking or its veracity is questionable, it becomes important for participants to explore the sensitivity of outcomes to a range of possible parameters for a given policy or project. Sometimes fishers and the model facilitators may not have experience with a certain technology, unaware of the technical challenges. By introducing a range of different parameters, such as operation costs, lifetimes, or ownership models, participants may be able to begin to understand how certain technical parameters could impact their behavior or decisions within the game, creating an awareness of tolerance levels for project specifications. For example, if game simulations had been done using an ice machine with limited capacity, high operation costs, and control by a single individual, many cooperative members may have balked at the small ice machine installed in Orinoco, preferring to only accept the project once the conditions changed. Of course, this also assumes agency and voice from among the cooperative members.

Wicked problems and participatory modeling

Resource management, and fisheries in particular, provide extremely challenging targets of information discovery and control. There are volumes written on the governance challenge of managing shared resources (Berkes, 2004; Bryant & Bailey, 1997; Goodman & Redclift, 1991; Ludwig, 2001), which have been described as 'wicked' problems: hard to define, offer no technical solution, and have no resolvable end point or test for a solution (Jentoft & Chuenpagdee, 2009, p. 553; Rittel & Webber, 1973, pp. 161–166). Wicked problems are particularly resistive to technical approaches. While there is a need for continued means of information discovery, more important is the necessity for structures that facilitate communication among stakeholders.

Every participant who I interviewed during the participatory modeling process stated that he or she believes that the fishing economy will worsen due to declining fish productivity, unless fishing behavior changes. The need for resource management is voiced by both community members and government. However, numerous conversations with community members revealed that they feel an overwhelming lack of agency with regard to fishery management. The majority of fishers believed that it must be the government that sets and enforces fishing regulations, such as limits on net size and banning the use of nets during spawning months.

While community members seem to have little faith in their own ability to manage resources, there is little evidence to support a belief that the government has the will or capacity for enforcement. As explained in Chapter 2, coastal communities have experienced over a century of resource exploitation by both private and government firms, and ongoing challenges protecting their traditional lands from the encroachment of poor farmers from the Pacific. To complicate matters, there may be an embedded rationale in the government's resistance to support communally managed projects, unless they are co-managed with government support. In a context where the national government is looking for ways to exploit coastal resources for national growth, encouraging local communities to take control of local resources could be contradictory. Though the Sandinista government has increased support for the demarcation of communal lands, as specified under the national constitution, its support has wavered where the repatriation of local lands conflicts with powerful national or private interests[69].

There is a critical need for community voice in the development of the regulations. There are already laws in place, but they are not enforced. An employee of INPESCA, the government's agency for regulating fishing, stationed in the town of Pearl Lagoon, explained that the existing laws do not work because they were formulated without the consultation of the communities (X. Gordon, personal communication, September 11, 2011). She said that the government has a more inclusive process that needs to be requested by the municipal government. A commission would be formed with delegates from the municipal government, communities, and fishers. The commission would then go to each of the communities and get a majority consensus from the community and the local communal board regarding restrictions. Enforcement would require monitoring the local buyers[70].

Even though a process exists, the challenge still remains for designing the restrictions and determining how they will be enforced, and by whom. Both fishers and buyers may claim to support a closed season because their experiences with declining fish stock have convinced them that it is necessary for the longevity of the fishing industry. However, agreeing upon, supporting, and actually following restrictions in a context where enforcement is weak and the need for income is great, is a daunting challenge. Over the course of the past twenty years there have already been a number of government and NGO projects aimed at supporting community management of lagoon resources (Christie, 1999; Christie et al., 2000; González, 2011b, pp. 294–298), most of them without any lasting impact.

During the game playing session, several games were played in Orinoco where fishers tried to maximize their income without any restrictions on the number of nets that they could use. Focusing on maximizing profits from fishing, without any form of regulation, is a certain path towards resource depletion[71]. The potential for overfishing catalyzed discussions regarding the maximum number of nets that were physically possible to handle, versus the maximum number that seemed fair for a boat to use, taking into account issues of equity and overfishing. There was a range of opinions, but it seemed that fishers tended to want to limit the number of nets based upon a slight increase to the number that each individual was currently using.

Although fishers support a closed season, they may not have a detailed, or shared, understanding of the costs and benefits of its impact. Also, there was a lack of understanding of how the ban would be enforced, and what resources or capacity the government or local

[69] CONENDETI, the community comprised group that is tasked with demarcating traditional lands, was told that the monetary support of the government would be jeopardized if they continued to pursue demarcation demands regarding land held by a private African palm plantation in Kukra Hill (personal communication with a member of CONENDETI, August 2010).

[70] The middleman in Pearl Lagoon said that he would have no problem with an enforced ban, and thought that a 5 month closed season on gill nets may be needed. During this time he would just buy fish caught with hand lines (A. Downs, personal communication, August 5, 2011).

[71] Nietschmann (1972) provides a description of the disastrous impact that the market economy for turtle meat in the 1970s had on turtle populations and local livelihoods, in the nearby community of Tasbapauni. Over a period of 10 years, during the '70s, Nietschmann observed that with the disappearance of the large foreign firms hiring the Miskitu as contract laborers, they increasingly turned to selling their local resources on the market in order to access money (Nietschmann, 1979). The arrival of a private turtle meat processing plant rapidly led to the over-hunting of turtle by the Miskitu of Tasbapauni.

communal boards would need to make the ban successful. In the community of Marshall Point, the game-playing participants said that they tend to adhere to their own closed season, not using gill nets during the dry season, but accused fishers from Orinoco of using gill nets during the entire year.

While there have been close seasons implemented on the coast for lobster as well as turtles, these resources had a smaller population of stakeholders, and were only implemented following resource collapse (Joseph, 2004; Nietschmann, 1972). A solution will likely only emerge through trial and error, and long-term democratic processes tied to actual management implementations, which will take time. Participatory modeling has the potential to be a complementary tool when the government and communities are ready to invest efforts in trying to find a resource management solution.

Due to the complex nature of resource management, game playing lends itself particularly well to exploring dynamics of the problem, since the approach is focused on the relationship of actors and their decisions, rather than directly on outcomes. There exists a history of games being used for modeling resource decline, with a number of games focused on fisheries, such as Fish Banks (D. L. Meadows et al., 1986). In fact, the exploration of natural resource management has been a primary focus of the companion modeling approach (Bousquet et al., 2005). Two recent studies describe the use of companion modeling for exploring fishery management in rural areas (Castillo et al., 2011; Worrapimphong et al., 2010). The approaches in both Castillo and Worrapimphong were more sophisticated than the participatory modeling used in my research, involving the creation of a mathematical model of fishery population dynamics. A separate computer model was then used to calculate resource changes in response to the resource-use decisions of the game players. In addition, the games were played in a more inclusive context, involving a variety of stakeholders, including government policy makers (Worrapimphong et al., 2010, pp. 1339–1341).

There are two important roles that participatory modeling could potentially play in natural resource management in the Pearl Lagoon basin. The first is for the development of aspirations. There are is no shared history of successful models of co-management, creating an absence of aspiration windows that could motivate community members to push for co-management solutions. In addition, participatory modeling would provide a forum for community members and government officials to explore the viability of proposed enforcement options. However, if the will and capacity for government action seems limited, participatory modeling can also provide a medium for opening dialogue between different communities to explore options for community management of lagoon resources[72].

Conclusions

Participatory modeling was used in three communities in order to explore how it might help fishers gain a more quantitative analysis of their fishing economy and the impacts of potential development projects. The implementation of the process was motivated by a will to

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[72] The nearby community of Tasbapauni, has set very strict laws regarding the use of their fishing resources, and routinely enforces these laws, confiscating equipment and making fishers leave their waters unless they have permission. Further north, the local government in the community of Desembocadura del Rio Grande has been burning the nets of fishers found to be using nets with holes below a given size (X. Gordon, personal communication, September 11, 2011).

improve development outcomes, based on the premise that the failure of development projects to deliver beneficial impacts is often a failure of access to information, both intentionally and unintentionally. The participatory modeling process attempted to make causal processes more transparent to target beneficiaries, and bring to light the relevance of detailed information embedded in technical solutions.

Since the participatory modeling process didn't actually precede a new development intervention, and the research didn't continue to monitor if new beneficiary understandings led to behavior change, we are limited in what can be said about the actual impact of the process upon fisher decisions. It remains to be seen whether or not this method, which uncovers information for beneficiaries and facilitates communication of expectations and priorities, actually leads to behavioral changes.

The process resulted in a game that helped participants explore possible project outcomes, what capabilities are needed to reach those outcomes, and what the costs might entail. In particular, the game proved to be a useful mechanism for exploring how a cooperative-owned business can increase earnings to cooperative members, without placing additional constraints on their independence. The game provided participants an accessible learning method for quickly understanding how a dividend was calculated and paid to cooperative members.

The game also characterized the use of ice in the daily habits of the fishers, stimulating conversations about the costs and benefits of local ice production. While ice was clearly important, the potential benefits of local ice production seemed to hinge on a number of additional capabilities, most notably having a well organized cooperative that could maintain the machine and take advantage of new markets by breaking their obligation to sell fish to the lenders of ice.

However, having a well functioning cooperative, without adequate resource management, could exacerbate the decline of lagoon fish, concentrating the benefits of the shared resources in the hands of the smaller population that is active in the monetary fishing economy. Resource depletion would not only hurt the economic livelihood of the most productive fishers, but could have dire consequences for the poorest community members who rely on fishing for subsistence living (González, 2011b, p. 298). While the game led to conversations discussing limits on the number of nets, a more involved process would need to be carried out, with the inclusion of additional villages and government officials, before leading to action. Work in other countries using companion modeling provides a helpful blueprint for evolving from analysis to policy proposals.

Like all forms of modeling, reality is characterized by perceptions of the way that processes work. If there is little experience regarding a new process or project, then the implementation of it within the game model would certainly be prone to error. The simplification of reality may result in very important processes or details being bracketed out. The creation of a useful representation of reality will require the facilitator and participants to debate and discuss the uncertainty and importance of information that is included or left out. Participants will need to maintain a wary eye for new information that is presented by 'experts', who may have a particular development agenda. Participatory modeling has the potential to play an important role in facilitating new aspirations, motivating contestation of development plans, and ultimately leading to the implementation of more thoroughly communicated development projects.

Dissertation Conclusions

Dominant economic and political paradigms will continue to shape economies and environments in rural communities, influenced by institution-led development projects. It is extremely difficult for localized agendas to alter the inertia of policies designed at the national and international level. Undoubtedly, evolution from a reliance on GDP per capita in the 1940s to the ever expanding array of UN metrics and indices[73] has led to a greater awareness of the wide range of inequalities that exist between and within countries, creating the potential for better welfare policies. Indeed, the availability of these informational databases has supported the mobilization of global discourses leading to international development efforts such as meeting targets specified in the Millennium Development Goals. However, there continues to exist a gap between the local capacity and priorities of target beneficiaries, and the policy and projects that are generated by experts. The disparate local realities of communities and their heterogeneous constituencies often become reduced to a single metric or index that is representative of the value system of the development institutions.

The continued production of unexpected consequences from development projects is partially a failure of the availability of information and communication. Even with the mainstreaming of an assortment of participatory methods, development experts too often design projects that are focused on impacting a narrow set of metrics, without understanding how the metrics link to local capabilities and priorities. In addition, community stakeholders often take development plans on faith, without having access to the embedded assumptions or possible outcomes of the experts' plans. In the rare cases where there is adequate information, short project timelines and a continued focus on outcomes reduces the chances that new information revealed through practice will be incorporated into the knowledge content of ongoing and future planning.

The government initiated CDCC Clean Energy and Water Project, discussed in the Introduction, led to the implementation of an energy efficiency campaign that resulted in insights for policy recommendations relating to climate change and poverty alleviation, an example of practice informing policy. In the context of extensive international policy making machines, there is, as Li argues, an endless desire to improve outcomes through the improvement of policies (Li, 2007, pp. 4–6). Carbon abatement cost curves provide one clear example where the global agenda of carbon mitigation, based solely on metrics of cost of carbon reduction and total tons reduced, will likely result in missed opportunities for decreasing global material inequalities. As well, when the carbon abatement cost curve is taken from the national level and applied to the local or village level, it reveals information and allows for conclusions obscured by aggregated macro-level studies.

In particular, it can be seen that the investment costs for carbon mitigation are cheaper, and often negative, due to the high costs of electricity generation in rural areas, where diesel microgrids are prevalent. This provides opportunities for the economic investment of climate dollars in areas that might also address aspects of material poverty. It was shown that there are opportunities for augmenting the metrics to include those that relate to welfare, beginning to highlight how costs and savings are distributed among the stakeholders. In particular, the

[73] See *hdr.**undp**.org/en/statistics/*

benefits to the most marginalized are heavily dependent on planners taking a pro-poor approach.

The eventual abandonment of the CDCC Clean Energy and Water Project created space to step back and reflect upon community demands for economic development, and understand how an energy project could support local priorities, highlighting the absence of an appropriate mechanism for effectively communicating information and desires between stakeholders and development actors. Acknowledging the role of information and communication in the failure of development projects, there is a large body of literature highlighting the need to include greater information from the local level. This has led to an abundance of participatory methods, most of which focus primarily on eliciting greater local level information, for inclusion in project planning and implementation.

However, there is a dearth of methods that effectively open up the development expert's black box of project designs, allowing their proposed solutions to be transparent to the target beneficiaries. I used a participatory modeling method that I adapted from an approach called companion modeling, which has been primarily used for addressing challenges related to natural resource management in Asia. The method, which results in the creation of a game that models local reality, provided the opportunity for fishers to look closely at the causal relations between development interventions, such as a cooperative-owned fish businesses and outcomes like income generation. Participatory modeling places a greater emphasis on understanding processes, rather than just focusing on outcomes. Coming to a more detailed understanding of the dynamics defining local realities, as well as exploring the assumptions and potential outcomes of development interventions, may allow new aspirations to emerge from local groups, crystallizing into action and demands for development to be done differently.

However, it is important to state that modeling has its uses and its limits. Even if a project is desirable to planners and potential beneficiaries, the actual implementation of the project may unfold in a very different manner than was envisioned. A policy planner who is looking for one-size-fits-all, scaled solutions has become oblivious to the realities of the complex systems in which we live, defined by unpredictable outcomes, often due to small changes. Solutions that provide long term benefits to various stakeholders will often only be discovered through ongoing trial and error. Once resources have been committed to a project, there must be feedback mechanisms for evaluating and modifying the project parameters as new information is discovered about local capabilities and aspirations.

Directions for future research

> *The poor, no less than any other group in a society, do express horizons in choices made and choices voiced, often in terms of specific goods and outcomes, often material and proximate, like doctors for their children, markets for their grain, husbands for their daughters, and tin roofs for their homes. But these lists, apparently just bundles of individual and idiosyncratic wants, are inevitably tied up with more general norms, presumptions, and axioms about the good life, and life more generally (Appadurai, 2004, p. 68).*

If one of the goals of development is to make life better, then it must account for the subjective reality of the beneficiaries, in addition to their objective reality. It is critical to understand the impacts on happiness that might result from the provision of new capabilities to a community or individual. Since the publication of Maslow's hierarchy of human needs (Maslow, 1943), there have been a number of researchers coming from fields such as sociology, psychology, and economics, presenting theories of various universal components of wellbeing (Diener, Emmons, Larsen, & Griffin, 1985; Diener, Oishi, & Lucas, 2003; Doyal & Gough, 1984; Inglehart, Foa, Peterson, & Welzel, 2008; Maslow, 1943; Max-Neef, 1992; Nussbaum, 2003; Schwartz, 1994). In addition, there are an increasing number of empirical studies demonstrating how certain capabilities relate to happiness or life satisfaction (Anand, Hunter, & Smith, 2005; Inglehart et al., 2008), bringing greater attention to the need to understand the subjectively defined impacts of development. Research in the area of subjective wellbeing (SWB), which refers to the personal assessment of happiness or life satisfaction (Pavot & Diener, 1993), could prove useful in evaluating the appropriateness of development projects (Camfield, Guillen-Royo, & Velazco, 2010; Gough & McGregor, 2007).

Once a targeted metric has been identified (e.g., income, water quality, or literacy), either through the demands of a particular stakeholder group, or the capacity and goals of the development experts, attention is then turned towards planning and implementing a project that will impact the metric. Excluded from this process is work to understand how the metric links to aspects of SWB. This is a problem that has become systemic with the implementation of a capabilities approach. The approach is based upon the premise that capability development is a good endeavor, often justified by arguments of equity, alone.

How various capabilities are utilized is left to the individual. In the real world, where resources are limited, there will be opportunity costs for developing a particular capability. While there may be a general set of capabilities and freedoms that everyone agrees are important, preferences will undoubtedly vary by personal identities, experiences and values. Whether or not an individual or group values a particular capability will inevitably be determined by how it will impact their SWB.

Mainstreamed development objectives, such as the targets specified in the Millennium Development Goals, don't account for needs or desires that are prioritized by local communities or groups. The commonly heard development mantra, of the need for scalable projects, will inevitably lead to unmet expectations due to heterogeneous capacities, aspirations, and values. The development agent must be aware of local priorities and existing capabilities, how a particular intervention influences other capabilities, and how the combined change in capabilities impacts SWB.

Due to the complex and often unobservable relationships between certain capabilities and processes, the primary challenge becomes understanding how best to meet a desired outcome, such as increased income, while understanding its impact on SWB. This places greater demands on the already information-poor development agent. Evaluating current community capabilities is difficult, but theoretically not impossible. However, the imagined impact of a project on the happiness of a stakeholder poses a difficult problem. Community members may not have relevant experiences that will help them properly imagine (and therefore evaluate) how a future set of capabilities will influence their reality. Without experiences that provide insight into the returns to a particular set of choices, there is an increased risk that the choice may result in an undesirable outcome.

The participatory modeling approach may be used to explore relations between development projects and social and cultural factors, including SWB. Survey and interviews related to SWB were only introduced, in a non-rigorous manner, during the very last game playing session during my research. The introduction of SWB surveys was motivated by the observation that fishers were clearly optimizing their decisions based on a more nuanced utility function than simply maximizing income. Many fishers would not fish every day, especially when the catch sizes were small. The opportunity cost for fishing didn't seem to necessarily involve losing other income earning opportunities. The tradeoff often appeared to be losing opportunities for 'taking it easy', passing time with neighbors or friends, highlighting the importance of leisure time and labor independence. The game provides a framework in which less quantitative returns can be introduced, such as hours of leisure time. Surveys, or even group discussions, could highlight the variety of social and cultural priorities that drive observed behaviors. However, due to our fallibility in estimating what makes us happy, it will be important to use methods for verifying stated preferences with field-based evidence.

It was beyond the scope of my research to determine if, or how, the participatory modeling process leads to actual behavior change among participants, or the development and implementation of new policies. Due to the ability of the approach to uncover information relevant to developers and beneficiaries, there is opportunity for greater adoption and experimentation of the approach within the context of institutional-led development. It will also be useful to understand the role of participatory modeling, not only during the planning phase, but also during project implementation. Participatory planning may help implementers and managers better understand the causality of ongoing events in order to redirect projects in desired directions. There is a need for longer-term, more quantitative evaluations to be done in order to understand how learning process, such as participatory modeling, impact ideas and actions of stakeholder groups, as well as project planners. It will also be important to look at the implementation of the methods under various contexts, investigating what conditions allow them to be used for empowering marginalized groups, and prevent co-option by local elites and outside experts.

A closing note of optimism and the unshakable will to improve

There are many examples of projects that are doing exceptional work. However, they don't tend to have characteristics that lend themselves to well defined policy planning, scale-up, and dissemination by dominant government or economic institutions, and therefore tend to receive little attention. The Foundation for the Autonomy and Development of the Atlantic Coast of Nicaragua (FADCANIC) provides a good example of what it takes to contribute to the development of locally embraced, lasting institutions and projects. FADCANIC's projects have emerged from a concerted effort to understand local priorities, and what capabilities are needed to support those priorities. Many of their most impactful projects have involved the local creation of institutions, such as schools or research centers, which emerged from information revealed through field practices being incorporated back into planning and policy.

FADCANIC was founded in 1990 by Dr. Ray Hooker[74], a native of the Atlantic Coast. Since its founding, the organization's keystone has been education, first focusing on kindergartens, then moving to primary schools and secondary schools, and playing a lead role in founding the Atlantic Coast's second university. Dr. Hooker has said that for "people in danger of extinction, education is one of the few instruments they have to transform their reality into a more meaningful existence."

FADCANIC's model has not been the simple adoption and propagation of non-local curricula. For their first elementary school, the PLACE School located in Pearl Lagoon, they focused on knowledge that helps support autonomy and development. They knew that mastery of Standard English was fundamental in order to open doors to the globalized world, but they also recognized the importance of focusing on creating a strong link to their mother tongue of Creole. "Language plays a critical role in identity development", explained Dr. Hooker. In addition, since Spanish is the country's official language, and the language of the continent, it also needed to be learned. "It is well accepted that the PLACE School is the best bilingual intercultural school in Nicaragua. USAID did an evaluation in the Caribbean region and found the school to be among the most effective." On the Pacific Coast the bilingual inter-cultural schools are private, expensive, and only attended by the elite. In contrast, FADCANIC's school is free and, therefore, populated with children from the poorest families. "The idea is that young leaders will be produced from this school. Strong regions have strong leaders who are committed to their culture as a whole – struggling populations that lack strong leadership, often also lack commitment to their culture."

FADCANIC also recognized that economic self-sufficiently needed to come from coastal resources, so they knew they needed to begin working with farmers. They founded a 260 hectare sustainable agro-forestry research center. In addition to creating locally appropriate seed banks, the center began by building the capacity to work with groups of 25 farmers in short courses. The idea was to learn by doing, and create models where farmers could work the land for 15 to 20 years, instead of the 3 years resulting from common slash and burn practices.

The children of many of the farmers may not have access to anything more than primary school. Recognizing the importance of working with multiple generations for sustainable economic development, FADCANIC added a sustainable-agriculture boarding school to the research center. There exist many historical tensions among the different coastal ethnic groups. "Cultural understanding and mutual respect are fundamental for the development of autonomy. During the first day of school, all the students from the different communities and ethnicities organize into armies; it takes time for them to learn to generate mutual respect and live with one another, but intercultural links start to become established and by the third year they are quite strong," explained Hooker.

In addition to learning the standard subject matter of the government schools, the students take technical agricultural classes. The majority of their time is spent in the field, not in the classroom. When the students finish the third year they can then complete their last two years in any school, or they have sufficient technical knowledge to return to their community and put into practice more sustainable agricultural techniques. They receive technical and inter-cultural education that is not present in other schools. They have a goal of having 50%

[74] The description of FADCANIC's work is taken from an interview with Dr. Ray Hooker on 12/02/2008.

men and women. Many families didn't want to send their girls there, and they had a hard time finding students at first. Now they have to turn students away.

FADCANIC's work has highlighted a non-linear and organic form of development. While planning is necessary, the evolution of the projects could not have been foreseen. Dr. Hooker stated that "Each endeavor generates experiences that give birth to other possible experiences." When they began work on the pre-schools their desire to develop other schools was not yet present. Later, they weren't aware that a school at the agricultural center would be necessary. Dr. Hooker explained that "We're not thinking of a model for the universe. We are locally oriented. There are parts of our work that can be meaningful for many parts of the world, but we are focused on the Caribbean."

Dr. Hooker's model, however, isn't driven by regional, national, or international policies. In fact, one of the reasons for founding FADCANIC was to attempt to remove themselves from the political constraints of government funds and agendas. Although, their funding comes from both multilateral and bilateral sources such as USAID, the Norwegian government, and the Austrian donor HORIZON3000, whose policies for 'best practices' likely create hurdles that constrain making decisions called for by local context. FADCANIC's policy is informed by their ongoing experiences of practice, which is, in turn, informed by feedback from the communities in which they work, where economic livelihood, autonomy, and cultural support provide a guiding framework.

However, even locally informed practices, where local politics and social and cultural constraints are much more obvious to planners, don't mean that communication is always clear, and local priorities are necessarily heard. I wonder how a tool such as participatory modeling could facilitate the flow of information between targeted beneficiaries and project implementers. And thus, I continue to grapple with what Tania Murray Li calls "the will to improve", and the "inevitable gap between what is attempted and what is accomplished" (Li, 2007, pp. 2–6,1).

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Appendix 1 Qualitative description of demand and supply side measures

This appendix discusses the details of the demand side conservation measures and supply side measures used in the analysis of the diesel microgrid in Orinoco and Marshall Point, presented in Chapter 1. These descriptions are primarily qualitative in nature, with the actual calculation details shown in Appendix 2.

Demand side measures

Meter installation

Prior to the meter installation the tariff charge was based on an estimation of the household consumption according to the appliances owned. ENEL conducted household audits to determine the power rating of each appliance coupled with an estimate of the number of hours that each appliance would be utilized. The time of use estimates were based upon the assumption that most of the appliances would be in use for the full operation of the grid. Because the consumers were aware that their tariff charge was not reflective of the actual amount of energy that they consumed, there was very little motivation within the community to conserve electricity. When the diesel plant would start during the day, the majority of loads would immediately come on. For example, light bulbs (the majority being incandescent bulbs) in houses and churches were frequently left on when the plant started in the afternoon.

Operators of microgrids may choose not to install household meters, often due to the capital outlay and operational costs. However, the costs of the meters can be transferred to the clients through a small charge bundled into the monthly bills[75]. There may be additional ongoing costs to the energy provider caused by the need for a person to take monthly measurements of the meter and additional administrative time for calculating monthly charges. However, in the case of Orinoco and Marshall Point, meter reading was added to the tasks of one of the salaried workers, so there were no additional labor costs for ENEL. It should be noted that there are important social components of successful metering, such as insuring that the clients trust the accuracy of the meters as well as the ability of the meter reader[76]. In addition, it is important that tamper resistant meter technology is chosen[77].

Following the installation of the electric meters, the peak load dropped by 30% from close to 50kW down to 35 kW, and the load profile took on the more familiar bell-shaped curve with an evening peak due to the loads from household lighting, as shown in Figure 1. The savings in diesel fuel that resulted from the decreased consumption allowed the administrators to increase the operation of the diesel grid by two hours every day. The estimated cost of conserved energy was 0.02 $/kWh[78], with an IRR of 293 %, showing the strong economic rationale for installing meters.

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[75] ENEL charges a monthly meter rental fee of $ 0.59
[76] In the neighboring town of Bluefields, several clients questioned whether or not their meter was accurate, but independent measurements by the author confirmed its accuracy.
[77] There exists anecdotal evidence from neighboring communities that individuals could be hired to tamper with older types of meters so that they under-represented the true consumption.
[78] A lifetime of 10 years and a cost of $25 per meter was used, with a $50 transport cost to the village.

Efficient residential lighting

Fluorescent lights typically provide the equivalent light output as incandescent bulbs while consuming only 25% of the electricity, with five to eight times longer operating lifetimes (Hong, 2002). However, barriers to widespread adoption include higher upfront costs, prevalence of poor quality brands, lack of awareness of the economic advantages, and lack of availability in rural communities (Gadgil & De Martino Jannuzzi, 1991; Kumar, Jain, & Bansal, 2003). The Nicaraguan Ministry of Energy and Mines (MEM) agreed to support an energy efficiency campaign in Orinoco and Marshall Point, in August of 2009. The MEM donated 330 15W CFLs and 165 brochures describing methods for household energy conservation. Household owners who had incandescent light bulbs were offered the opportunity to remove two of their incandescent light bulbs in exchange for two 15W CFLs[79].

In an electric system where the marginal production cost is subsidized (i.e. money is lost with each unit of energy produced) it is economically rational for the provider to look for ways to reduce consumption, while maintaining the same level of energy service to the clients. The estimated cost for purchase and installation of each bulb was $3.12. Using a conservative bulb lifetime estimate of two years[80], the estimated cost of conserved energy for the CFL campaign was 0.03 $/kWh, resulting in a 17% reduction in demand. The CFL installation provided the most attractive financial investment, with an IRR of 528%.

Due to the economic advantages of CFLs and the existing distribution chains of the bulbs in developing countries, policy strategies such as educational campaigns may help increase the rate of adoption in rural areas (Kumar et al., 2003), and the actual distribution could be left to local store owners and entrepreneurs. In addition, it is important to fully understand the barriers to adoption of energy efficiency in every community setting (Jaffe & Stavins, 1994).

Energy efficient public lighting

Public lighting is an important aspect of rural energy systems, increasing security and mobility during the evening hours (Cecelski, 2000). It is estimated that the public lighting in Orinoco and Marshall Point currently accounts for over 25% of the daily load. This consumption can be reduced by providing more appropriate levels of illumination on public walkways and increasing the reliability of the individual photo-sensors that are used to automatically turn on each light after dark.

In Orinoco and Marshall Point there are a total of 54 public street lights. While there are several CFL lights used for public lighting in Marshall Point, the majority of the lights are 150W, 220V high pressure sodium (HPS) bulbs. In the communities of Orinoco and Marshall Point (where there are no vehicles) the public lighting is utilized for illumination of walkways and public spaces. Low pressure sodium (LPS) bulbs have higher efficiencies than HPS bulbs at a given wattage, though they provide poor color rendering. For example, manufacturer data from Sylvania states that a 55W LPS bulb has an average efficiency of 140 lumens/watt, compared to

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[79] In order to insure that all houses had the opportunity to receive two CFLs, and to account for broken/malfunctioning bulbs, the NGO provided additional CFLs.

[80] The CFLs have a manufacturer stated lifetime of 7,000 hours. This is usually calculated as the expected lifetime for 50% of the manufactured bulbs. If we assume a usage of 5 hours/day, this would give a lifetime of 3.8 years. However, since we do not yet have empirical data on the lifetime of the bulbs used (brand-name Liya), a conservative lifetime estimate of 2 years was used.

90 lumens/watt for a 150W HPS bulb. In places where color rendering is not important, such as walkways, the community members could replace the HPS bulbs with LPS bulbs. Replacing the 150W high pressure sodium bulbs with 55W bulbs would result in a 40% decrease in illumination, but a 65% drop in energy consumption. In order to discern the utility loss to the customers, several demonstration lights should be installed in order to test public preferences. In addition, 55W fluorescent lights, or HPS lights, could replace the higher power HPS lights in places where color rendering is desired, but less illumination would be satisfactory.

Technicians at ENEL have made unverified claims that the lifetimes of the photo-cells is typically on the order of 3 months, resulting from the high salinity and humidity of the coastal environment. Due to the remote location of the communities, as well as time lags and bureaucratic hold-ups between light sensor replacements, there are several approaches to addressing the problem of non-functioning sensors. ENEL has experience in other communities retrofitting the public lighting system with a photosensitive switch that controls the entire lighting system, rather than separate ones for each bulb. This requires additional capital investment to set up a parallel wiring system for the bulbs, but once it is installed it is much easier to manage the replacement of a single sensor. The second approach would be for the energy provider to take account of the large fuel costs resulting from failed sensors (when the sensors fail, the light remains on during the daylight hours) and prioritize having a stock of sensors at each microgrid and replacing the sensors as soon as they fail. An individual sensor retails for five dollars, so it would pay for itself after only 11 days of use[81].

Supply side measures

There are a number of modifications that can be made on the supply side to an existing diesel system in order to decrease the fuel consumption, while still meeting demand. The options include increasing the efficiency of the diesel machine by making sure that it is better matched to the loads, integrating other generation sources to supplement the diesel production, or switching the fuel from petroleum based diesel to other combustible fuels such as biomass-based oil or gas.

Resizing the capacity of the diesel plant

Fuel savings can be achieved by proper matching of a diesel generator to the load (Baring-Gould et al., 1997; Hunter & Elliot, 1994). The average efficiency of a diesel generator varies with load; there is an initial amount of fuel consumed in order to overcome frictional and electromechanical losses and begin turning the generator before the first kWh of electricity is produced. Therefore, the average efficiency, (total kWh produced divided by total kWh of fuel consumed) is highest when the generator is running close to its greatest output.

HOMER, a micro-power optimization model, was used to calculate the potential fuel and dollar savings if the current 110 kW sized generator were to be replaced with a 55 kW generator. The table below shows the decrease in fuel consumption and the increase in efficiency resulting from changing to a smaller engine. The load of 197 kWh/day is the resulting load following the implementation of the more economic conservation measures; as demand side measures decrease the total load, the diesel engine becomes less efficient. The

[81] This assumes the grid is operated during 6 hours of daylight, and the marginal production of the diesel generator is 0.43 $/kWh (based on the performance of the Orinoco generator, and diesel at 1.06 $/liter).

replacement with a smaller diesel plant could result in a potential savings of 24 liters per day, with an IRR of 28 %.

Plant capacity	Load kWh/day	L/day	kWh/liter	Efficiency
55 kW plant	197	80	2.46	25.0%
110 kW plant	197	104	1.90	19.3%

Table 15: HOMER simulation results for a 55kW plant versus a 110 kW plant

Displacement of diesel using wind and solar energy

There are numerous successful, village-scale micro-grids that utilize intermittent renewable energy technologies, such as wind or solar photovoltaics (PV), used to supplement diesel systems (Baring-Gould et al., 2003; Flavin & Aeck, 2005; Illindala, Siddiqui, Venkataramanan, & Marnay, 2007). Due to the intermittency of some renewable energy sources and the expense of energy storage, it is common for such systems to utilize diesel generators to meet the base loads, supplemented by wind or solar. When the PV or wind generators are producing power, the diesel generator experiences a decreased load and reduces its output based on voltage or frequency control. As mentioned in the previous section, diesel systems operate most efficiently when running at greater loads, therefore such hybrid systems require a careful technical and economic analysis to determine the optimal level of renewable energy integration, where the fuel savings from renewable integration aren't mitigated by decreased diesel performance. The simplest systems, which do not typically require additional diesel control equipment, are those that are sized so that the diesel system never falls below 30-40% of its maximum load (Baring-Gould et al., 2003; Hunter & Elliot, 1994).

The cost effectiveness of wind or solar integration is sensitive to lifetime estimates of fuel cost trends, as well as the wind and solar resources. The case study area has moderate solar resources and marginal wind resources (4.6 kW/m^2/day solar resources and class 1-2 wind regimes). The table below shows lifetime cost estimations for the integration of wind or solar PV into the Orinoco and Marshall Point microgrid. As can be seen in the table, lifetime costs for wind generation decrease considerably when located in better wind resources.

Technology	Capacity (kW)	Lifetime (yrs)	Capital cost	Levelized cost ($/yr)	kWh/day	$/kWh
Wind turbine (class 1)	10	15.0	$55,557	$7,066	22.0	$0.88
Wind turbine (class 2)	10	15.0	$61,557	$7,767	54.0	$0.39
Solar photovoltaics	10	20.0	$92,300	$9,501	33.4	$0.78

Table 16: Lifetime costs for wind/solar integration into Orinoco and Marshall Point electric grid. Class 1 wind data typical of case study area, using Weibull probability distribution, $f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right]$, where *v* is wind velocity with parameters k = 2.4, and c =4.8 at height of 25m. The system uses Trojan L16 batteries with a nominal capacity of 17kWh. Class 2 wind characterized with Weibull distribution parameters of k = 2.4, c = 6.5 at 25m, and a battery bank with a nominal capacity of 69 kWh. Solar photovoltaics estimated at 20 year lifetime, horizontal average solar radiation of 4.6 kWh/m^2/day, with 86 kWh of nominal battery capacity.

It is important to note that the supply costs are sensitive to the particularity of this case study. The grid is currently operated from noon to midnight, resulting in a need for battery storage in order to capture the energy generated by the wind or sun before the grid is in operation, which contributes to slightly elevated system costs. In the class 2 wind regime, greater battery storage is needed. Possible solutions to decrease energy storage costs include running dispatchable loads such as ice-production or water pumping.

Displacement of diesel using biogas

There have been a number of studies demonstrating the economic benefits that rural users can attain through the incorporation of agricultural residues into their local energy systems (Gowda, Raghavan, Ranganna, & Barrington, 1995; Parikh, 1985; Romijn, Raven, & de Visser, 2010). Some of the most common sources of energy generation utilizing biomass derived fuels include wood gasification, biogas production through anaerobic digestion, or oil extraction from plants. All of these biomass derived fuels can act as direct fuel substitutes or supplements to diesel powered engines. In order to demonstrate the potential cost benefits that may be derived from creating a locally available, less expensive diesel substitute, an example calculation is provided based on the production of methane gas from the anaerobic digestion of existing agricultural residues. The system design costs and production values are based on a recently constructed biogas system constructed on a dairy farm in Costa Rica (Arias, 2009). The costs, shown in the table below, do not include the costs of a diesel generator, since diesel generators can be run in a duel fuel mode, operating with up to 90% methane and 10% diesel (Tippayawong, Promwungkwa, & Rerkkriangkrai, 2007).

Financial parameters for anaerobic digester	
System lifetime (years)	10
Daily filtered gas production (kWh/day)	221
Electricity generation (kWh/day) from biogas	43
Present value of capital cost	$13,500
Present value of labor for O&M ($2000/year)	$13,420
Net Present Cost	$26,920
Annualized Cost	$4,012
Annualized energy cost ($/kWh)	$0.26
IRR	49%

Table 17: Lifetime costs and production values for an anaerobic digester. The system design costs and production values are based on a recently constructed biogas system constructed on a dairy farm in Costa Rica (Arias, 2009)

Appendix 2 Carbon abatement calculations and poverty metrics

This appendix presents the calculation details of the demand side conservation measures and supply side measures used in the analysis of the diesel microgrid in Orinoco and Marshall Point. Both the cost and mitigation details are presented, as well as the calculations for the poverty metrics presented in Chapter 1.

Description of fixed parameters used in calculations

- Diesel fuel price: 1.06 $/liter

  This fuel price is based on the average retail diesel price for 2008 (derived from data from the Nicaragua Institute of Energy, http://www.ine.gob.ni/). The diesel prices in rural areas in 2009 remained at or above this price.
- Annual discount rate: 8.0%

  The discount rate accounts for market interest rate minus inflation (i.e. the real interest rate). In 2003, 14% was an average cost of capital in Nicaragua (World Bank, 2003), and the rates of interest between 2003 and 2009 were not dissimilar (see lending rates at the national bank: http://www.bcn.gob.ni/). However, due to the fact that many of these systems for rural electrification are subsidized by the government or supported by international lending institutions such as the World Bank and the Inter-American Development Bank, they would most likely have access to capital at interest rates lower than the typical market rates in the country, which is why 8.0% was chosen.
- Lower heating value (LHV) of diesel fuel: 9.84 kWh/liter

  The default value from the micro-optimization model, HOMER (www.homerenergy.com). The LHV is the net heat value of a fuel, assuming that all water is in the vapor stage following combustion (i.e., the latent heat of vaporization is not recovered), which is the case for diesel plants that do not use any heat recovery processes. Note that the marginal cost of generation is equal to diesel fuel price / (9.84 kWh/liter x diesel efficiency).
- kg CO_2 / liter of diesel: 2.668

  Value is that recommended by the US Environmental Protection Agency (EPA) calculated in accordance with IPCC guidelines (http://www.epa.gov/otaq/climate/420f05001.htm).

Description of abatement curve calculations

The marginal abatement cost is calculated relative to a business as usual scenario:

$$\frac{\text{Annualized cost of the investment}}{\text{tCO}_2\text{ abated}} - \text{BAU \$/tCO}_2$$

It is informative to also write this as:

$$\frac{(\text{Annualized cost of the investment}) - (\text{Annual savings})}{\text{tCO}_2\text{ abated}}$$

This follows from the definitions of $\text{tCO}_2 \text{ abated} = \text{liters diesel conserved} \times \frac{\text{tCO}_2}{\text{liter}}$, and $\text{BAU \$/tCO}_2 = \frac{\$/liter}{tCO_2/liter}$, giving:

$$\frac{\text{Annualized cost of the investment}}{\text{liters/yr conserved} \times \text{tCO}_2\text{/liter}} - \frac{\text{\$/liter}}{\text{tCO}_2\text{/liter}} = \frac{\text{Annualized cost of the investment} - \text{\$/liter} \times \text{liters/yr conserved}}{\text{liters/yr conserved} \times \text{tCO}_2\text{/liter}}$$

The potential of the tCO_2 abated is calculated relative to the previous measure, rather than the business-as-usual load (before any measures were implemented). The ordering of the measures is determined through an iterative process, ordering the measures from the greatest to the least savings, per unit of abatement.

Annualized cost calculations

All costs are annualized values (AV) of the net present values (NPV) of an intervention, which includes all lifetime costs (fixed and variable). They are calculated using a discount rate of 8.0%, using the formula:

$$AV = NPV \frac{.08}{1 - 1.08^{-t}}$$, where *t* is the technology lifetime.

Abatement cost calculations

- η = efficiency of the diesel plant. The generation efficiency of a diesel plant changes with load.
- Liters of diesel conserved/year = $\frac{365 \frac{days}{year}}{LHV \frac{kWh}{liter}} \left(\frac{P_1 \frac{kWh}{day}}{\eta_1} - \frac{P_2 \frac{kWh}{day}}{\eta_2} \right)$, is the equivalent amount of diesel fuel (in liters) which was conserved, either through the reduction load, where η_1 is the diesel efficiency before the measure and η_2 is the efficiency following the measure. P_1 is the daily demand before the conservation measure and P_2 is the demand following the conservation measure.
- tCO_2 abated = Liters conserved x 0.002688 tCO_2/liter. The CO_2 per liter is based on the values from the US EPA (http://www.epa.gov/otaq/climate/420f05001.htm).
- Unit abatement cost (UAC) = Annualized Cost / tCO_2 abated
- Business as Usual (BAU) carbon dioxide costs = (1.06 \$/liter) / (.002688 tCO_2/liter) = 397 \$/t CO_2
- Marginal abatement cost vs Business as Usual = UAC – BAU cost = UAC - 397 \$/t CO_2

Methodology for poverty measure calculations

Poverty headcount ratio

The headcount ratio shows the percent of population that has below a certain income or consumption level, and can be defined as: $p = \frac{q}{n}$, where n is the total population size and q is the percent of the population below the given cutoff. The cutoff range for the calculations were based upon the World Bank's recent international poverty line of $1.25. It is important to note that this value, for the given community of Orinoco, is not very meaningful for assessing the consumption aspect of poverty, due to the higher cost of basic foods goods, as well as the subsistence nature of consumption of a number of the families. However, the value does provide insight into the potential for market consumption in comparison to other regions of the country.

Kuznets Ratios

Kuznets ratios are comparisons between the top and bottom of the Lorentz curve. They give the ratio of the share of income held by the poorest 20 percent to the share of income held by the richest 20 percent, as a measure of inequality.

Gini coefficient

$Gini = \frac{2}{n\mu}\text{cov}(y,r)$, where *n* is the population size, μ is the mean income, and cov(y,r) is the covariance between the rank, *r*, of the population members, and their incomes, *y*. The energy Gini is a similar calculation, except it is calculated using the residential electricity consumption instead of monetary income.

The impact of the various installations was determined based on income data from household surveys as well as residential electricity bills. There were a total of 172 households in the two villages. The poverty metrics were calculated for a random sample of 69 households from one of the villages (which had 121 households connected to the grid). The estimated changes to household income are based on the calculations in section S3, for each carbon mitigation measure.

	Mitigation measure	Poverty headcount	20/20 Kuznets ratio	Income share of bottom 20%	Income share of top 20%	Gini	Energy Gini
	BASELINE	0.53	18.39	3.07	56.46	0.51	0.45
1	Meter installation	0.52	17.74	3.18	56.37	0.51	0.43
2	CFL installation	0.50	18.09	3.13	56.53	0.51	0.48
3	More effective street lights	0.50	17.22	3.27	56.28	0.51	0.45
4	Biogas	0.48	11.23	4.84	54.33	0.47	0.45
5	Reduce diesel plant capacity	0.48	11.23	4.84	54.33	0.47	0.45
6	Wind turbine (class 2)	0.48	11.23	4.84	54.33	0.47	0.45

Table 18: The change to various measures of poverty and inequality following the implementation of various carbon mitigation measures. The metrics are calculated based upon earnings and electricity consumption data from 69 of the 121 households that have electricity service in one of the rural villages.

Details of calculations for each carbon abatement measure and poverty metric

Meter Installation

Between June 6 and June 12, 2009, employees from the Nicaraguan national electric company (ENEL) installed conventional, digital electricity meters on the building of each client in Orinoco and Marshall Point. July was the first month in which clients received a bill based on the meter reading. The estimation of the immediate impact on load was determined by using an estimation of the typical weekday load, taken on June 6, 2009, prior to the meter installations, and comparing it with the measured load on August 1, 2009. The measurements can be found in village MAC curve.xls.

Annualized cost calculations

We were unable to find out the true costs which ENEL paid for their meters. Cost estimations were based on meter purchases by another power provider (ATDER-BL) in Nicaragua, which pays about 25 $/meter, including shipping to Nicaragua. We then assumed another $50 in shipping costs to bring them to the community.

- Technology lifetime: 10 years
- Capital costs: 25 $/meter x 172 meters + $ 50 shipping = $4,350
- Labor cost: No additional labor costs, since the work was carried out by salaried ENEL employees.
- NPV = $4,350
- Annualized Value: 648 $/year

Abatement cost calculations

- Load before meter installation: 408 kWh/day
- Load following installation: 293 kWh/day
- kWh/day conserved = 408 – 293 kWh/day = 115 kWh/day
- Liters of diesel conserved/yr: 365 days/yr / (9.84 kWh/liter) x (408/.25 -293/.23) kWh/day = 12006 liters/yr
- tCO_2/year abated = 12006 liters/year x 0.002688 tCO_2/liter = 32 tCO_2/year
- UAC = 648 $/year / 32 tCO_2/year = 20 $/ tCO_2
- Marginal abatement cost vs Business as Usual = 20 $/ tCO_2 - 397 $/t CO_2 = -377 $/t CO_2

Impact on poverty/equity calculations

- New income = old monthly income + (value of December 2009 bill) – (value of July 2009 bill)

Installation of compact fluorescent lights (CFLs)

The Nicaraguan Ministry of Energy and Mines (http://www.mem.gob.ni/) agreed to support an energy efficiency campaign in Orinoco and Marshall Point, administered by blueEnergy (http://www.blueenergygroup.org). The Ministry of Energy and Mines donated 330 15W compact fluorescent lights (CFLs) and 165 brochures describing methods for household energy conservation (http://www.blueenergygroup.org/spip.php?article589&lang=en). Between August 3,2009 and August 6, 2009, two employees from blueEnergy and one employee from ENEL worked together to visit every household that is currently connected to the electric grid in Marshall Point and Orinoco. Each household received the following information:

- CFLs produce the same amount of light as incandescent bulbs, but only consume 25% of the energy, which would result in both energy and monetary savings.
- CFLs have a much greater lifetime than incandescent light bulbs, and may last as long as 3 years, depending on the usage and the quality of the bulb.
- CFLs contain tiny amounts of mercury (5 mg) and should be brought to ENEL in order to be properly disposed
- Household appliances may be damaged by current/voltage surges upon diesel start-up, and should therefore only be turned on following the start-up of the diesel system.

Household owners that had incandescent light bulbs were offered the opportunity to remove two of their light bulbs in exchange for two 15W CFLs. If the household already was utilizing CFLs, or only utilized one bulb, they still had the right to receive the two CFLs. Not all households were available during the campaign.

<u>Annualized cost calculations</u>

As was mentioned, the initial 330 bulbs were donated. In order to come up with the cost estimation for the administration of the bulbs, equivalent 15W CFL bulbs, priced at 2.50 $/bulb, were found in the capital city of Managua. Transportation costs to the village were estimated at $20 for all of the bulbs. The labor costs for the two employees of the organization blueEnergy were $184.50.

- Technology lifetime: 2 years. The CFLs had a manufacturer stated lifetime of 7,000 hours. This is usually calculated as the expected lifetime for 50% of the manufactured bulbs. If we assume 5 hours/day of use, this would give a lifetime of 3.8 years. However, since we did not have empirical data on the lifetime of the bulbs used, a conservative lifetime estimate of 2 years was deemed appropriate.
- Capital and installation costs: 2.50 $/bulb x 330 bulbs + $ 20 shipping + $184.50 labor = $1030
- NPV = $1030
- Annualized Value: 577 $/year

<u>Abatement cost calculations</u>

- Load before CFL installation: 293 kWh/day
- Load following installation: 243 kWh/day
- kWh/day conserved = 293 – 243 kWh/day = 50 kWh/day
- Liters of diesel conserved/yr: 365 days/yr / (9.84 kWh/liter) x (293/.23 -243/.21) kWh/day = 5265 liters/yr
- tCO_2/year abated = 5265 liters/year x 0.002688 tCO_2/liter = 14 tCO_2/year
- UAC = 577 $/year / 14 tCO_2/year = 41 $/ tCO_2
- Marginal abatement cost vs Business as Usual = 41 $/ tCO_2 - 397 $/t CO_2 = -356 $/t CO_2

Impact on poverty/equity calculations

- The estimated impact of streetlights results in a 46 kWh/day reduction of diesel. This savings could be passed on to consumers, uniformly distributed, at the value of the marginal cost: 0.43 $/kWh x 46 kWh/day = 19.78 $/day / total number of clients(172) = 0.12 $/day/client or house
- New income = old annual income + 365 days x 0.12 $/day

Installation of more effective street lights

In Orinoco and Marshall Point there are a total of 54 public street lights. While there are several CFL lights used for public lighting in Marshall Point, the majority of the lights are 150W, 220V high pressure sodium (HPS) bulbs. Orinoco and Marshall Point are isolate communities on the bank of a lagoon, and can only be reached by boat, so the public lighting is utilized for illumination of walkways and public spaces. Low pressure sodium (LPS) bulbs have higher efficiencies than HPS bulbs at a given wattage, though they provide poor color rendering. Manufacturer data from Sylvania state that a 55W LPS bulb has an average efficiency of 140 lumens/Watt, compared to 90 lumens/Watt for a 150W HPS bulb. In places where color rendering is not important, such as walkways, the community members could replace the HPS bulbs with LPS bulbs. Replacing the 150W high pressure sodium bulbs with 55W bulbs would result in a 40% drop in illumination, but a 65% drop in energy consumption. In order to discern the utility loss to the customers by replacing the bulbs, several demonstration lights would need to be installed in order to test public preferences. In addition, 55W compact fluorescent or HPS lights could replace the higher power HPS lights in places where color rendering is desired, but less illumination would be satisfactory.

Annualized cost calculations

It was assumed that fifty-four 55W LPS street lights would be purchased, each for a cost of 40$/bulb. This would be a conservative calculation, since the public may decide to have a number of cheaper 55W CFL bulbs which would provide superior color rendering for certain locations. For lifetime and lighting specs see: http://www.sylvania.com/BusinessProducts/ProductLiteratureDownload/Product+Literature2/HID/LPS/.

- Technology lifetime: 7 years.
- Capital and installation costs: 40 $/bulb x 54 bulbs + $ 1080 for shipping and installation = $3240
- NPV = $3240
- Annualized Value: 622 $/year

Abatement cost calculations

- Load before light installation: 243 kWh/day
- Load following installation: 197 kWh/day

  Based on the assumption that 50% of the lighting sensors don't currently work. This means that half of the street lights are on as soon as the plant begins operation at noon, and operate for 6 hours of daylight, before the other lights turn on at 6 pm, when it gets dark. Therefore, the load reduction is calculated as:

Prior lighting load: 150W*6hrs*54bulbs/2 + 150W*54bulbs*6hrs = 72.9 kWh/day
Following installation: 55W*6hrs*54bulbs/2 + 55W*54bulbs*6hrs = 26.73 kWh/day
Load reduction: 72.9 – 26.73 = 46.17 kWh/day.

- kWh/day conserved = 46 kWh/day
- Liters of diesel conserved/yr: 365 days/yr / (9.84 kWh/liter) x (243/.21 -197/.19) kWh/day = 4813 liters/yr
- tCO_2/year abated =4813 liters/year x 0.002688 tCO_2/liter = 13 tCO_2/year
- UAC = 622 $/year / 13 tCO_2/year = 48 $/ tCO_2
- Marginal abatement cost vs Business as Usual = 48 $/ tCO_2 - 397 $/t CO_2 = -349 $/t CO_2

Impact on poverty/equity calculations

- The estimated impact of streetlights results in a 46 kWh/day reduction of diesel. This savings could be passed on to consumers, uniformly distributed, at the value of the marginal cost: 0.43 $/kWh x 46 kWh/day = 19.78 $/day / total number of clients(172) = 0.12 $/day/client or house
- New income = old annual income + 365 days x 0.12 $/day

Installation of a biogas digester

In order to demonstrate the potential cost benefits that may be derived from creating a locally available, less expensive diesel substitute, an example calculation is provided based on the production of methane gas from the anaerobic digestion of animal waste. The system design costs and labor requirements are based on a recently built (2009), plug-flow system constructed out of tubular PVC membranes on a dairy farm in Costa Rica (Arias, 2009). The system is designed so that the total hours of consumption are increased so

Annualized cost calculations

The costs do not include the costs of a diesel generator, since the diesel generators can be modified to run in duel-fuel mode, operating with up to 90% methane and 10% diesel (House, 2006).

- Technology lifetime: 10 years.
- Total capital and installation costs: $13,500
  $8,000 for four 100m^3 tubular digesters, $3,000 for a composting area to filter out fibers from manure , $10,000 for effluent processing tanks, $2,000 for a system to filter hydrogen sulphide out of the gas, and $4,000 for misc./over-run costs.
- Present value of labor costs: $26,840/year
  To operate and maintain the digesters, it will require 2 full time (5-days/week) and 2 part-time (2.5 days/week) employees, receiving a local wage of $5/day.
  Annual labor costs: $4,000/year
- NPV = $26,000 + $26,840 = $52,840
- Annualized Value: 7,875 $/year

Abatement cost calculations

- Daily lower heat value of biogas production: 321 kWh.
  The digester is sized with a total volume of 200m^3. The assumption is made that 80% of the volume, with the remaining 20%of volume to contain the gas production. Assuming

the digester has a hydraulic retention time of 25 days, this would result in a daily input of 12,600 liters of feedstock mixed with water. Using values from *The Biogas Handbook* (House, 2006) a 450 kg cow can produce 23 liters/day of manure, resulting in 0.78 m^3 of methane, or 7.49 kWh (LHV) of methane (using a lower heating value of 9.61 kWh/m^3 for methane: http://bioenergy.ornl.gov/papers/misc/energy_conv.html).Thus, if 11% of the incoming liquid is cow manure, this could result in the production of 442 kWh/day of methane, from 58 cows.

- Liters of diesel conserved/year: 365 days/year x 442 kWh/day methane / 9.84 kWh/liter diesel = 16,395 liters/year
- tCO_2/year abated = 16,395 liters/year x 0.002688 tCO_2/liter = 44 tCO_2/year
- UAC = 4,012 $/year / 44 tCO_2/year = 180 $/ tCO_2
- Marginal abatement cost vs Business as Usual = 180 $/ tCO_2 - 397 $/t CO_2 = -217 $/t CO_2

Impact on poverty/equity calculations

- Four employees: 2 full time (5-days/week) and 2 part-time (2.5 days/week) employees, receiving a local wage of $5/day. Annual labor costs: $4,000/year
- Biogas will be purchased by electric company at their avoided costs of 16,395 liters/yr *1.06 $/liter = $17379 per year for the biogas.
- Part of this is captured by a cooperative of 16 farmers, who's profit margin (after subtracting costs) is 50%, providing $542/household/year.
- The additional income was added to 20 of the poorest families.

Reduce diesel plant capacity

Fuel savings can be achieved by proper matching of a diesel generator to the load (Baring-Gould et al., 1997; Hunter & Elliot, 1994). The average efficiency of a diesel generator varies with load; there is an initial amount of fuel consumed in order to overcome frictional and electromechanical losses and begin turning the generator before the first kWh of electricity is produced. Therefore, the average efficiency, (total kWh produced divided by total kWh of fuel consumed) is highest when the generator is running close to its greatest output.

Utilizing HOMER, a micro-power optimization model that can be downloaded at www.homerenergy.com, we calculated the potential fuel and dollar savings if the current 110 kW sized generator were to be replaced with a 55 kW generator. The simulation used the reduced load of 197 kWh/day, which resulted from the installation of the meters, CFLs, and more efficient street lights.

The peak load measured in August was about 27 kW. Replacement with a 55kW machine would lead to an estimated annual diesel reduction of over 7000 liters, yet still providing the potential for the peak load to increase by over 50% before the bigger plant would need to be utilized again. As well, when the load outgrows the capacity of the smaller engine, the larger engine can be run at the peak times, and still utilize the smaller plant during the off-peak hours.

Annualized cost calculations

- Technology lifetime: 5 years (under proper maintenance, plants can last 10-20 years (ESMAP, 2007; Herman, 2003). However, interviews with a number of operators in neighboring villages suggested that 5-10 years was typical where the plant operators had limited training for plant maintenance).

- Capital and installation costs: $23,000 (based on 2003 EPRI costs of 342 $/kW (Herman, 2003), with 20% increase for higher prices in Nicaraguan market, or costs to transport from foreign market, such as the US).
- No ongoing maintenance costs would be necessary, in addition to those currently needed for the 110 kW plant.
- NPV = $23,000
- Annualized Valuet: 5,760 $/year

Abatement cost calculations

The HOMER model used a load profile which was based on the load measured on Aug 5, and then was modified to take into account the reduction in street lighting. The measured and modified loads can be found in the excel spreadsheet village MAC curve.xls, and the HOMER file microgrid simulation.hmr has also been provided. The lower heating value (LHV) for the fuel used was HOMER's default value of 43.2 MJ/kg (9.84 kWh/liter). The simulation produced the values of liters/yr in the table below. The KWh/liter value is calculated by dividing the value in the first column, by that in the second. The efficiency is computed as the plant kWh/liter divided by the fuel's LHV.

	kWh/day	Liter/yr	kWh/liter	Efficiency
55 kW plant	197	29232	2.46	25%
110 kW plant	197	37872	1.90	19%
Homer Diesel Value (LHV) kWh/liter	9.84			

- Liters of diesel conserved/yr: 37872-29232 = 8640 liters/yr
- tCO_2/year abated = 8640 liters/year x 0.002688 tCO_2/liter = 23 tCO_2/year
- UAC = 5760 $/year / 23 tCO_2/year = 250 $/ tCO_2
- Marginal abatement cost vs Business as Usual = 250 $/ tCO_2 - 397 $/t CO_2 = -147 $/t CO_2

Wind turbine

The integration of wind generation was modeled using HOMER, and is part of the same file used to simulate the reduction in diesel sizing, microgrid simulation.hmr. Due to the fact that the grid only operates from noon to midnight, both wind and solar electrical systems require some quantity of battery storage capacity to minimize production losses during the time when the grid is not in operation, resulting in slightly elevated lifetime costs for both wind and solar. Thus, energy produced by the wind turbine outside of the hours of grid operation would be stored in a battery bank, and could then be fed into the grid during operation hours. The diesel plant operates as a 'load following' generator, meaning it increases or reduces production in response to demand, and therefore responds to wind/solar production as a 'negative' demand, resulting in the conservation of diesel fuel (Baring-Gould et al., 2003; Hunter & Elliot, 1994).

Annualized cost calculations

- Turbine and tower lifetime: 15 years (based on manufacturer specifications)
- 10 kW turbine: $27,600.

The performance of several wind turbines was modeled using HOMER in class 1/class 2 wind sites. Abundant Renewable Energy's ARE 442 was found to have lower overall lifetime costs than other turbines, even though it required additional hardware costs to make it compatible with both a battery bank and the micro-grid. The wind turbine's power curve has been verified by the US National Renewable Laboratory (NREL) (http://www.nrel.gov/wind/smallwind/abundant_renewable_energy.html). In 2010, Abundant Renewable Energy was purchased by a new company, Xzeres. The authors assume that the Xzeres 442 is the same as the ARE 442 (http://www.xzeres.com/products/xzeres442/).

- Turbine tower (25 meters): $5,000 (this price was based on local fabrication)
- O&M (maintaining the turbine and batteries) : $500/year (Present value: $4,922)
- Inverter: $16,157 (this is more expensive, almost double that of utilizing a typical cost of 0.75 $/W for an inverter. This is because the ARE442 needs to utilize a specific grid-tie inverter (SMA Wind Boy), and then another inverter (SMA Sunny Island) in order to maintain a grid voltage and interface with the battery bank. Even with the additional cost, the ARE 442 produced lower modeled lifetime costs due to greater efficiencies at low wind speeds, in comparison to other wind turbines available in North America.
- Installation, wiring, and shipping: $2,800. Estimation of $1,300 for crating and shipping from the US. $1,500 for land/water transport in Nicaragua.
- NPV of Batteries: $10,000. 32 Trojan L16P deep cycle batteries, with a nominal capacity of 69.1 kWh. Capital cost of $150/battery, O&M of 10 $/yr, and lifetime of 6.5 yrs.
- NPV = $27,600 (turbine) + $5,000 (tower) + $16,157 (inverter) + $10,000 (batteries) +$2,800 (install.) + $4,922 (O&M) = $66,479
- Annualized Value: 7,767 $/year

Abatement cost calculations

- Wind resource. There has been no wind measurement within the villages of Orinoco and Marshall Point. However, the non-profit blueEnergy has a number of wind data sets measured in other villages in the same region. Most of the data sets correspond to Class 1 wind regimes (see http://rredc.nrel.gov/wind/pubs/atlas/tables/A-8T.html for definition of wind classes). Annual wind data from the most complete data set was chosen for this study, and HOMER was used to scale the wind speeds to a class 2 wind regime. Model runs were carried out on both class 1 and class 2 wind sites (see HOMER file). Since only 1 MAC curve was included in this study, the class 2 simulation was chosen due to the fact that it is more illustrative of the impact of wind production in villages that have slightly improved (yet still marginal) wind regimes. A forthcoming publication by the authors includes two cost of conserved energy curves, calculated for the class1 and class 2 wind sites.

Data from the class 1 wind regime are well represented by the Weibull probability distribution, $f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right]$, where *v* is wind velocity with parameters k = 2.4, and c =4.8 at height of 25m. The wind regime scaled to class 2 has Weibull parameters of k = 2.4, and c = 6.5 at 25m. Details of the wind data are available in the HOMER file microgrid simulation.hmr.

- Daily wind production: 54.04 kWh/day (19,726 kWh/year). The turbine produces 21,537 kWh/yr, 1,811 kWh are lost due to shortage of storage capacity in the battery bank.
- Liters of diesel conserved/year: 365 days/yr x (54.04 kWh/day wind generation) / (9.84 kWh/liter) /0.24 = 8019 liters/year[82]
- tCO_2/year abated = 8019 liters/year x 0.002688 tCO_2/liter = 21 tCO_2/year
- UAC = 7,767 \$/year / 21 tCO_2/year = 363 \$/ tCO_2
- Marginal abatement cost vs Business as Usual = 363 \$/ tCO_2 - 397 \$/t CO_2 = -34 \$/t CO_2

[82] Note that this is currently a slight simplification. A more complete calculation would be $\frac{365 \frac{days}{year}}{LHV \frac{kWh}{liter}} \left(\frac{P_1 \frac{kWh}{day}}{\eta_1} - \frac{P_1 - P_{solar} \frac{kWh}{day}}{\eta_2} \right)$