Solar Distributed Generation: An Alternative to Large Scale Hydropower in Costa Rica

Aaron Michael Sutch
Substantial Research Paper

The University for Peace / American University
Natural Resources and Sustainable Development / International Affairs
Summer 2011

Table of Contents

Introduction

Costa Rica's Not So Green Electricity Generation Paradigm

The generation of electricity is a major driver of environmental degradation while also exacting great social costs. Emissions of greenhouse gasses from the burning of fossils fuels used in the generation of electricity are primary contributors to global climate change and localized pollution. Furthermore, land use change from the construction of large generation projects such as hydroelectric dams exacts considerable costs on human populations and local ecosystems. Energy extraction, generation and consumption are major causes of environmental degradation in both developed and developing countries. Heat and electricity generation is responsible for nearly 30 % of all worldwide emissions of carbon (IPCC. 2007). Accounting for full life-cycle costs, including infrastructure, generation and extraction, the environmental and social impact of electricity consumption is a substantial driver of issues related to development and sustainability. The intangible nature of electricity as a power source, delivering clean, convenient power to end use sectors, makes its environmental and social consequences easy to overlook. Yet these consequences, although often geographically and temporally displaced, are none the more tangible requiring immediate action if humanity is going to address one of the biggest threats to environmental and social sustainability.

The country of Costa Rica presents a unique opportunity to compare electricity generation paradigms in light of its wide recognition for environmental sustainability. With nearly 25% of its land mass designated as a protected area and its commitment to achieving carbon neutrality by the year 2021, Costa Rica is often viewed as a model of sustainable development. In fact, the country proudly claims that nearly all of its electricity is generated from renewable sources. However, about 80 percent of this electricity is generated from environmentally-damaging hydroelectric sources. Many would argue that the country's power generation infrastructure relying mostly on large scale hydro power is unsustainable in light of the country's projected growth in electricity demand. There appears to be great interest in developing the country's hydroelectric resources to meet growing demand for electricity. In addition to the 128 MW Pirrís project scheduled to come online in late 2011, there are large hydro projects being initiated on the Río Reventazón in the eastern highlands, on the Río Savegre near the central Pacific Coast and on the Río Grande de Térraba in the far south (Fletcher 2010).The continuing effort to construct large scale hydro power generation projects coupled with the reliance on fossil fuel as a backup generation source exacts environmental and social costs. These costs may be perceived as incompatible with the country's overall commitment to environmental stewardship and warrant the consideration of other electricity generation options. This study aims to investigate and ultimately make a practical case for the viability of solar distributed electricity generation as a socially and environmentally sustainable alternative to large scale hydroelectric projects in Costa Rica. It is intended to be part of a larger dialogue in which politicians, private sector and civil society can make well-informed decisions regarding the ultimate sustainability of the country's electric generation infrastructure. I have chosen Costa Rica as a case study for the following reasons: As Costa Rica is often viewed as a model of sustainable development, there is great potential for lessons learned to be applied to other developing countries in the tropics and global south, in addition, Costa Rica's solar energy sector, while still in its nascent stage, possesses great potential to expand and fulfill an important social and economic role in the country while lastly my internship experience and one year of my current academic experience took place in the country, allowing me to conduct hands-on research.

Through synthesis of current academic discourse, studies of past and current policy frameworks as well as practical experiences gained during my internship with a Costa Rican solar company, I will argue that a solar distributed generation model based on photovoltaic (PV) technology presents a practical, environmentally and socially beneficial way to shift from reliance on large scale hydro. I have chosen to focus on solar PV as opposed to concentrating solar thermal systems due to its ability to be used in modular, distributed generation (DG) systems. This case study will outline the benefits of solar distributed generation and describe a model of its implementation. This work will present a general background and history of Costa Rican electricity generation regimes including analysis of hydro electric generation, situate current academic debate regarding the scalability of renewables, quantitatively analyze the feasibility of a solar-based distributive generation model in the country and make specific recommendations facilitating its implementation. The methodology of the study is primarily qualitative, based on analysis of current theory regarding the implementation of renewables found in academic and trade publications, data collected from interviews of professionals working in the power and renewable energy sectors, and synthesis of my own internship experience with a Costa Rican solar company. I also draw on quantitative analysis from technical publications as well as general data collection from academic and non-academic sources. The limitations of this study include the challenges of linking academic theory and realities on the ground, the short time frame in which to cover a relatively complex issue, personal biases towards renewables as well as my lack of background in engineering and physics.

In spite of this study's inherent limitations, its importance lies in the fact that it addresses the implementation of scalable renewable generation applicable to development models in other countries. As large hydro, coupled with other traditional sources of electricity generation, encounters limits imposed by increasing scarcity of water and fuel resources as well as the growing trend to internalize full life cycle social and environmental costs, an analysis of alternatives becomes important and timely. There appear to be relatively few studies addressing specific strategies for shifting away from hydro to non-traditional renewable sources in developing countries. In fact, there seems to be a regional push to develop hydro resources in Central America (Anderson Pringle and Rojas 2009, Valladares 2010). In providing a case-appropriate solution applicable to Costa Rica, my greater hope is that other countries regionally and worldwide can build upon the lessons presented in this case study moving towards more socially and environmentally sustainable methods of electricity generation.

Chapter 1

The Promise of Renewables

In order to place current debate within the renewable energy context, it is helpful to review the basic technical aspects of electricity generation and transmission infrastructure. Most industrialized countries use a centralized model of electricity generation relying on power plants located outside urban centers to generate electric power supplied through transmission infrastructure known collectively as 'the grid'. Grid infrastructure contains power lines, voltage transformers and other 'power conditioning' equipment to deliver safe and useable electricity to end use sectors such as residences, industrial and commercial sites (Gates 1983). The nature of grid electricity is that it is often made and consumed on demand (literally within seconds) as it is challenging and expensive to store. Although technology in storage devices (apart from pumped hydro) such as fuel cells, batteries, flywheels and capacitors has advanced considerably, it is prohibitively expensive and technologically immature. An electrical utility must constantly generate what is referred to as 'baseload' electricity in order to meet the minimum average power needs of its customers (Smil 2003). This is a relatively stable amount of power based on average consumer demand over a specific time period such as a year. In general, hydroelectric, fossil fuel, nuclear, biomass and geothermal provide predictable baseload electricity due to the relatively consistent supply of their fuel source. In addition to baseload power, seasonal or even daily variations in demand may require the utility to produce more or less power at any given time. For example, extensive air conditioner use during certain times of the day or throughout summer months can require more power to meet demand than what is supplied from baseload generation. In this case, utilities must use ‘intermediate ‘or ‘peak demand’ generators to satisfy this additional spike. These ‘dispatchable’ generation resources can be put online often in a matter of minutes but tend to be more expensive (and in some cases more inefficient) to run. Historically, thermal power plants have been the most common type of power generators. These plants use fuels ranging from coal, natural gas, nuclear, biomass, and petroleum derivatives to directly or indirectly drive a generator producing electricity.

Renewables including wind, solar photovoltaic (PV), and concentrating solar power (CSP) (without storage capacity) are referred to as ‘intermittent’ generation resources. Unlike baseload generation plants, they do not always provide a predictable supply of power. This is due to the simple fact that the sun does not shine all the time nor does the wind blow consistently. Given the fact that electricity is expensive and difficult to store on a large scale, the intermittency of renewable generation is considered one of its biggest drawbacks as consumers desire a predictable and steady source of electricity. For this reason, plants that have a reliable source of fuel in the form of coal, gas, nuclear or even hydro (to a lesser extent) have historically been used to satisfy electric demand (Gates 1984). Much of the current infrastructure has been built around a centralized generation model in which large power plants operating just outside major population centers transmit electricity via high-voltage electric power lines to load centers in a mostly predictable manner. This type of generation network is the dominant paradigm in use in many countries today (Smil 2003). An alternative to centralized distribution exists in the form of distributed generation (DG). With

DG, electricity from relatively small, localized units provides power to satisfy local demand relying less on long distance transmission and large, centralized power facilities. This type of generation infrastructure is more favorable to renewable power sources and will be explained in more detail in the forthcoming chapters.

There is robust debate centering on the ability of renewable energy sources to meet scalability challenges in replacing the highly centralized, technologically mature and subsidized fossil-fuel-based electricity generation paradigm used in much of the world. There is also debate on their ability fully to integrate within the grid infrastructure. The challenges of replacing a widespread and well-established system with immature, developing technologies embodied in renewable energies are nearly impossible to overstate. Caltech professor Nate Lewis states, “Energy is the single most important technological challenge facing humanity today” (Lewis 2007). The historical lentitude of energy transitions, the physical nature of renewable based sources, as well as the changes required to upgrade and adapt infrastructure for renewables are major points of contention in assessing their ability to replace non-renewable sources. On one side of the debate, pessimists doubting the ability to make a smooth and rapid transition to widespread use of renewables, cite the inertia inherent in energy infrastructure and sheer time requirements for energy transitions as reason that fossil fuel technologies will continue to dominate the energy generation landscape for some time. On the other side, those arguing that a rapid shift towards the widespread integration of renewables is not only possible but inevitable cite an abundant renewable resource supply, technological optimism, market trends, as well as a greater impetus to internalize the full environmental, economic and social costs of fossil fuels.

Environmental Scientist Vaclav Smil is one of the prominent voices arguing against the ability of renewables to rapidly integrate into widespread scalable use in the short term. Defining energy transition as “the time that elapses between the introduction of a new primary energy source and its rise to claiming a substantial share of the market or becoming the single largest contributor or leader in national or global energy supply”, he asserts that such a shift takes a substantial amount of time measurable in decades (Smil 2008). For example, citing what he calls ‘the last great energy transition’ in which the world shifted from wood-based biomass fuel to mostly coal-based fossil fuels, he notes that starting in the 1850’s it took 40 years for coal and other fossil fuels to equal the same amount of energy produced from biomass sources (Smil 2006). He also argues that unlike the current transition to renewables, this transition was to fossil fuels, a more energy dense fuel source containing more energy per unit of weight and volume apart from being more convenient to transport and use than the biomass they replaced (Smil 2006). In addition to the slow transitional phase of switching to a new fuel source, Smil cites the inertia of changing an energy infrastructure already in place. In his article *The Harsh Realities of Energy,* he notes that it took 45 years for the U.S. to raise its crude oil up to 20 percent of energy supply and natural gas required 65 years to do the same. Furthermore, he observes that coal accounted for 66% of U.S. electricity generation in 1950 and still provided 49% in 2007 (Smil 2009). He sees this inertia as an inherent difficulty in converting existing infrastructure to accommodate renewables. Furthermore, Smil cites the difficulty in rapidly constructing a renewable energy infrastructure, stating "…whether it is converting the country's filling stations to natural gas or hydrogen, or building new long-distance high-voltage transmission lines to carry Arizona's solar electricity to New York and North Dakota's wind power to California, the new requisite infrastructures are unlikely to be completed in the next few years" (Smil 2008). Energy writer Jeff Vail, in what he refers to as the 'renewables gap', further alludes to the difficulty of adapting infrastructure accommodating renewables in saying: "our infrastructure is currently adapted to burning oil…Therefore to the extent we want to use renewably-generated electricity to replace this oil we need to adapt this infrastructure to electricity...using renewable-generated electricity will require additional investment in the transmission grid to handle higher loads and to balance or store electricity"(Vail 2009).

Boston University professor and founding editor and chief of The Energy Library, Dr. Cleveland Cutler, expresses concerns similar to Smil regarding the magnitude of an energy transition to renewables. In his essay: *Energy Transitions Past and Future* , Cutler notes that the scale of a current transition from fossil fuels would be unprecedented in size. "Consider what it would take today to replace even just one-half of U.S. fossil fuel use with renewable energy: we would need to displace coal and petroleum energy flows of 2.9 T W (Terawatts), or 32 times the amount of coal used in 1885. Current global fossil fuel use is about 13 TW, so we need more than 6 TW of renewable energies to replace 50% of all fossil fuels. This is a staggering shift."(Cutler 2007). In addition to the size of such a shift, Cutler, like

Smil before him, brings to light the difficulty in switching to a less power dense source of energy citing initial reduction of energy return on investment (EROI) by switching to renewables. He notes that fossil fuels are extremely energy dense offering very high energy production per unit of earth area due to the large amount of geologic energy invested in their formation (Cutler 2007). In order to achieve the same amount of energy production offered by fossil fuels, renewables require large amounts of land needed to concentrate their diffuse power characteristics. Cutler asserts the only renewable resource with the sheer physical capacity to overtake fossil fuels would be solar which would still have problems with land requirements, intermittency, as well as up-front cost in equipment (Cutler 2007). Yet unlike Smil, Cutler expresses some degree of optimism that an energy transition may indeed take place in spite of the obvious technological challenges: "The need to restrain carbon emissions may provide the political and social pressure to accelerate the transition to wind, biomass and solar, as this is one area where they clearly trump fossil fuels" (Cutler 2010).

In spite of Cutler's measured optimism and Smil's pessimism regarding the ability of renewables to rapidly overtake the current fossil fuel infrastructure, many argue it is only a matter of time before they become the world's dominant electricity generation paradigm due to their inherent net social and environmental benefits compared to fossil fuels. Although possessing differing implementation strategies and time horizons, there appears to be a unified voice from nearly all in the environmental field believing a relatively rapid transition to renewables is not only within reason but is inevitable. Author and president of the

Earth Policy Institute Lester Brown asserts that “Just as the nineteenth century belonged to coal and the twentieth to oil; the twenty first century will belong to the sun the wind and energy from the earth” (Brown 2008). Janet Sawin in her 2004 Worldwatch Paper *Mainstreaming Renewables in the 21st Century* states: “Renewable technologies are poised for a global takeoff as they impose significantly lower, social, environmental and health costs than conventional fuels, They are generally domestic, pose far fewer fuel and transport hazards and are much less vulnerable to terrorist attack.” (Sawin 2004 :7). Energy writer Howard Geller asserts that renewables can provide all the energy consumed in the world and that an ‘energy revolution’ is taking place because humanity can no longer live with the costs in climate change, geopolitical security, local and regional air pollution and social inequities imposed by fossil fuels (Geller 2003). World Wildlife Fund Director General James Leape states, “By 2050 we could get all the energy we need from renewable sources… such a transition is not only possible but also cost effective providing energy that is affordable for all and producing it in ways that can be sustained by the global economy and the planet” (Deng 2011: 7).

One of the main voices promoting renewables has been Amory Lovins. Author and chief scientist for The Rocky Mountain Institute, Lovins has been writing on the topic of replacing fossil fuels with renewable sources since the 1970’s when he published *The Soft Energy Path*. He argues that a transition from fossil fuels to renewables can be made swiftly and economically by shifting away from a centralized generation model, as well as improving end-use energy efficiency. In his 2010 article *Renewables, Micropower, and the Transforming Electricity Landscape* he states, “The transition from fossil fuels to renewables is only one of the shifts transforming the electricity landscape. Equally important is the ‘scale story’- the transition from large to small scale and away from giant central thermal power plants to micropower” (Cohen, Bennet, Lovins 2010). He asserts that ‘micropower’ (distributed generation) in which electricity generated by smaller scale, mostly renewable-based units for local use, can be a key factor in facilitating an energy transition. He argues that micropower, with its lower financial risk, modular nature, easy implementation into existing grid infrastructure, more efficient transmission profile and potential to use mostly renewable power sources will help facilitate such a transition (Cohen, Bennet Lovins 2010). He writes, for example, that of all the new generation capacity put online in the U.S., 43% was micropower compared to 44% for gas and 12% for coal centralized power plants (Cohen, Bennet, Lovins 2010). In addition to shifting towards a model of distributed generation, he asserts that energy efficiency measures aimed at reducing end-use demand can be another key factor in the coming energy transition. In his essay *Profitable Solutions to Climate Oil and Proliferation* he argues that improving efficiency standards can drastically curtail the burning of fossil fuel inputs needed for the production of electricity (Lovins 2010). For example, he states that “electricity generation is nearly 50 percent coal in the U.S. and about 42 percent worldwide, so each unit of electricity saved displaces 3 units of carbon intensive fuel” (Lovins 2010). This savings is due to the fact that electricity generation from thermal power plants converts only about one third of the original primary energy content into electricity. Hence, for each unit of electricity used, approximately 3 units of primary fossil fuels went into generating it. Lovins argues that efficiency measures aimed at achieving massive savings in the building, transport, and commercial sectors will allow renewables to more easily fill in the gaps and integrate fully into domestic and world energy profiles (Lovins 2010). Geller corroborates this position in stating “Greater energy efficiency would reduce growth in energy consumption, decrease investment requirements…shifting to renewable energy sources would address all the problems associated with a business as usual energy future” (Geller 2003: 16).

Apart from energy efficiency and the shift of generation paradigms, the crux of the debate centers on the ability of renewable resources themselves to meet the challenges in providing for a growing human population of energy consumers. These challenges, outlined by Smil and Cutler, need to be addressed if renewables are to displace fossil fuels and dominate energy production. Richard Smalley of Rice University in his article *The Terawatt Challenge* asserts “what we need to do is find the new oil, a basis for prosperity in the 21^{st} century that is as enabling as oil and gas has been in the last century”(Smalley 2005). Yet many argue that renewable resources are more than ample to meet world demand for energy in spite of their disbursed and intermittent nature. Jacobson and Delucchi in their article *Providing all Global Power with Wind Water and Solar Power* note that worldwide wind resources near shore and overland can provide between 73-100 TW energy production, half of which could be developed. Developable solar resources in the form of PV and CSP account for even more at 580 TW, making wind and solar capable of powering the world at 3-5 times and 15-20 times respectively at projected worldwide energy consumption patterns of 17 TW

(Jacobson, Delucchi 2010). They assert that the only barriers to producing all new energy by wind wave and solar (WWS) by 2030 "are social and political not technological or economic"(Jacobson, Delucchi 2010). Using a different metric, Saya Kitasei in *WorldWatch Report 184, Powering the Low Carbon Economy* , estimates the current recoverable wind energy resources at 570 Quadrillion BTU, much greater than the 450 BTU global primary energy consumption in 2008. His estimate of solar resources is even greater at 1,500 Quadrillion BTU (Kitasei 2010). Cutler himself, when studying energy return on investment (EROI) profiles for wind energy concludes that "wind is in a favorable position relative to other forms of power generation…(and) could yield significant economic and social relative to other power generation systems" (Kubiszewski, Cutler, Endres 2009: 225). In addition to the sheer potential of wind and solar, other renewables (not accounting for sustainable biomass) such as geothermal and tidal power offer robust developable potential in a combined 48 terawatts (Jacobson, Delucchi 2010). In fact, the World Wildlife Fund citing the IPCC Working Group III, states that geothermal can provide up to 10 times current energy production (Deng 2011: 34). Although the literature points out that many single fuel sources are capable of providing for all of the energy needs of the planet, many argue that a combination of renewables used where regionally appropriate will be the most likely scenario to displace fossil fuels (Brown 2008, Sawin 2004, Geller 2003).

In addition to the physical potential of renewables in providing energy, many point to the increasing growth rates in installed capacity and new investment as a sign that renewables will quickly scale up and integrate to existing infrastructure.

Brown makes the comparison to the takeoff of telecommunication industry in which mobile phone and personal computers grew at impressive rates often leapfrogging older technologies, noting that this type of growth is happening in the renewable industry (Brown 2008). For example, in the *Renewables 2010 Global Status Report* Sawin and Martinot state that renewables reached 1,230 gigawatts of capacity in 2009 up 7% from 2008 and now supplies about a quarter of global capacity (including large hydro) (2010). Specifically, wind capacity grew to 38 gigawatts in 2009 representing a 41% increase over 2008. In addition, grid connected solar power increased an estimated 7 gigawatts from 2008-2009 representing a 53% increase while between 2004 and 2009 grid connected PV grew at annual average rate of 60% (Sawin, Martinot 2010). Kitasei further highlights this growth noting "in marked contrast to fossil fuels, renewable energy (excluding hydropower) has achieved growth rates of more than 20 percent for the last five years with solar power averaging 40 percent (Kitasei 2010). Furthermore, according to UNEP report *Global Trends in Sustainable Energy Investment,* between 2008 and 2009 renewable energy still grew faster than conventional energy sources in spite of the economic recession (Holer, Tyne et al. 2010).

As renewables achieve increased market penetration, many are citing the capability to move towards a new technologically advanced energy infrastructure incorporating what is often referred to as 'smart grid' technology to address both demand and supply side issues of renewable integration. Kitasei, notes that technologies improving grid reliability on the supply side will include wider geographic displacement of renewables, interconnected grids, and energy storage in the form of pumped hydro as well as rapidly advancing technologies including lithium ion batteries, compressed air, molten salt, and hydrogen. On the demand side, technologies such as advanced metering and a range of smart appliances will react to real-time price information allowing for balance of increasing variable loads (2010). Lovins asserts that intermittency issues can be resolved by taking demand-side measures aimed at efficiency. This would include curtailing non-essential loads during peak energy usage intervals, switching to a distributed generation paradigm as well as relying on more accurate weather forecasting to better aid the in the prediction of sun and wind (2009,2010). WWF argues that dynamic pricing strategies can encourage customers to purchase power when it is cheap and abundant and discourage use when it is scarce and expensive . This, as well as increasing grid interconnectivity to enable aggregation of renewables over a greater geographic area, can smooth out supply and demand fluctuations further addressing intermittency issues associated with large scale renewable integration (Deng 2011). Furthermore, Sawin, as does Lovins, cites the benefits of switching to a locally-based distributed generation network reducing transmission inefficiencies and facilitating the modular construction of power sources (Sawin 2004, Lovins 2009). Many argue that these technological advances will pave the way for a new energy generation paradigm and hasten the spread of renewables by directly addressing their weaknesses in providing reliable, scalable energy (Sawin & Martinot 2010, Lovins 2009, Brown 2008). Thus, as the above review of literature demonstrates, there are excellent arguments supporting the ability of renewables to make a full-scale integration into electricity generation infrastructure. Their capacity to provide in excess of all human societal energy needs coupled with increasing market penetration and emerging technology facilitating integration into electricity generation paradigms, positions them as a clear successor to the current fossil fuel-based electricity generation paradigm.

Chapter 2

Hydropower and Costa Rica

In spite of increasing dialogue surrounding renewables as scalable replacements to fossil fuel generation, large scale hydro power (generally defined as more than 10 megawatts (MW) (McCully 2001) is receiving less attention as a means towards ultimate sustainability. Although the concept of large scale hydropower can vary depending on country, for the purpose of this work it will be defined as generation greater than 10 megawatts (MW) requiring a large reservoir affecting natural river flow (McCully 2001, Rothkopf 2009). Accounting for about 20 percent of the world's electricity generation (WCD 2000) and being traditionally viewed as a clean and renewable electricity generation source, large scale hydro projects have come under intense scrutiny due to their negative environmental and social impacts. This has lead to increasing doubts regarding their overall sustainability and viability as a development model. This marks a major shift in public perception, since historically large dams were often touted as sustainable or renewable resources and given great reverence as symbols of societal development. As the historian McCully writes,

> Massive dams are much more than simply machines to generate electricity and store water. They are concrete, rock and earth expressions of the dominant ideology of the technical age: Icons of development and scientific progress. (McCully 2001: 02)

Yet, as more public policy analysis and academic study are undertaken assessing the net environmental and social costs of large hydro projects, the irony of associating sustainability with the brute imposition of man's will over nature is becoming more evident. Many are questioning a development paradigm implementing large top down projects privileging the “national” interest while imposing large environmental and social costs on local communities. Many grassroots movements, transnational NGOs, as well as dam-affected people have cited these costs in their ever more widening critiques of this development model (WCD 2000). These projects disrupt and change the physical and social landscape by excluding populations from inhabiting the land while altering the physical and biological landscape of upstream and downstream communities. All too often, the human rights costs in forcible relocations are enormous, the ecological damage profound, and the benefits in flood control and electricity generation not as great as initially hoped.

Social Consequences

When subjected to analysis, dam construction for hydro electric projects sets into motion a large and often complex set of social consequences affecting local populations. Cernea divides the social impacts into four categories including: 1) Forced population displacement and impoverishment: 2) Boomtown formation around major constructions; 3) Downstream unanticipated changes in agro production systems; and 4) Loss of cultural assets (Cernea 2004). The forced population displacement and impoverishment of local populations is not only a problem of numbers as it is estimated that 40-80 million people worldwide have been displaced by dams (WCD 2000), but also a problem of content and nature. According to Cernea, consequences such as (a) Landlessness; (b) Joblessness; (c) Homelessness; (d) Marginalization; (e) Food insecurity; (f) Increased morbidity; (g) Loss of access to common property resources; and (h) community disarticulation are among the many issues faced by peoples displaced from their land (Cernea 2004:14). The establishment of 'boomtowns' around dam construction with imported labor brought into often traditional and remote communities can cause social, health, economic and cultural problems at a local level (Cernea 2004 : 5). Communal agricultural systems dependent on 'recessional' or 'wetland' agriculture taking advantage of seasonal flooding and nutrient flows from upstream sources are adversely affected by the construction of dams and may lose production altogether (Cernea 2004: 6). McCully expands on this idea by citing examples of downstream livestock grazers as well as traditional fishing livelihoods being lost from lack of seasonal flooding in addition to upstream flooding resulting in further resettlement due to seasonal land inundation (McCully 2001:69-70). Lastly, the loss of cultural assets is more difficult to quantify as their value is intrinsic. Yet Cernea divides them into two categories: underground areas of historical importance and current locations of religious significance used by current generations (Cernea 2004)). All of the four factors are exacerbated when the peoples being displaced are of indigenous origin. The resettlement and social disruption of indigenous peoples is traumatic because of their strong spiritual ties to the land, the communal bonds and cultural practices which define societies and the loss of common resources from which they base their economy (McCully 2001: 70).

Environmental Consequences

In addition to the many wide ranging social costs of large hydro projects, an increasing body of evidence supports the idea that they are environmentally unsustainable. Not only do they alter and drastically affect river habitats causing damage to both upstream and downstream flora and fauna, but recent studies have shown that they are also net emitters of greenhouse gasses. The World Commission on Dams (WCD) and McCully cite the primary environmental effects of large hydro projects as: decreased biodiversity, impeded fish migration, reduced upstream and downstream water quality, increased disease prevalence (e.g. malaria), increased downstream erosion, flood danger, reduced floodplain soil replenishment (WCD 2000, McCullly 2001). When examining the specific effects on flora and fauna the Foundation for Water and Energy Education offers the following:

> Riparian vegetation and its bordering waters provide critical habitat for birds, waterfowl, and small and large mammals. When a hydroelectric project results in inundation of a free-flowing river, the nesting, forage, and cover provided by these areas is temporarily or permanently lost. (FWEE 2010)

This loss is often in critical habitats key to the reproduction cycles of many plants and animals. River and floodplain ecosystems play important roles in hatching, migration and other vital lifecycle stages of flora and fauna. (McCully 2001 :47) Furthermore, changes in sedimentation and nutrient flow both upstream and downstream are altered permanently. Changes in water pH and siltation levels can further alter the delicate balance of river and floodplain ecosystems. In addition to these negative effects on local ecosystems, studies by Fearnside examining the greenhouse gas emissions of dams have concluded that dams in the tropics emit considerable amounts of greenhouse gasses in the form of carbon dioxide and methane. Fearnside’s studies of greenhouse gas emissions from the Tucuruí dam in Brazil as well as citations of measurements taken from the Balbina dam in Brazil and Petit-Saut Dam in French Guiana confirm that a surprising amount of greenhouse gas in the form of methane from vegetation decaying anaerobically underwater is released into the atmosphere (Fearnside 2009). According to Fearnside, organic matter originally buried during construction of the reservoir or accumulated from carbon entering it every year, decomposes in the thermally stratified, oxygen-poor water near the bottom of the reservoir. This lack of oxygen ends with decomposition producing CH4 (methane) rather than C02 (carbon dioxide). This methane is released once it flows through turbines and spillways (Fearnside 2009). Because one ton of methane has the global warming impact of 21 tons of carbon, dams in tropical areas are a significant contributor to climate change (Fearnside 2009). This is in addition to the C02 emitted from the massive amounts of concrete and fossil-fuel powered machinery required to build the physical dam structure itself as well CO2 and methane released from exposed decaying vegetation during reservoir draw-downs.

Hydropower in Costa Rica

Costa Rica, with its rich freshwater resources, has had a long relationship with hydro power. Up until 1980, Costa Rica generated 100% of its electricity from hydropower. Since 1958, fifteen large dam projects and numerous small ones have been completed (Fletcher 2010). Only 47% electrified in 1973, the country is currently 99% electrified with most of that electricity provided by hydro power (Nandawani 2005). The country's hydropower network consists of numerous generators located primarily on gradient breaks in mountainous areas of the country with a majority located in the central region (see figure 1). The largest of which is the 177 MW Angostura hydro station situated 120 km east of San Jose in the in the Cartago province (Grupo ICE 2010). Many smaller and medium sized hydro operations ranging from over 100 MW to under 10 MW make up a significant part of the hydro generation profile. These generators are either operated by ICE, Compañia Nacional de Fuerza y Luz (CNFL) (a private corporation but majority-owned by ICE) or by private interests selling electricity to ICE (Anderson Pringle and Rojas 2006). As of 2009, hydro projects produced 78% of the country's electricity with the rest made up mostly by geothermal (12%), fossil fuels (5 %), wind (4%) and 1% from a mix of biomass and solar (Minaet 2010). Yet, there have been widespread environmental and social costs resulting from the construction of these hydroelectric projects. Costs range from damage to river ecosystems, displacement of human inhabitants of the affected areas as well as lost tourist revenue from river recreation activities such as fishing and whitewater rafting. In spite of these costs (not to mention the greenhouse gas emissions outlined by Fearnside), the Costa Rican government has plans to move forward with new hydro projects as they aim to achieve the widely publicized goal of achieving carbon neutrality by the year 2021 championed by former president Arias. The fact that hydropower is largely perceived as 'clean energy' despite emerging evidence to the contrary has fueled a push to implement more large scale projects as a way of reducing greenhouse emissions (McCully 2001). Costa Rica appears interested in implementing more hydro projects to achieve 'clean' electricity generation with the ultimate goal of achieving carbon neutrality and reducing dependency on fossil fuels (Minaet 2010). The Costa Rican national electricity company, *Instituto Costaricense de Electricidad* (ICE) has proposed seven new dams with a potential of 1440 MW. Three projects on the Rio

Reventazón, the Rio Savegre, and Rio Grande de Térraba have already been initiated. The last one, named El Diquís, will be the largest in Central America with a height of 170 meters and a generating potential of 631 MW (Fletcher 2010 :16,17, Grupo ICE 2010). Large-scale projects such as the Diquís as well as other ones on the Río Reventazón are seen as "essential" to fulfill projected energy demand in the country by 2010 (Minaet 2010: 23).

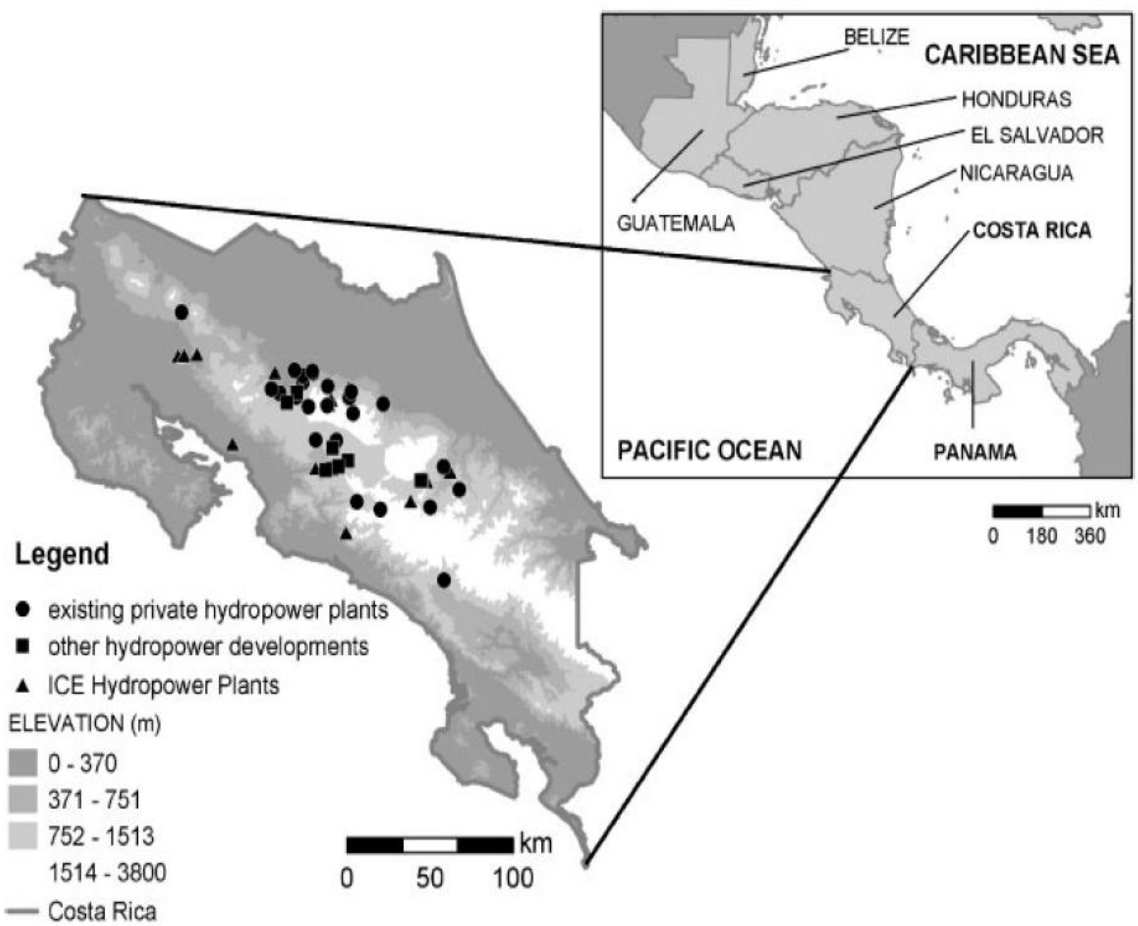

Figure 1. This map shows existing hydropower installations owned either privately or by ICE. Source:Anderson, Pringle, Rojas 2006:681)

Hydropower and Policy

Costa Rica has traditionally relied on policy frameworks supporting a centrally-based hydropower generation infrastructure with ICE the dominant player in transmission and generation. Law 7200 known as the "Private/Parallel Generation Law" was passed in 1990 with subsequent modifications taking place in 1995. The result was to limit electricity produced by private entities to 15% of national capacity and cap the size of private power plants to 20 MW. This protected ICE's primary role in generation and transmission as well arguably hindered increased efficiency and participation of non-hydropower distributed renewable resources (ACOPE 1995). In spite of this approach, there appears to be a shift towards a liberalization of the electricity sector which may open up more opportunity for private, renewable-based distributed generation within the ICE transmission framework. The legislative assembly is currently debating the General Electricity Law Expediente 1812 which would allow up to 35% percent of national electricity to be produced by private sources thus creating a wholesale market for electricity in which private producers including those employing renewables would compete with the public utility and amongst themselves to supply electricity at the cheapest price (Pardo 2010). Furthermore, In October 2010, ICE initiated the Distributed Generation Pilot Plan in which residential and small business renewable energy sources such as solar, wind, micro hydro and biomass, would be connected to the power grid via a two way meter. This allows the customer to feed back any excess generation of electricity produced back to the grid with possibility of receiving a zero balance on their electricity bill (Grupo ICE 2010). According to members of ICE, the purpose of this project is to research the effects of distributed generation on transmission infrastructure as well as investigate market effects and rate designs generating data for the possible implementation of a Feed in Tariff (to be explained in Chapter 3)(Grupo ICE 2010).

Policy shifts allowing for more private generation, although not explicitly expressing a departure from the entrenched hydropower paradigm, demonstrate an increased consideration of other types of electricity generation on behalf of Costa Rican government. The deployment of liberalized energy markets and possibility of progressive measures such as a Feed In Tariff for distributed renewables has the potential to break the near monopoly that hydropower has had on electricity generation in the country. In fact, spikes in oil prices and highly publicized events such as the Gulf oil spill have brought an increasing sense of urgency regarding the need to operationalize a diverse array of clean energy technologies to address the environmental as well as energy security concerns of Costa Rica. In her July 03, 2010 editorial featured in *La Nación* newspaper, newly elected President Laura Chinchilla emphasized the following points regarding Costa Rica's national energy policy:

> The energy policy that we will put forth in the coming years will be based on the clear principles of conservation, sustainable development, universal solidarity, efficiency, competiveness, innovation, valuing the environment, and the social and economic participation of both the public and private sectors….. In spite of the contribution that petroleum has played in the development of the twentieth century, it has been a cause of atmospheric warming bringing with it a punishment to future generations. Our country has the opportunity to act in this regard and prepare ourselves right now to substitute the use of petroleum with renewable and sustainable sources of energy (Chinchilla 2010).

If actions are to follow words, the social and environmental costs of large scale hydropower projects will have to be considered when determining the sustainability of Costa Rica's electricity generation paradigm. It is evident that these projects have tangible, deleterious effects on both the environment and human populations, making them incompatible with a policy trajectory based on the principles of sustainability, conservation and human equity outlined by President Chinchilla. The aforementioned consequences of greenhouse gas emissions, damage to riparian habitats and loss of biodiversity make large hydro projects unsustainable from an environmental perspective while the social costs of population displacement, economic marginalization and loss of cultural assets makes them unsustainable from a social perspective. For example, the Diquís hydroelectric project being initiated in the southern region of Costa Rica will displace 1,547 persons (resulting in 60 million dollars in resettlement payments), inundate 915 acres of indigenous territory as well as flood 3.6 kilometers of the Central American highway (Grupo ICE 2010). The project has encountered opposition from the indigenous Teribe people as well as environmental organizations concerned about effects to riparian habitats flooded to construct the reservoir (Earth First 2011). Furthermore, in light of emerging frameworks such as the country's goal of carbon neutrality by the year 2021, continued development of large scale hydropower with its high emissions of methane will effectively make this goal harder to reach. The Diquís project, in addition to other large hydro installations such as the nearly completed Pirrís facility, requires the construction of a large reservoir and subsequent inundation of land burying huge tracts of organic matter (Grupo ICE 2010). The decay of this material in tropical reservoirs, according to Fearnside, has the potential for high methane emissions (Fearnside 2009, Lima et al. 2007).

Costa Rica would be well-served to implement energy generation policies addressing and accounting for the social and environmental impacts of large hydro projects. A paradigm of unquestioning confidence in large hydro power could be replaced with one of caution and full consideration of costs and favorable alternatives. By maximizing the benefits of existing hydro projects as well as internalizing full social and environmental costs of future projects, the country would match its political objectives with concrete actions. Such actions would most likely shift the country's power generation towards more socially and environmentally benign sources of generation such as renewables, yet a complete departure from hydropower would not be likely. Instead, renewables and other measures such as end use efficiency improvements would gradually integrate into the energy paradigm complementing existing hydro power infrastructure while decreasing the need for continued construction of new projects. This integration would be a step towards balancing growing electricity demand with a trajectory of socially and environmentally sustainable development.

Chapter 3

Integrating Solar Distributed Generation

The incorporation of solar DG into Costa Rica's electricity generation paradigm would offer social and environmental benefits while complementing and potentially improving the reliability and efficiency of the electricity grid. The wide scale deployment of a DG system based on solar photovoltaic (PV) technology can initially complement and support the country's current centralized generation model while over a longer horizon be capable of providing an ever increasing share of the nation's electricity. This would shift the current electricity generation trajectory away from large hydro to an alternative more compatible with the country's goals of environmentally and socially sustainable development. As mentioned earlier, such a shift would not encompass a rapid decommissioning of existing hydro resources yet rather a deliberate and consistent transition to a source of energy externalizing considerably less environmental and social costs on local populations and the environment. Although a transition away from large hydro would be beneficial and arguably in the country' best interest, there are still challenges needing to be addressed before it occurs. These challenges include intermittency, cost, policy and regulatory hurdles reflecting the institutional and political inertia of large hydro. Yet given the country's robust solar resources as well the potential net social and environmental benefits of solar DG, such a transition is not only possible but some would argue that it is inevitable.

Costa Rica's Solar Resources

Costa Rica is a tropical country lying between 8 and 11 degrees north latitude from the equator. Its weather is divided into two seasons: rainy and dry. The rainy season generally runs from May until January and is characterized by clear mornings and rainy afternoons with rain occasionally lasting all day. The dry season with clear, sunny days extends from late December until May (Eggar 2011). In addition to the marked difference between rainy and dry seasons, weather patterns in the country can also vary greatly based on elevation and regional microclimate. The country's higher mountain elevations experience cooler temperatures and receive more consistent rainfall and cloud cover throughout the year. The Central Valley, in which the capital of San José is situated, is known for relatively moderate temperatures and rainfall patterns closely dictated by the dry and rainy seasons while the lowland Pacific and Caribbean coastal regions experience a marked difference between rainy and dry seasons with individual variances in timing and intensity. Although solar output may be diminished in areas of higher elevation or during rainy season due to cloud cover, Costa Rica, as a whole, is considered by many experts to have excellent solar resources. The North Pacific province of Guanacaste is considered to have the most abundant solar resources in the country due to its long, arid dry season (Carey 2011). Based on a study by the Universidad Nacional de Costa Rica (UNC), the country receives an average of 1500 kilowatt hours (KWh) of sun energy per square meter. With an average land area of 50,000 km2 the total solar energy received is equal to 75,000 terra watt hours (TWh) per year. This output was 2600 times the 28 TWh of energy consumed in 2005 (Nandwani 2005). The Costa Rican Ministry of the Environment, Energy and Telecommunication

(MINAET) identifies 10,000 MW of solar resources that could be theoretically developed. To put this in perspective, geothermal and wind energy which both accounted for nearly 15% of the country's 2009 energy production, have a theoretical development potential of 1,465MW. Solar energy with 10,000 MW has over 6 times the development potential of wind and geothermal and approximately 40% of the potential of hydropower which currently accounts for 78% of the country's electricity production (MINAET 2010). Utilizing other metrics, solar still appears to be a robust yet vastly underutilized resource accounting for less than 1% of all electricity generated in the country (MINAET 2010). This is despite the ample sun radiance known as 'insolation' that Costa Rica receives. Insolation is the average amount of direct sunlight falling on a location measured by the average amount of direct 'sun hours' a location receives per day. For example, accounting for seasonal variation and cloud cover, Costa Rica averages between 4.5 – 5 direct sun hours a day depending on local microclimate (see figure 2). This is considered favorable to wide scale solar use and is about the same average that the state of Florida, USA, (known as the 'Sunshine State') receives. In comparison, Germany, the world leader in solar PV implementation, receives less than 3 sun hours on average or about the same as the U.S. state of Alaska (NREL 2010).

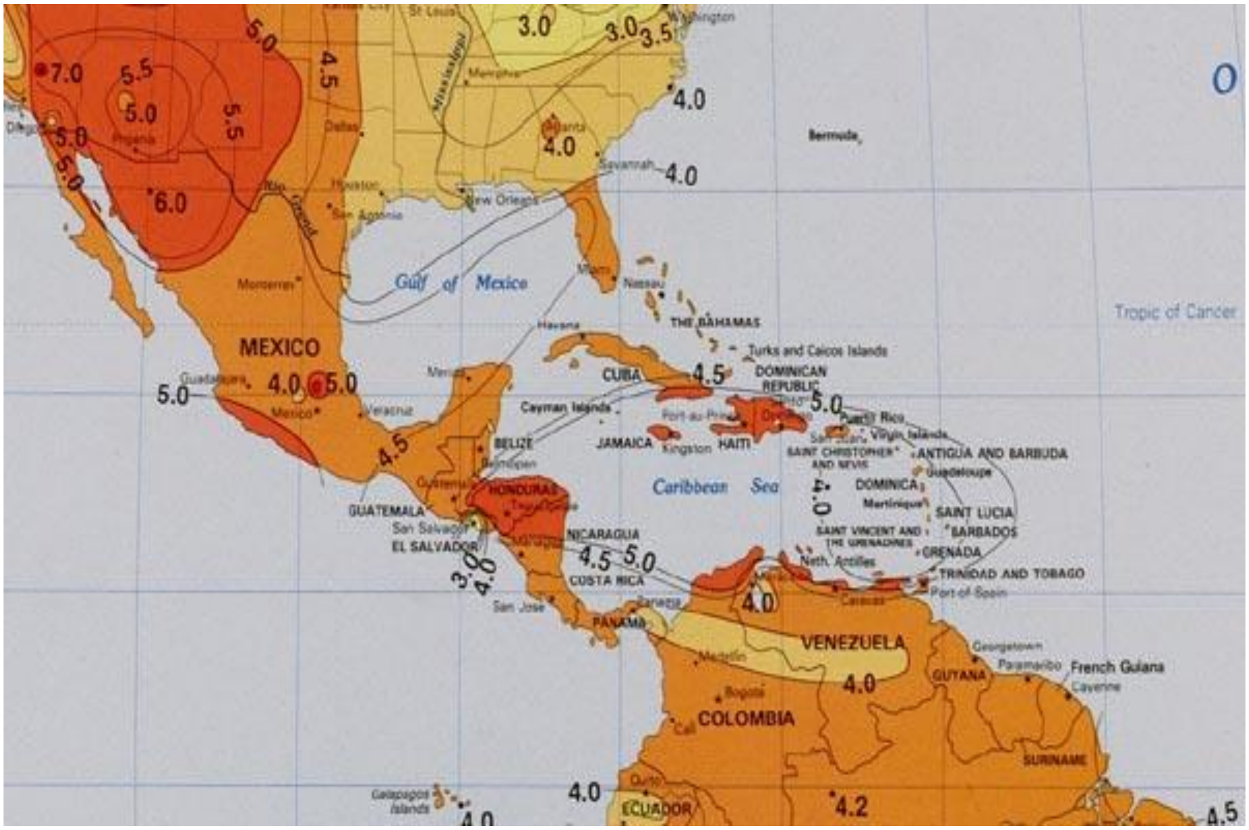

Figure 2. Insolation rates measured in average 'sun hours'. Source: NREL Solar Insolation Map: North America, Central America and Caribbean

Environmental Benefits of Solar PV Compared to Large Hydro

The expansion of PV-based solar DG taking advantage of Cost Rica's rich solar resources has the potential to diminish the environmental costs associated with the expansion of electrical capacity in the country. Meeting the country's projected 5-6% projected annual growth in electricity demand(Grupo ICE 2010) within the current large hydro-based trajectory means continual construction of new generation and transmission infrastructure damming rivers, permanently altering sensitive habitats and producing methane emissions. If this growth in demand were met with solar DG integrated into existing building infrastructure the land use consequences as well as emission of methane would greatly be reduced or avoided. Solar DG incorporated onto existing building infrastructure requires very little land use change or additional construction of transmission and distribution infrastructure as electricity is either used on site or fed back into the grid via existing transmission equipment. Furthermore, solar PV does not emit any pollutants as a by-product of energy production. This is in contrast to large hydro, which in tropical areas can produce more GHG emissions than similar fossil-fuel powered facilities (Fearnside 2009, McCully 2006). The urban and peri-urban areas of San José would be favorable locations to utilize roof-space and grid infrastructure already in place to produce solar DG electricity. These areas with their existing residential and commercial buildings could produce electricity without major changes in land-use regimes. In addition to environmental benefits realized from reduced land-use consequences, solar PV compares favorably to large hydro when using life-cycle analysis employing the concept of 'embodied energy' which Fernando and Bodger define for energy systems as "the energy cost of the entire life cycle process chain including raw materials extraction and transportation, plant construction, energy generation and recycling and disposal stages following actual use"(2010). The embodied energy in solar PV systems results from the raw material extraction, manufacture, transport and disposal of system components. Depending on the type of panels and system requirements, it can take 1 to 4 years to recoup the energy required to manufacture solar components (NREL 2010, Bankier and Gale 2006). In addition to being considerably less than large hydro and fossil fuels, the embodied energy in solar is negligible in light of the long useful life of PV systems (often over thirty years) (Branstetter 2010). Costa Rica, by employing solar DG to meet increasing demand for energy, can potentially decrease land use consequences and emissions of methane while using a source of electricity with considerably less embodied energy.

Socioeconomic Benefits of Solar DG in Relation to Large Hydro

Apart from its environmental benefits, solar distributed generation has the potential to provide an alternative to the population displacements and pejorative effects to local communities embodied in large hydro development. Construction of large hydro often entails considerable disruption to local landscapes and the communities inhabiting them. For example, the indigenous Teribe people will lose 658 acres of land to the Diquís project already underway in the southern part of Costa Rica (Univ Texas 2011). The Diquís dam will flood at least 10% of the Teribe's land inundating a large number of sites of possessing cultural, religious, and archeological significance to the Teribe people (Earthfirst 2011). Previous hydro projects such as the Arenal have flooded towns and resulted in substantial disruption to communities by changing free flowing rivers into lentic (slow-moving) systems (Anderson Pringle Rojas 2006). The completion of the Angostura hydroproject on the Río Reventazón in the year 2000 substantially impacted the region's whitewater industry and local economy dependant on river guides and influx of paddlers for tourism revenue (Fletcher 2010). Solar PV installations do not involve the massive relocation of human populations and subsequent loss of cultural, social and economic assets. Their integration onto existing building infrastructure requires very little (if any) land-use change. If the country incorporated more solar PV into existing infrastructure to meet growing demand for energy, the need to displace and affect local populations with large hydroprojects could be obviated.

Deployment of solar DG can benefit both national and local-level economies in Costa Rica by providing long-term employment options and opportunities for industry growth. There are currently 33 solar PV installation and distribution companies in the country (Grupo ICE 2011). Most of these companies are small-scale operations with no more than 5 full-time employees. Yet more robust deployment of solar DG in Costa Rica can stimulate expansion of the country's solar energy sector leading to increasing numbers of companies and employment opportunities for the country's citizens. Costa Rica, reflecting regional trends in Latin America, has the potential for a surge in green jobs due to the slow employment growth in traditional industries and greater labor intensity of renewables (Garten Rothkopf 2009). Furthermore, with solar PV creating more jobs per unit of energy production than any other renewable energy technology (Wei, Patadia and Kammen 2009) there is great potential for the country's relatively small solar sector to grow substantially. This growth, in contrast to the destabilizing 'boom and bust' cycles of hydro projects (Cernea 2004), would provide long term employment for national and local communities while preserving areas of cultural and communal importance. Furthermore, solar DG could integrate into regional economies providing an economic multiplier effect stimulating local-level economic sectors not directly related to solar. For example, Rancho Mastatal, a sustainable learning center and ecolodge located 50 Km west of San José, offers participants of solar workshops the opportunity to stay with local families in the community providing the families an opportunity to generate additional income (Rancho Mastatal 2011). Additionally, solar DG has the potential to empower all members of the community from youth to women creating long-term 'distributed' employment for a diverse array of skill sets. (Wei, Patadia and Kamman 2009). In Costa Rica these types of employment opportunities would exist in building, construction and installation of systems as well as administrative and support work.

Solar DG within Costa Rica's Electricity Generation Model: A Technical Case for integration

Currently, electricity generation in Costa Rica is based on a centralized distribution model in which a relatively small number of power plants generate electricity transmitted to 'load centers,' or areas where it is consumed by end users (Minaet 2010). ICE is the government-owned monopoly in charge of all the transmission and a vast majority of the electricity generation (ARESEP 2010). Electricity is provided primarily by hydroelectric power plants dispersed throughout with country with most located in the more mountainous central region (see figure 1). Electricity produced from these plants is distributed to population centers throughout the country via high voltage transmission lines. Although offering benefits mainly in the form of electrical grid reliability, economies of scale allowing for larger generation plants, and the ability to place generators outside major population centers reducing localized pollution and land use consequences, there are many disadvantages to the centralized distribution model (Martin 2009: 8). These include transmission and distribution infrastructure costs, inefficiency in transmission resulting in power loss, limited rural electrification, grid insecurity as well as the environmental and social costs associated with large centralized generation facilities (Martin 2009: 10). For example, in industrialized countries such as the U.S., up to 8-10 percent of power generated is lost through transmission (National Council on Energy Policy 2009:17). This number is even higher in developing countries in which poorly maintained or substandard transmission equipment can bring losses as high as 40 percent (Sawin 2004:14). Furthermore, the electrification of rural areas poses challenges for centralized models as expansion of transmission infrastructure such as power lines is cost prohibitive and thus demonstrates what many would argue is the need for decentralized models (Nandwani 2005).

Compared to centralized distribution models using a relatively small number of large-scale generation facilities often located long distances from end use sectors, distributed generation (DG) sources are smaller electric generation systems located at or near the site where they are used and may be fueled with renewable or non-renewable sources. Such systems may include micro turbines, fuel cells, small reciprocating engines, micro hydro, wind turbines, photovoltaic panels as well as combined cycle engines (Brinch 2010). When compared to centralized models, DG offers many advantages mainly in the form of increased efficiency via reduced transmission infrastructure, minimal siting requirements, reduction of peak demand, increased grid reliability and power quality, shorter lead times in construction, ability to utilize renewable fuel sources and increased security from terrorism (DOE 2007). For example, solar DG projects readily integrate into existing building infrastructure providing electricity for the grid while requiring no new transmission and distribution infrastructure (although large-scale penetration of renewables may require upgrades to grid infrastructure). In addition to reduced transmission losses as a function of minimized transmission infrastructure, solar DG benefits the local grid by offering peak demand reduction, voltage regulation and other ‘ancillary services’ related to power quality. In contrast, large, centralized hydropower projects require careful siting considerations, construction of new transmission infrastructure and take a number of years to build. Although individual hydropower projects tend to generate a much greater quantity of electricity compared to solar DG projects, (a large hydropower generator can produce in the hundreds of MW compared to an individual solar installation which may produce a few KW) it is possible to aggregate many small solar DG generators across a wide geographic range to produce in the MW range making up for the smaller output of individual units. For example, inter-regional aggregation of generators in areas of robust solar resources such as the Guanacaste province could help produce in the MW range while helping to smooth out supply profiles resulting from local weather factors.

The development of a solar-based DG model in Costa Rica can complement the existing hydroelectric infrastructure while potentially obviating the continued construction of large hydro projects and the use of thermal power plants as peak demand generators. Based on Costa Rica’s electricity generation profile as well as the unique attributes of solar photovoltaic applications, solar generation from distributed sources could provide electricity to meet peak daily and seasonal demand when hydro capacity is at its lowest. This has the potential to diminish or ultimately avoid the use of more costly thermal power plants supplying peak demand. For example, solar photovoltaic panels produce at their highest output during Costa Rica's dry season (January – May) when clear, sunny days prevail. This is when hydro output is significantly diminished due to lower water levels in reservoirs (Minaet 2010). In addition, these hot 'summer' months often correspond to the highest consumer demand for energy-intensive cooling devices such as air conditioning and ventilation fans. As a result, daily peak electricity demand during these times is often provided by fossil fuel-powered thermal plants making up for lack of hydro generating capacity. In 2009, fossil fueled power plants (burning imported diesel and bunker fuel) generated 4.8% of the country's total electricity with even higher percentages of 8% and 9% in 2007 and 2008, respectively (Minaet 2010). These plants produce GHGs and other pollutants, are expensive to build and operate and lead to energy security concerns. For example, ICE has finished construction of the Garabito thermal plant which cost $360 million dollars (U.S.) to build and will emit up to 2,728 tons of CO_2 per year in addition to other particulate emissions (Aguero 2010). Furthermore, because Costa Rica does not produce any petroleum, all fossil fuel powering thermal plants has to be imported from foreign countries such as Venezuela, Mexico, Nigeria, leading to energy security concerns (Minaet 2010). Including the Garabito facility, the country currently maintains four fossil fuel-powered thermal plants supplying peak power during the dry season (Aguero 2010). If peak seasonal demand and a growing percentage of the country's 5-6% projected annual growth in electricity demand (Grupo ICE 2011) were met by a robust distributed generation infrastructure of solar PV, the necessity to rely on polluting, capital intensive, thermal power plants and the construction of large hydro power plants could be obviated.

Challenges to be Addressed

The challenges of intermittency and high cost of solar PV must be addressed when proposing its wide-scale integration into Costa Rica's electricity generation profile. As an intermittent resource, many assert that solar DG needs to be coupled with robust grid or customer-side storage to provide reliable power on par with traditional sources of generation such as hydro (Ton et al.2008, Epri 2010, Smally 2005). While not downplaying the importance of storage, Lovins, amongst others, argues that intermittency issues can also be addressed through the development of 'smart grid' technologies with demand-side load management as well as aggregation of individual generators over a wide geographic range coupled with accurate forecasting (2010, Deng 2011). It seems likely that a combination of large-scale storage capacity as well as smart grid technologies would help facilitate an increasing deployment of solar in Costa Rica. Yet until such storage and smart grid technologies are technically, economically and commercially feasible, solar DG in its current form would have to integrate into Costa Rica's electricity generation structure as a less predictable resource incapable of providing highly-valued baseload capacity. In spite of this limitation, solar DG still offers valuable services as a complement to the country's hydroelectric baseload generators by improving system reliability, reducing peak power requirements, as well as providing grid ancillary services (Ton et al. 2007).

High up-front costs present another major challenge to the integration of solar DG in Costa Rica. High costs associated with solar PV are a result of capital investment in solar modules (panels) and balance of system (BOS) components including wiring, mounting, electrical power conditioning equipment and installation. These fixed capital costs (mostly in components) account for over 90% of total system expense and contribute to higher 'levelized cost' reflecting capital as well as variable operating costs assessed over a lifetime per unit of energy output (Holtberg 2011). Depending on the type of system and region in which it is installed, levelized cost of solar PV in Costa Rica ranges anywhere from 21 –50 cents per kWh (Poderco 2011, Carey 2011, Zwick 2011) compared to 5-10 cents per kWh for hydro (Aguero 2011, ARESEP 2011). In addition to higher levelized costs, solar PV in Costa Rica requires significant financial outlays in order to initiate. In contrast, the country's state-supported hydro infrastructure makes it easy to use mostly hydro-generated electricity as customers need only initiate an electric utility account with ICE or any of its regional affiliates. The use of solar PV requires the purchase of a complete system, which in Costa Rica can cost upwards of $10,000 for the most basic of systems with more robust systems commonly retailing for over $40,000 (Solar Costa Rica 2011, Poderco 2011, Intitech 2011). Furthermore, Costa Rica's lack of substantial policy support for solar PV forces private investors to bear the burden of high capital costs with little assistance in the form of public investment and favorable policy regimes aimed ameliorating such costs. Even with return on investment (ROI) or 'system payback' horizons as low as 9-10 years (Poderco 2011, Zwick 2011), solar PV tends to be a prohibitively expensive investment for most Costa Rican businesses and private citizens.

In spite of these high costs, the prospect of favorable policy regimes (to be discussed in the following) as well as continuing price reductions in module and BOS costs has the potential to make it more cost-effective. With over 90% of the cost of solar PV embodied in modules and BOS (Holtberg 2011), considerable price reductions are possible due to technological advances and increased competition amongst manufacturers (Holtberg 2011). For example, between 1998 and 2005 PV modules experienced an average price drop of 4.8% per year (Wiser, Barbose, Peterman 2008:8). Between 2008 and 2009 the price per watt of PV modules dropped by 40% from between $3.50-$4.00 per watt to $1.85-$2.25 per watt. (SEIA 2010:6) With modules making up over 50% of the total PV system cost, a reduction in their price has a drastic effect on overall system costs. Furthermore, advances addressing BOS costs accounting for the other 50% of system cost can drive further price reductions. For instance, Bony et al. assert that a BOS cost reduction improvement of 50% over current best practices is 'readily achievable' and has the potential to make PV more competitive with conventional generation sources (2010:1).

Solar in Costa Rica

In spite of very favorable solar resources, solar PV is still minimally employed on a national level in Costa Rica. With solar contributing to less than 1% of the national electricity mix, the country possesses no solar manufacturing capacity and very little standardization or certification of solar providers (Carey 2011). ICE, although the central state actor in the development of the country's energy infrastructure, has had an arguably minimal role in efforts to develop a viable solar infrastructure. Apart from controlling transmission and generation regulatory regimes affecting solar and other renewables, most of their direct participation with solar has been with rural electrification projects bringing solar energy to off-grid areas or pilot projects feeding a small amount of solar electricity into the grid from panels placed on thermal generation plants. ICE claims to have brought solar electricity to over 1000 areas since 1980 (Grupo ICE 2011). Although arguably laudable, such efforts could be also labeled as pragmatic given that is often more cost-effective to install a solar distributed system in a remote area than to expand transmission and distribution infrastructure serving a limited amount of customers (Ton et al. 2007, Martin 2009). Furthermore, the total amount of solar generation capacity ICE feeds back to the grid from thermal power plants is minimal. For example, the solar output of all four plants participating in national grid-feed pilot projects (San Antonio, Barranca, Colima and Garabito) adds up to a total installed capacity of 38.5 KW (Grupo ICE 2011). This is about the same installed capacity used to power 2 medium size houses (Solar Costa Rica 2011).

In spite of what can be viewed as limited past participation by state actors such as ICE in promoting solar infrastructure, two important developments with the potential to positively impact solar penetration in the country have taken place. First, the Costa Rican Environmental Ministry (MINAET) in the last quarter of 2010 announced that renewable energy components are exempt from sales tax (Solar Costa Rica 2011). This means that customers purchasing solar components including panels, batteries, and other BOS components do not have to pay the

13% nationally- imposed sales tax. This results in substantial reductions in component price while potentially increasing customer demand due to the lower net price of solar PV systems. The second, and arguably the most important step, has been ICE’s October 2010 introduction of the ICE Distributed Generation Pilot Program (IDGPP). The IDGPP allows customers to connect to the grid allowing bi-directional flows of electricity between the customer and utility. In essence the grid acts as a giant battery supplying electricity to the customer when solar production is low or non-existent while absorbing excess electricity when there is an oversupply of solar production. This allows customers to feed excess electricity generated from renewables back into the power grid with the possibility of receiving a zero balance on their utility bill (Grupo ICE 2010).

The IDGPP is an extremely important development likely to stimulate the country’s nascent solar industry through cost reduction and simplification of solar PV systems. Before the introduction of the IDGPP, nearly all of the solar PV installations in Costa Rica were ‘off grid’ or ‘stand alone’ systems employing battery storage technologies. Although offering benefits in the form of energy independence and rural electrification, these systems are less efficient and more expensive than similar grid-connected variations. Batteries add around 40% to the price of a system, decrease total efficiency by up to 20% and require regular maintenance (Butler et al. 2008, Solar Costa Rica 2011). Since the introduction of the IDGPP, customers now have the option to purchase a cheaper and easier to maintain ‘grid tied’ system. For example, when comparing the prices of two similar PV systems from Solar Costa Rica located just outside of San Jose, there is a significant cost differential between grid-tied and remote systems requiring batteries. As of June 2011, cost (excluding tax and installation) of an 8 KW grid tie system was $9700 while an identically-sized system requiring batteries was $15,700 (Solar Costa Rica 2011). Because system cost is one of the biggest barriers to widespread customer adoption, cost differentials such as these will result in more customer interest. Several local companies including Solar Costa Rica, Poderco, Intitech, and Interdinamica have noted increases in business due to the IDGPP in spite of the program being in effect for less than 1 year old (Zwick 2011, Poderco 2011, Dovale 2011, Interdinamica 2011).

Policy Options as a Solar DG Roadmap for Costa Rica

Although recent steps made in tax exemption for renewables and the IDGPP are promising, Costa Rica must still address lack of favorable policy structures, institutional inertia favoring hydropower and lack of incentives to develop non-hydro renewables. Despite the country's reputation for coupling development with environmental stewardship, Costa Rica faces the same obstacles encountered by the rest of Central and Latin America in implementing solar and other non-hydro based renewables. These obstacles, in the form of regulatory shortcomings, lack of policy incentives and limited access to financing, have held back the widespread deployment of non-hydro renewables in the region (Garten Rothkopf 2009). Furthermore, Costa Rica's traditional reliance on large hydro and the fact that its environmental and social sustainability is still largely unquestioned by government officials may help to explain the relative lack of effort in addressing such obstacles. Teófilo de La Torre, head of Costa Rica's environmental ministry (MINAET), sums up the attitude of many occupying high-ranking government positions regarding the country's large hydro trajectory in this 2011 quote: "We will continue to make efforts to keep ICE as the leading hydroelectricity producer…ICE's expertise in clean energies will keep us the leader in green electricity in Central America. It is one of the most successful institutions in the country"(Tellez 2011). In light of such unquestioning faith in large hydro, it is easy to see why renewables such as solar face policy and regulatory hurdles hampering their development. Meisen and Krumpel assert that this is part of a broader trend in which Latin American countries relying on a locally abundant resource (in this case hydro) lack the incentive and foresight to invest in non-hydro renewable energy and create appropriate renewable energy policies and regulatory frameworks (2009). Although, Costa Rica has been recognized for progressive, government-sponsored initiatives promoting wind and geothermal (Rothkopf 2009), there are still measurable gaps in financing, regulatory frameworks and national policies promoting solar DG programs.

Addressing Policy Gaps

It is an opportune time for Costa Rica to address policy gaps hindering widespread deployment of solar and other renewable distributed sources. Instead of focusing on individual projects, top-down policies would aim to create regulatory and market structures maximizing benefits to private investors, public utilities and ratepayers. This type of framework would embody the "social and economic participation of both private and public sectors" outlined by president Chinchilla in her plan for national energy policy (Chinchilla 2010). Ideally, the central government would establish national goals for renewable DG generation while empowering both private and public sectors to achieve them through an architecture of enabling regulatory frameworks. This would incentivize private investment in the scale-up and deployment of renewable energy while lending public support addressing the cost and intermittency limitations of renewables themselves (Weicher et al.). Indeed, some progress has been made towards this end with the introduction of the IDGPP as well as pending legislation promoting increased private sector participation in the energy wholesale market. However, these can be seen as merely preliminary steps towards enacting the large-scale and robust policy measures needed to facilitate the integration of solar and other renewable DG.

Official targets aimed at achieving a given percentage or additional capacity of non-hdyro renewables are a critical first step in Costa Rica's progress towards adopting effective policy measures increasing the integration of solar DG in overall power mix. Since their introduction internationally in the 1980s, government-mandated policies establishing targets for renewable energy have impacted the speed and extent of renewable development exerting substantial influence on market, investment and industry developments (Weischer et al. 2011, Sawin and Martinot 2010). Germany, currently the world leader in solar PV implementation, has employed ambitious renewable energy targets aimed at increasing national share of renewable energy to more than 35% by 2020 up to a total of 80% by 2050 (Lacey 2011). National policy targets for renewable energy exist in over 85 countries worldwide (as of 2010) with numerous other ones existing on sub-state and local levels (Sawin and Martinot 2010: 35). These targets along with diligent political follow-through, characterize many successful approaches increasing renewable energy deployment worldwide. Costa Rica would be well-served in establishing quantifiable targets for non-hydro renewable generation. Such targets would underline political commitment to the future role of non-hydro renewables while providing a level of certainty to investors (Wiescher et al. 2011). In addition, they may provide technical and administrative data enabling the development of larger-scale policies. Such targets could be small and incremental at first increasing in size as regulatory and payment mechanisms become more robust.

Once concrete goals are established, then appropriate regulatory and implementation mechanisms can facilitate the deployment of renewable DG. Ideally, these mechanisms would provide an institutional framework bridging the gap between national goals and multi-sectorial participation. One such framework is ‘net metering’ or ‘two way metering’ allowing customers to offset or receive credit on their utility bills by sending electricity produced on-site back to the grid. Net metering is a key driver of solar installation and one of the most important incentives for electricity customers to install renewable DG (Branstetter 2010). Due to its relative ease of implementation and ability to be used as an accounting mechanism for bi-directional electricity flows, net metering is often seen as an important first step in establishing more complex distributed generation regimes (Newton 2007). Costa Rica currently has in place the very limited IDGPP allowing customers to receive a zero balance on utility bills with no option to receive cash credits for excess generation. Furthermore, the plan is not available country-wide and has total limit to participation of 5 MW (ICE 2011). Although the IDGPP is an important first step, it would be in the country's best interest to develop a more robust net metering program allowing customers country-wide to receive cash credits for electricity produced in excess of consumption. This would help build the administrative and institutional capacity needed to deploy more overarching and effective policy measures such as the Feed in Tariff.

A Feed in Tariff (FIT) is a type of Power Purchase Agreement (PPA) in which a government establishes a guaranteed rate that a private or commercial power producer will be reimbursed for each kWh of renewable electricity fed into the grid. This usually involves a long term contract with price per kWh determined by the type of generation. FITs are considered one of the most successful mechanisms for incentivizing renewable generation as 75% percent of global solar PV capacity was supported by FITs in 2008 (Weischer et al. 2011). According to Roney, "The most important solar incentive to date is the feed-in tariff, which guarantees generators of renewable electricity—including homeowners, private firms, and utilities—a long-term purchase price for each kilowatt-hour they produce. This powerful incentive to invest in renewables has now been adopted by some 50 countries" (2010). This incentive improves return on investment horizons for residential and commercial investors and helps to overcome many market inequities privileging fossil fuels, large scale hydro and other mature technologies (Geller 2003). Bruce Carey, owner of Solar Costa Rica, states that the introduction of a FIT in the country would be one of the most crucial steps to encouraging widespread investment in solar. The ability to sell excess electricity back to the grid would allow solar investors to more quickly recoup their investment improving return on investment horizons and thus lead to increased willingness to invest in systems (Carey 2011). Once the challenge of determining a per kWh hour rate attractive enough for investors, but avoiding over-subsidization is met, FITs can be very effective in scaling up renewables (Weischer et al. 2011).

The establishment of a FIT serving to increase penetration of solar DG in Costa Rica has the potential to accrue benefits to a wide range of stakeholders. By guaranteeing a price for electricity fed back into the grid, a FIT would reduce risk profiles for investors helping to mediate the high capital cost of solar PV systems resulting in increased private sector investment in distributed generation. Increased private generation as a result of favorable market conditions could provide additional production capacity to utilities without the capital outlays and long lead times required for centralized projects. Furthermore, increased solar DG production resulting from FIT incentives can provide for peak daily and seasonal demand requirements and help to address Costa Rica’s growing national demand for electricity. If a higher percentage of national electric demand was met with solar DG, the need to construct new large hydro projects or rely on polluting thermal generators would be reduced or avoided. In addition to potentially enhancing national electric infrastructure, the aforementioned positive socioeconomic effects of long-term job creation and diminished population relocation resulting from increased solar generation would benefit local populations. A FIT would be an important overall tool in advancing Costa Rica's trajectory toward an environmentally and socially sustainable solar DG energy paradigm.

CONCLUSION

Real challenges lie ahead for Costa Rica with regard to its energy generation paradigm. It will prove harder to juggle national goals of environmentally and socially sustainable development with an electricity generation paradigm increasingly out of step with these principles. An unquestioning reliance on large scale hydro will undoubtedly run up against limits imposed by its own lack of environmental and social sustainability. The country can yield to inertia clinging to an increasingly unsustainable trajectory or chose to embrace a paradigm more in line with its international reputation as a leader in sustainable development. Although not without its challenges, solar DG has the potential to provide a socially and environmentally sustainable alternative to Costa Rica's continued reliance on large hydro for its electricity generation needs. A measured and deliberate shift integrating solar DG into existing grid infrastructure can produce socioeconomic benefits in the creation of local and national-level employment while decreasing the need to resettle populations for large hydro-development. Furthermore, preservation of riparian habitats, decreased GHG emissions, and lack of massive land use changes would be amongst the environmental benefits brought by widespread deployment of solar DG.

As we have seen, solar PV is capable of providing an alternative to the continuing construction of large hydro in meeting Costa Rica's growing demand for electricity. As Chapter Two demonstrates, the environmental and social consequences of large hydro in Costa Rica are becoming more difficult to overlook in light of emerging data illustrating its effects to climate change, biodiversity and surrounding communities. These consequences are increasingly incompatible with Costa Rica's reputation for environmental stewardship and trajectory of socially and environmentally sustainable development. Solar PV is capable of integrating into Costa Rica's power generation paradigm providing clean, sustainable electricity while externalizing minimal environmental and social costs. Costa Rica possesses ample solar resources and infrastructure to facilitate solar DG's role as a major contributor to the county's overall energy mix. Furthermore, solar DG's unique attributes providing for seasonal and daily peak demand can further facilitate its increasing role in the country's energy profile. Although physically and technically capable of providing an ever-increasing share of Costa Rica's energy, solar DG must overcome policy barriers reflecting institutional inertia favoring large hydro. In spite of this inertia, small, yet promising, steps favoring the increasing role of solar and other renewables are being initiated. These steps can lay the foundation for the development of more robust measures such as the FIT necessary for wider scale deployment of solar DG. FITs and other proactive policy measures would increase deployment of solar DG helping to supply an increasing share of the country's electricity while also spurring the growth of an important domestic economic sector. This growth has the potential to bring economic, environmental and social benefits to a wide range of stakeholders from local communities to businesses and utility ratepayers.

Although offering many benefits, solar DG is no panacea nor is it a quick fix to the energy issues facing Costa Rica. In this light, this work intends to present a realistic picture analyzing challenges as well the attributes and benefits of incorporating solar DG in to the country's energy mix. In addressing the issues of cost and intermittency, two of the most significant challenges to the widespread deployment of solar and renewables in general, I hoped to demonstrate that these challenges are not only surmountable with the right degree of technological, policy and market advances, but are worthy of resolution in light of the many benefits gained from renewable DG. When discussing the disadvantages of large hydro, my intent was to give a practical and well-reasoned analysis of why the ultimate sustainability of large hydro should be called into question. The conclusion that solar DG presents a viable option worthy of serious consideration for Costa Rica will no doubt challenge the country's current institutional and bureaucratic status quo favoring large scale hydro. Yet, a healthy degree of questioning is in order considering the undeniable consequences of such a paradigm. Hopefully this will provide the opportunity and impetus to move forward with electricity generation paradigms reflecting an evolving understanding what is ultimately environmentally and socially sustainable. I believe that many of the arguments and data presented in this work are hard to ignore and will hopefully lead to robust debate and action leading to the incorporation of solar DG in Costa Rica.

References

ACOPE-Ley 7200 Reformada Por 7508." *Asociacion Costarricense De Productores De Energia*. 1995. Web. 27 Dec. 2010. http://www.acope.com//Documentos/.../Ley7200%20reformada%20por%207508.doc

Aguero, Mercedes. "País Desaprovecha Potencial Privado Para Generar Energía." *El Pais* [San Jose, Costa Rica] 07 Dec. 2010, 4A sec.: 4. Print.

Aguero, Mercedes. "Planta Térmica Garabito Ya Funciona a Media Máquina." *La Nacion* 03 Oct. 2010: 1-5. Print.

Anderson, Elizabeth P., Catherine M. Pringle, and Manrique Rojas. "Transforming Tropical Rivers: an Environmental Perspective on Hydropower Development in Costa Rica - Anderson - 2006 - Aquatic Conservation: Marine and Freshwater Ecosystems."*Wiley Online Library*. 2006. Web. 24 Jan. 2011. <http://onlinelibrary.wiley.com/doi/10.1002/aqc.806/abstract>.

ARESEP- Autoridad Reguladora De Los Servicios Públicos." *ARESEP*. 2010. Web. 27 Dec. 2010. <http://www.aresep.go.cr/cgi-bin/index.fwx>.

Bankier, Colin, and Steve Gale. "Energy Payback of Roof Mounted Photovoltaic Cells." *Energy Bulletin*. Energy Bulletin, 16 June 2006. Web. 01 June 2011. <http://www.energybulletin.net/node/17219>.

Bony, Lionel, Stephen Doig, Chris Hart, Eric Maurer, and Sam Newman. "RMI: RMI Report: Achieving Low-Cost Solar PV." *RMI: Rocky Mountain Institute - Driving the Efficient Use of Resources*. Rocky Mountain Institute, Sept. 2010. Web. 01 May 2011. <http://www.rmi.org/rmi/RMIReportLowCostSolar>.

Branstetter, Shannon M. *Distributed Renewable Generation: The Trifecta of Energy Solutions to Curb Carbon Emissions, Reduce Pollutants, and Empower Ratepayers*. Rep. Bepress, Mar. 2010. Web. Apr. 2011. <http://work.bepress.com/shannon_baker_br>.

Butler, Roy, Ryan Mayfield, Jay Peltz, and Joe Schwartz. "Issue #126." *Home Power Magazine: Solar | Wind | Water | Design | Build*. Home Power, July-Aug. 2008. Web. 16 June 2011. <http://homepower.com/issue/?issue=126>.

Carey, Bruce: Future of Solar in Costa Rica." Telephone interview. 12 Feb. 2011. Interview of Bruce Carey owner of Solar Costa Rica

Cernea, Michael. UNDESA. 2004. U.N. Department of Economic and Social Affairs (Division for Sustainable Development) Energy: United Nations Symposium on Hydropower and Sustainable Development27-29 October 2004. Cearna, Micheal. Keynote address: Social Impacts and Social Risks in Hydropower programs. Web: http://www.un.org/esa/sustdev/sdissues/energy/op/hydrosymposium.htm

Chinchilla, Laura**.** Presidential OpEd. “El Futuro Energético” *La Nacion.* 03 July, 2010. Print

Cleveland, Cutler (Lead Author); Peter Saundry (Topic Editor). 2007. "Energy transitions past and future." In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: EnvironmentalInformation Coalition, National Council for Science and the Environment). [First published April11, 2007; Last revised May 3, 2007; Retrieved August 7, 2007].

Cleveland, Cutler. "The Oil Drum | Energy Transitions Past and Future." *The Oil Drum | Discussions about Energy and Our Future*. 8 Aug. 2007. Web. 28 Jan. 2011. <http://www.theoildrum.com/node/2856>.

Cohen, Bennett, and Amory B. Lovins. "RMI: Renewables, Micropower, and the Transforming Electricity Landscape." *RMI: Rocky Mountain Institute - Driving the Efficient Use of Resources*. Apr. 2010. Web. 28 Jan. 2011. http://www.rmi.org/rmi/RenewablesMicropowerTransformingElectricityLandscape

Deng, Yvonne, Barney Jeffries, and Stephan Singer. *The Energy Report - 100 % Renewable Energy by 2050*. Gland: WWF International, 2011. Print.

Dovale, Rafael" representative of Intitech solar." Telephone interview. 20 June 2011.

Earth First*! Newswire*. 31 Mar. 2011. Web. 14 June 2011. <http://earthfirstnews.wordpress.com/2011/03/31/the-terraba-fight-proposed-hydro-electric-dam-in-costa-rica/>.

Eggar, Marc. "Costa Rica Weather Climate." *Worldheadquarters*. Web. 14 June 2011. <http://www.worldheadquarters.com/cr/climate/>.

Energy Matters. "Renewable Energy News : Solar Power : Grid Connect, off Grid and Hot Water Systems, Solar Panels, Batteries, Wind Turbines - Energy Matters Australia." *Solar Power - Grid Connect, off Grid and Hot Water Systems, Solar Panels, Batteries, Wind Turbines - Energy Matters*. Energy Matters, 29 Jan. 2009. Web. May 2011. <http://www.energymatters.com.au/index.php?main_page=news_article>.

EPRI. *Functional Requirements for Electric Energy Storage Applications on the Power System Grid*. Rep. Palo Alto: Electric Power Reserach Institute, 2011. Print

Fearnside, Philip. "Why Hydropower Is Not Clean Energy - Scitizen." *Scitizen, a Collaborative News Publishing Initiative by Scientists, for Everyone.* 09 Jan. 2007. Web. 09 Dec. 2010. <http://scitizen.com/future-energies/why-hydropower-is-not-clean-energy_a-14-298.html>.

Fernando, Deshan, and Pat Bodger. *Embodied Energy Analysis of New Zealand Energy Sytems*. Proc. of Second IASTED International Conference Environmental Management and Engineering (EME 2010), Canada, Alberta. 773-80. Print.

Fletcher, Robert. "When Environmental Issues Collide: Climate Change and the Shifting Political Ecology of Hydroelectric Power." *Peace and Conflict Monitor* 5.1 (2011).*Peace & Conflict Review*. 2010. Web. 24 January 2011. <http://www.review.upeace.org/index.cfm?opcion=0>.

FWEE. Foundation for Water And Energy Education. "Turning to Hydropower" web: 2010 www.fwee.org

Gates, David. Energy and Ecology. P. 55, Sunderland Mass. Sinauer Associates Ince. 1981

Garten, Jeffrey E., and David J. Rothkopf. *A Blueprint For Green Energy in The Americas*. Vol. 1. Washington, DC: Garten Rothkopf, 2009. Print

Geller, Howard. Energy Revolution Washington: Island Press. 2003.

"Germany Trade & Invest - Renewable Energies & Resources Sector." *Germany Trade and Invest - Home*. Nov. 2010. Web. 24 Dec. 2010. <http://www.gtai.com/homepage/industries/renewable-energies/>.

"Grupo ICE:Plan Piloto Generación Distribuida." *Plan Piloto Generacion Distribuida*. Oct. 2010. Web. 27 Dec. 2010. <http://www.grupoice.com/esp/temas/so_plan_piloto/so_plan_piloto_generacion_distribuida.html>.

"Grupo ICE | Proyecto Hidroeléctrico Del Diquís." *PROYECTO HIDROELECTRICO EL DIQUIS*. Grupo ICE, Nov. 2009. Web. 27 Dec. 2010. <http://www.grupoice.com/esp/ele/infraest/proyect/icelec/proy_diquis/proyecto_diquis_icelec.htm>.

"Grupo ICE: Proyectos de Electricidad - Generación." *Grupo ICE Proyectos Hidroelectricos*. 2010. Web. 21 Jan. 2011. <http://www.grupoice.com/esp/ele/infraest/electric/instalac1d.htm>.

Holer, Alice, Alice Tyne, Fatma Ben Fadhl, Nicole Aspinall, Richard Greenwood, and Rohan Boyle.*Global Trends in Sustainable Energy Investment*. Rep. (UNEP) United Nations Environment Programme, 2010. Print.

Holtberg, Paul D. "EIA - Annual Energy Outlook 2011 - Overview." *EIA Annual Energy Outlook 2011*. EIA, 26 Apr. 2011. Web. 30 May 2011. <http://www.eia.gov/forecasts/aeo/>.

IPCC 2007. "IPCC Assessment Report 4 (2007), A Summary for Policymakers. http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf

Jacobson, Mark Z., and Mark A. Delucchi. "Providing All Global Energy With Wind, Water and Solar Power Part I." *Energy Policy* (2010). *Elsevier*. Nov. 2010. Web. Feb. 2011. <www.elsevier.com/locate/enpol>

Kitasei, Saya. *Powering the Low Carbon Economy: The Once and Future Roles of Renewable Energy and Natural Gas*. Rep. no. Worldwatch Report 184. Washington, DC: Worldwatch Institute, 2010. Print.

Kubiszewski, Ida, Cutler J. Cleveland, and Endres, Peter K. "Meta-analysis of Net Energy Return for Wind Power Systems." *Renewable Energy* 35 (2010): 218-25. *Elsevier*. 2010. Web. 14 Feb. 2011. <www.elsevier.com/locate/renene>.

Lacey, Stephen. "No Nukes, No Problem. Germany Is Proving a Rapid Transition to Renewable Energy Is Possible." *ThinkProgress*. Think Progres, 16 May 2011. Web. 25 May 2011. <http://thinkprogress.org/romm/2011/05/16/208107/nukes-germany-transition-renewable-energy/>.

Lima, Ivan, Fernando Ramos, Lisa Bambase, and Reynaldo Rosa. "Methane Emissions from Large Dams as Renewable Energy Resources: A Developing Nation Perspective."*IDEAS: Economics and Finance Research*. Mitigation Adaptation Strategies for Global Climate Change, 2 Mar. 2007. Web. 24 June 2010. <http://ideas.repec.org/a/spr/masfgc/v13y2008i2p193-206.html>

Lovins, Amory B. "Profitable Solutions to Climate, Oil, and Proliferation." *Ambio* 39 (2010): 236-48. *Www.springerlink.com/content/ou401176160q6196/fulltext.pdf*. Royal Swedish Academy of Sciences, 10 June 2010. Web. 15 Jan. 2010.

MacKay, David**.** Sustainable Energy Without the Hot Air PP. 23-24 Cambridge. Cambridge University Press. 2009

Martin, Jeremy. 2009. ED. Antyone Hayifil. *An Introduction to Distributed Generation*. Tech. 2009 Print.

McCully, Patrick M. *Fizzy Science: Loosening the Hydro Industry's Grip on Reservoir Greenhouse Gas Emissions Research*. Rep. Ed. Lori Pottinger. Berlkey: American Rivers, 2006. Print

McCully, Patrick. 2001. *Silenced Rivers: The Politics and Ecology of Large Dams*. 2nd ed. London: Zed Books.

Meisen, Peter, and Sebastian Krumpel. *Renewable Energy Potential of Latin America*. Rep. San Diego: Global Energy Network Institute. Web. 01 May 2011. <http://http://www.geni.org/globalenergy/research/renewable-energy-potential-of-latin-america/Potential%20of%20Renewables%20in%20Latin%20America-edited-12-16%20_Letter_.pdf>.

MINEAT. 2010. "Hacia un Nuevo Modelo Energético para Nuestro País (Costa Rica-Sector Energía)"

Morgan, Jason. "Comparing Energy Costs of Nuclear, Coal, Gas, Wind and Solar." *Nuclear Fissionary | Clean—safe—reliable*. Nuclear Fissionary, 04 Apr. 2010. Web. 30 May 2011. <http://nuclearfissionary.com/2010/04/02/comparing-energy-costs-of-nuclear-coal-gas-wind-and-solar/>.

Nandwani, Shyam S. "Uses of Solar Energy in Costa Rica." *Renewable Energy* 31.5 (2006): 689-701. *Elsevier.com*. Elsevier, 23 Sept. 2006. Web. 12 Nov. 2010. <Elsevier.com/locate/renen>.

NHA. " Hydropower Is Affordable." *National Hydropower Association*. National Hydropower Association. Web. 01 June 2011. <http://hydro.org/why-hydro/affordable/>.

NRDC. "NRDC: Renewable Energy for America: Solar." *NRDC: Natural Resources Defense Council - The Earth's Best Defense*. Web. 30 May 2011. <http://www.nrdc.org/energy/renewables/solar.asp>.
Pardo, Arturo. "Ley General De Electricidad Será Prioridad Uno En Sesiones Extraordinarias." *La Nacion*. 30 Nov. 2010. Web. 27 Dec. 2010. <http://www.nacion.com/2010-11-30/ElPais/UltimaHora/ElPais2608122.aspx>.

NREL. 2010. National Renewable Energy Lab. http://www.nrel.gov/solar/

Oveido, Esteban**. "**El Diquis Sustetuye el gran proyecto Boruca" *La Nacíon* 21 December 2008, Web

Pardo, Arturo. "Ley General De Electricidad Será Prioridad Uno En Sesiones Extraordinarias." *La Nacion*. 30 Nov. 2010. Web. 27 Dec. 2010. <http://www.nacion.com/2010-11-30/ElPais/UltimaHora/ElPais2608122.aspx>.

Poderco. "Solar Information in Costa Rica." *SOLAR ENERGY HOME*. Web. 23 June 2011. <http://poderco.com>.

Rancho Mastatal. "Solar in the Developing World." *Welcome to Rancho Mastatal*. 2011. Web. 14 June 2011. <http://www.ranchomastatal.com/>.

Roney, Mathew J. "Eco-Economy Indicators - Solar Power | EPI." *Earth Policy Institute – Building a Sustainable Future | Home*. 21 Sept. 2009. Web. 24 Dec. 2010. <http://www.earth-policy.org/index.php?/indicators/C47/>.

Sawin, Janet L. *Mainstreaming Renewable Energy in the 21st Century*. Washington, DC: Worldwatch Institute, 2004. Print.

Sawin, Janet and Martinot, Eric**.** "Renewables 2010 Global Status Report." Renewable Energy Policy Network, Sept. 2010. Web. 15 Dec. 2010.

Schwartz, Lou. "China's Growing Confidence in Its Emerging Renewable Energy Leadership | Renewable Energy News Article." *Renewable Energy World - Renewable Energy News, Jobs, Events, Companies, and More*. 23 Dec. 2010. Web. 29 Dec. 2010. <http://www.renewableenergyworld.com/rea/news/article/2010/12/chinas-growing-confidence-in-its-emerging-renewable-energy-leadership>.

Smalley, Richard. "Future Global Energy Prosperity: the Terawatt Challenge." June 2005. *Energy Bulletin*. Web. 01 Jan. 2011. <http://www.energybulletin.net/node/8169>.

Smil, Valav**.**. Energy at the Crossroads pp.89 -91 Boston. MIT Press.2003

Smil, Vaclav. "21st Century Energy: Some Sobering Thoughts." *OECD Observer*. Organization for Economic Co-operation and Development. 2006. Web. 28 Jan. 2011. <http://www.oecdobserver.org/news/fullstory.php/aid/2083/>.

Smil, Vaclav. "Moore's Curse and the Great Energy Delusion." *The American* Nov.-Dec. 2008: 1-6. Web. 26 Jan. 2011. <http://http://www.american.com/archive/2008/november-december-magazine/moore2019s-curse-and-the-great-energy-delusion>.

Smil, Vaclav. "The Harsh Realities of Energy § SEEDMAGAZINE.COM."*SEEDMAGAZINE.COM*. 7 Apr. 2009. Web. 28 Jan. 2011. <http://seedmagazine.com/content/article/the_harsh_realities_of_energy/>.

Solar Costa Rica. "Grid Tied Solar." *Solar Costa Rica Home Page*. Web. 08 June 2011. <http://solarcostarica.com>.

Solar Energy Industries Association. *Solar Industry Year in Review*. Rep. Washington, DC: Solar Energy Industries Association (SEIA), 2010. Print.

USDOS**.** 2010. United States Department of State . Request for Funding Regional Environmental Hub.”Smart Grid Renewable energy projects Costa Rica”

Tellez, Rommel. "Chinchilla Administration Furthers Push for Renewable Energy Sources."*The Tico Times*. 15 Apr. 2011. Web. 13 May 2011. <http://www.ticotimes.net/Current-Edition/Top-Story/News/Chinchilla-Administration-furthers-push-for-renewable-energy-sources_Friday-April-15-2011>.

Ton, Daniel, Georgianne H. Peek, Charles Hanley, and John Boyes. *Solar Energy Grid Integration Storage-Energy Storage (SEGIS-ES)*. Rep. U.S. Department of Energy Sandia Labs, 2008. Print.

University of Texas. *Swimming Against the Current The Teribe Peoples and the El Diquis Hydroelectric Project in Costa Rica*. Rep. Austin: University for Texas Human Rights Center, 2010. Print.

Vail, Jeffrey. "2009 ASPO Presentation - "The Renewables Gap"" *Jeff Vail - Litigation Strategy & Innovation*. www.jeffvail.net, 2009. Web. 01 Jan. 2011. <http://www.jeffvail.net/2009/11/2009-aspo-presentation-renewables-gap.html>.

Valladares, Danilo**.** "CENTRAL AMERICA: Doors Wide Open for Renewable Energy - IPS psnews.net." *IPS Inter Press Service*. 15 July 2010. Web. 15 Dec. 2010. <http://ipsnews.net/news.asp?idnews=52165>.

WCD. World Commision on Dams. *American Rivers WCD 2001*. Rep. American Rivers, 2000. Web. 12 Feb. 2011. <http://www.internationalrivers.org/files/world_commission_on_dams_final_report.pdf>.

Wei, Max, Shana Patadia, and Daniel M. Kammen. "Putting Renewablesandenergyefficiencytowork:Howmanyjobscanthe Clean EnergyindustrygenerateintheUS?" *Energy Policy* 38 (2010): 919-

Wiser, Ryan, Galen Barbose, and Carla Peterman. *Tracking the Sun: The Installed Cost of Photovoltaics in the U.S. from 1998 -2007*. Rep. Washington, DC: Lawrence Berkley National Lab, 2008. Print.

Zwick, Andrew.” Sales Rep fro Solar Costa Rica.” Telephone interview. 20 June 2011