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Renewable energy sector development in the Caribbean: Current trends and lessons from history

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HIGHLIGHTS

► We examine relationships between energy sector players in the Caribbean.
► We conduct a cost benefit analysis of four Caribbean renewable energy projects.
► Results show early, innovative alternative energy projects provide numerous benefits.
► Islands differ greatly in energy industry scale, utility ownership and government involvement.
► We provide subsequent considerations for an enabling regional energy policy framework.

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ABSTRACT

Island regions and isolated communities represent an understudied area of not only clean energy development but also of innovation. Caribbean states have for some time shown interest in developing a regional sustainable energy policy and in implementing measures which could help to protect its member states from volatile oil markets while promoting reliance on local resources. Here we examine four case studies of renewable energy advancements being made by public utility companies and independent energy companies in the Caribbean. We attempt to locate renewable energy advances in a broader historical framework of energy sector development, indicating a few policy lessons. We find that different degrees of regulatory and legislative sophistication have evolved in different islands. Islands should have specialized policy focus, contrasting the ad-hoc nature of current regional energy policy discussion. We also conduct a cost benefit analysis which shows that these early, innovative alternative energy projects show themselves to be both profitable and significant sources of emissions reduction and job creation. This lends support to the potential benefits of regional energy policy.

1. Introduction

Island regions represent an understudied area of potential energy development. Due to the absence of local fossil fuel resources, transportation costs and the lack of economies of scale, these regions generally rely on imported petroleum for electricity generation. Petroleum products are the main source of energy in the Caribbean with 90% of commercial energy supplies being imported into the region (Loy, 2007). Energy expenditure is such a large part of national budgets that the region spends over $4 billion USD a year on oil imports though having a total electricity capacity of less than 6 Gigawatts (GW) (OLADE, 2009). As a consequence some islands now spend as much as half of their export revenues on imported fossil fuels while regional demand, estimated to be growing at 3.7% per year, will double by 2028 (Nextant, 2010). Retail electricity rates in the Caribbean average 0.35 US$/kW h (CARILEC, 2010), finding themselves amongst the most expensive in the world. This is compounded by the geographic parameters of smallness and remoteness which often characterize Small Island Developing States (SIDS) by limiting local resources and market size (Weisser, 2004a,2004b, 2004c).

In response the Caribbean's power supply sector is currently witnessing important changes in its energy regulatory framework. There are a number of energy policy reports such as the CREDP Caribbean Energy Policy 2007 (Loy, 2007) and the Organization of American States' (OAS) Sustainable Energy Policy Initiative Report for Latin America and the Caribbean 2007 (CARICOM, 2007) that regional development agencies have developed to support the advancement of local renewable resources.

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Nevertheless there are a number of barriers that hinder the advancement of renewable energy integration (Mitchell et al., 2011).

In this study we highlight four prominent advances being made by both public utility companies and independent energy companies in both utility and distribution scale technology within the Caribbean. We explore the history of utility ownership and current operations, as well as the history of regulatory bodies and their interactions with utilities, to create a picture of trends in the energy landscape. We learn that island state power sectors vary greatly in structure and operation, with regard to privatization, regulatory oversight and government involvement. Sensitivity to these nuances is an important part of regional policy framework development Fig. 1.

2. Case studies

Grenada, Barbados, Jamaica and the Netherland Antilles are the Caribbean islands that have been selected for study as they represent progressive islands in the region with regard to renewable energy development. They create a spectrum of size, industrialization, economic complexity, energy demand, government involvement and utility cooperation (see Table 1).

2.1. Photovoltaics in Grenada

Grenada Electricity Services Ltd (GRENLEC) has been the sole provider of electricity to Grenada since its establishment in 1960. It was first incorporated as a private liability company subsidiary to the UK's Commonwealth Development Corporation (CDC) but its shares were purchased by the local government in the 1980s. The company was divested in the mid-1990s and is now owned by WRB Enterprises – a US based utility company – and partly by the government of Grenada, the national insurance board, employees, local and regional investors (GRENLEC, 2011). GRENLEC owns and operates one main 39 MW diesel engine generating station in Grenada with two smaller stations in the sister islands of Carriacou and Petite Martinique. Together these stations meet a peak daily load of 30 Megawatts (MW) and produce 195 GW h/year (GRENLEC, 2009). The Electricity Supply Ordinance of 1960 gives GRENLEC sole and exclusive license to generate, transmit, distribute and sell electricity in Grenada for a period of 80 years from incorporation (REEP, 2009). The average domestic electricity rate of $0.34 USD/kW h is one of the highest in the Caribbean region (CARILEC, 2010) and is comprised of a fixed non-fuel charge and a variable fuel surcharge based entirely on diesel fuel (see Fig. 2). The Electricity Supply Act of 1994 makes provision for an adjustment of the non-fuel charge only when the rate of inflation is over 2% and mandates that GRENLEC use a three month average for computing the fuel charge. Aside from these simple rate change mechanisms, the other legal basis for GRENLEC adjusting electricity price is to aid recovery after a natural disaster. This guards against sharp increases in customer rates in any given period and also encourages GRENLEC to consider efficiency measures (GRENLEC, 2008).

In 2005, as the cost of electricity soared to an all-time high after the devastation of Hurricane Ivan, a local Grenadian family founded Grenada Solar Power Ltd (GRENSOL) through private financing. GRENSOL systems tend to perform very well given the solar regime in the Eastern Caribbean. After the early success of three pilot projects, the company succeeded in encouraging GRENLEC to expand its interconnection policy and since 2007 there has been 1:1 net metering at retail rates for systems less than 10 kW (Hosten, 2009). GRENSOL eventually secured a 5% duty and 5% handling waiver after government negotiations to

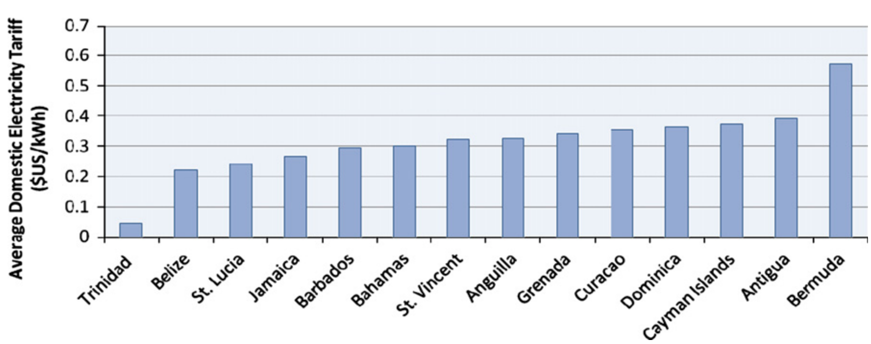

Fig. 1. Domestic retail electricity rates in Caribbean islands (CARILEC, 2010).

Table 1
Summary characteristics of the case study islands as of 2010.

	Grenada	Barbados	Jamaica	Aruba	Curacao
Area (km^2)	344	430	11,000	180	444
Population	110,000	285,000	2800,000	103,065	142,180
GDP per capita	$5,969	$14,307	$4,390	$23,831	$20,567
Regulatory Agency	None	Fair Trading Commission	Office of Utility Regulation	None	None
Utility	Grenada Electric Services Ltd (GRENLEC)	Barbados Light and Power Company (BL&P)	Jamaica Public Services Company (JPS Co)	W.E.B. Aruba N.V.	Aqualectra
Installed Capacity (MW)	49	239	820	149	226
Peak Demand (MW)	30	165	600	77	130
Annual Electricity Sold (GW h)	195	1,068	6,000	782	530
Average Rate (US$/kW h)	0.34	0.29	0.26	0.26	0.35
Official Renewable Energy Share	Less than 1%	Less than 1% (15% with solar water heating)	5% (hydro 4%, wind 1%)	13% (wind)	5% (wind)
RPS Goal	None	20% by 2020	20% by 2030	None	None

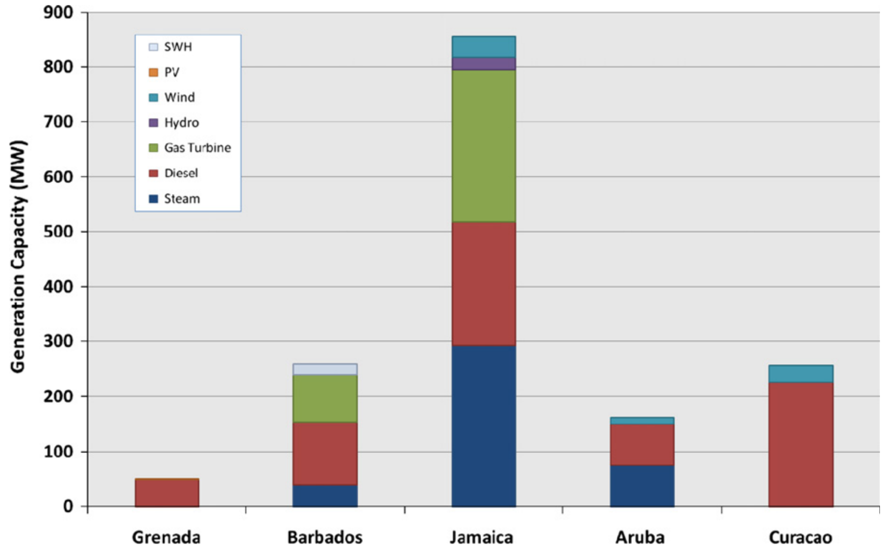

Fig. 2. Capacity by generation type in case study countries.

reduce import costs (Burkhardt, 2008). The cap on net metering significantly limits access to larger customers and along with the modest government subsidy, have contributed to GRENSOLS struggle for support. To date GRENSOL has installed 120 kW (through 25 grid connected systems) (GRENLEC, 2009).

Photovoltaics are not yet cost competitive when compared to the avoided cost of current electricity production in Grenada (see Section 3.1). Furthermore the renewed Electricity Supply Act of 1994 extended GRENLEC's exclusive rights to generate, transmit, distribute and sell electricity through the year 2073. There is little impetus for GRENLEC, a private and foreign owned company, to divest sales by introducing third party generators (GRENLEC, 2007). This situation is exacerbated by the fact that there is no overarching body that governs GRENLEC (Weisser, 2004a,b,c). Only since late 2003 have the Ministry of Agriculture, Land, Forestry, Fisheries, Public Utilities and Energy as well as the Marketing and National Importing Board taken official responsibility for the energy sector, making Grenada one of the few Eastern Caribbean countries with a specific energy unit in government (Loy and Farrell, 2005).

2.2. *Solar water heating in Barbados*

The Barbados Light & Power Company Limited (BL&P) is the sole electricity provider in Barbados. The company started operations in the early 1920s under complete ownership of a London based holding company. In 1955 the company was divested is now owned by primarily Barbadian investors. The minority shares are owned by Canadian International Power Co. Ltd. The 1907 Electricity Supply Act gives BL&P sole rights to generate and transmit electricity and does not make provision for Independent Power Producers (IPPs), prohibiting sale or injection into the grid. Since 2001 the utility has been regulated by the Fair Trading Commission, which was preceded by the Barbados Public Utilities Board, established since 1955 (Leacock, 1976).

Barbados' $0.29 USD/kW h domestic electricity rate is one of the lowest in the Caribbean region due in part to a more diverse fuel mix (CARILEC, 2010) (see Fig. 2). The Government of Barbados has long been an advocate of developing renewable sources of energy. In the 1980s and early 1990s BL&P sold electricity produced from bagasse from local factories during the sugar crop season (Headley, 2002). Since then the utility has installed 40 kW of photovoltaics and is currently considering a 10 MW landfill gas generation plant and a 10 MW wind farm (BL&P, 2011). Even more successful has been development of the solar water heating industry.

The commercial solar water heater (SWH) finds its origins in the 1970s through a local church initiative to provide jobs for young men using the innovation and expertise of industry fledgling Solar Dynamics Limited. A demonstration of the locally designed and manufactured technology at the Prime Minister's residence led to government implementation of initial fiscal incentives to promote the use of SWH (UNDP, 2003). Through the Fiscal Incentives Act of 1974 import tariffs for SWH raw materials have been waived and a 30% consumption tax was placed on electric water heaters (BIDC, 2010). Further, under a 1980 Income Tax Amendment, the full purchase and installation cost of a SWH was allowed as a home-owner tax deduction. This tax deduction was reinstated in 1996 following its suspension during a period of economic recession that extended from the 1980s. The government also actively engaged in purchasing over 1200 units for five different housing development projects since the mid 1970s, further stimulating the industry (UNDP, 2003; Perlack, 2003).

As interest in the new technology grew, other competitors quickly joined the market and by the beginning of the 1980s SunPower Corporation and AquaSol Components Limited had established themselves as industry players. By 2003 there were over 35,000 solar water heaters installed in Barbados, 70% residential and 30% commercial systems—predominantly hotels. Together this represents 30% penetration across building properties in Barbados (Perlack, 2003). More recent estimates put the total at 45,000 installations island-wide (Epp, 2009). Solar Dynamics has expanded to own manufacturing operations in St. Lucia, a distribution center in Jamaica and agents in the Bahamas, Belize, Dominica, Grenada, Guyana, St. Maarteen, St. Vincent, St. Kitts and the British Virgin Islands (CARICOM Energy Programme, 2010).

Government support of the SWH industry is an indication of its interest in local energy resources. Furthermore, unlike most Eastern Caribbean States, the government has a majority stake in BL&P with the National Insurance Board being the largest shareholder. However the 1907 Electricity Supply Act and the 1951 Public Utilities Act are to date the only major pieces of legislation that govern the power sector, making it difficult for IPPs to market themselves. The National Energy Policy was published in 2007 and in 2010 the Fair Trading Commission approved a renewable energy rider pilot project which allows eligible customers with renewable power sources to sell excess power to the grid. The program is currently limited to 5 kW for domestic and 50 kW for other tariff brackets. All electricity supplied to the grid is credited at almost twice the rate of the Fuel Clause Adjustment (BL&P, 2011).

It is difficult to judge the program's success after only a few months however it seems that the capital costs of PV systems and the lack of financing options is a major barrier. Oil price increases may make the program more attractive in the near future but to date there has been less interest shown than expected. Other initiatives from the Fair Trading Commission will be needed to encourage the utility to explore new generation and markets.

2.3. Wind development in Jamaica

The Jamaica Public Service Company Limited (JPS) is the sole distributor of electricity in Jamaica, inheriting an electricity sector that dates back to 1892 when electricity was first generated on the island. Jamaica was one of the first countries in the world to develop electricity infrastructure. Initially the service was provided through the Jamaica Electric Light Company. Within the coming decades several private electric companies cropped up in different towns. Through a process of consolidation JPS emerged as the parent company, being granted an all-island franchise in 1966, making it the island's sole public supplier of electricity (JPS, 2010). JPS has changed ownership a number of times during its history. Starting as a private company owned by foreign shareholders, it was later acquired by the government but in 2001 majority shareholder ownership was sold to Mirant Corporation—a US based energy service provider (Ministry of Energy and Mining, 2006). JPS is a regulated utility with rates subject to the Office of Utility Regulation (OUR). Power generation was liberalized in 2004 and several independent power producers now supply electricity to the national grid (JPS, 2010).

Jamaica has a peak daily demand of 600 MW. JPS has approximately 820 MW total installed generating capacity provided through a number of steam and combustion gas turbines plants as well as eight hydro plants (Ministry of Energy and Mining, 2009). About 25% of this generating capacity (197 MW) is supplied by IPPs (JPS, 2010). JPS no longer has monopoly on bulk electricity generation. Its exclusive franchise is limited to transmission, distribution and retail supply. Jamaica has a high price of electricity at $0.26 USD/kW h, with almost half the generation capacity over 30 years old and transmission losses being estimated at 23%. It places a significant pressure on the countries manufacturing industry (Ministry of Energy and Mining, 2009).

The constant need for increased generation capacity has recently prompted the Petroleum Corporation of Jamaica (PCJ) to explore alternative energy solutions for the island. PCJ was established in 1979 as a statutory corporation in response to the 1973 oil crisis, tasked with negotiating contracts with international oil suppliers, exploring the potential for oil development on island and operating the oil refinery and retailing company. In 1995 PCJ was mandated to develop indigenous renewable energy resources in accordance with the Jamaican Energy Sector Policy drafted that same year. Following rigorous feasibility study the PCJ established a wholly owned subsidiary – Wigton Wind farm Limited (Wigton) – incorporated in 2000 through Dutch subsidy[1] (Loy and Manilo, 2005). Wigton is the first commercial wind farm, and the second project of any sort in the Caribbean, to qualify for carbon credits under the Clean Development Mechanism (Loy and Manilo, 2005). Electricity purchase agreements originally allowed Wigton to sell electricity to JPS at the avoided cost of fuel in addition to a 15% premium.

Jamaica had thus in a short space of time become one of the fastest growing renewable energy hubs in the region due in large part to the historical structure of the Jamaican Energy Sector where IPPs are able to both generate and sell electricity on the national grid system. JPS does not represent a monopoly in generation but rather acts as a single buyer. The heavily industrialized Jamaican economy may have played a role in this development as industrial plants are often able to obtain power more effectively under this regime. PCJ's resource exploration and development of Wigton also represents a significant government investment in alternatives. A number of other wind resource assessments have been conducted across the island identifying other sites for power production. The government also approved both a National Energy Policy and a National Renewable Energy Policy in 2009 highlighting a number of renewable energy goals (Ministry of Energy and Mining, 2009).

2.4. Wind development in the Netherland Antilles

2.4.1. Curacao

Despite being sister islands Aruba and Curacao have separate governments and utility providers. Electricity production and desalination on the island of Curacao began in the early twentieth century through a single private company. Over subsequent decades similar companies emerged and eventually all water production, electricity generation, transmission and distribution companies were integrated into a single company now known as Aqualectra, jointly owned by the government and the international Marubeni Corporation (Integrated Utility Holding, N.V., 2009). Since its establishment Aqualectra has not been regulated by the government. Despite a privatized and largely unregulated monopoly within its electricity sector, Curacao was one of the first Caribbean islands to experiment with the integration of renewable energy. During the 1980s Aqualectra established a 3 MW wind farm in Tera Cora. Based on this success another 9 MW wind farm was commissioned in Playa Kanoa in 2000. This wind farm was initially developed by a Dutch company but rights to its ownership have recently been bought by renewable energy development company NuCapital. Government support for the Aqualectra and NuCapital projects has come in the form of rights to land for development and waivers on import taxes for all materials imported from Europe. An official energy policy for Curacao was developed by the Ministry of Economics and the Environment in 2011 (Department of Economic Affairs, 2010).

2.4.2. Aruba

Commercial electricity production in Aruba began in the 1920s with a small company whose generating capacity was expropriated by the government to be handed over to a Dutch owned corporation. This corporation, later known as Elmar, had sole control over the generation and distribution of electricity on island. Years later the government bought a diesel power station with three times Elmar's operating capacity, through which the government established the state owned Water and Power Company (WEB N.V.) (Elmar, 2004). The government then established an agreement with Elmar, unbundling electricity operations such that Elmar would be responsible for distribution, transmission and maintenance while WEB N.V. would be the sole generator. In the 1990 s a government owned holding company, Utilities Aruba N.V., took over N.V. Elmar so that both generation

[1] The Dutch Development and Environment Related Export Transactions Program (ORET/MILIEV) awarded a subsidy to the Wigton Wind Farm project at a rate of 35% of the value of the supply of wind turbines and ancillaries from Holland (Fisher, 2004).

and transmission capacity are now under state ownership (Elmar, 2004). Wind energy took longer to develop in Aruba than in Curacao, with the first wind farm on Aruba beginning production in late 2010. The push for this project came not from the utility but from independent project developers, NuCapital. Overtime the utility was persuaded to enter into a PPA agreement and provide grid access to the project. Given the consistent trade winds received by this part of the island the 30 MW wind farm has one of the highest capacity factors in the world (NuCapital, 2012). NuCapital is currently expanding the project through another 30 MW installation.

Historically, utilities in Curacao experienced relatively little government involvement outside of the purchasing of shares in an established company, while in Aruba the government has been more forceful in designating authority over assets and functions. Interestingly, neither of these local governments has taken to regulation and today there is no legislative body overseeing the operation of these utility companies. Rather the predominant impetus behind wind farm projects thus far has come from private developers. This all creates a context with no incentive to standardize a bidding and PPA process or to standardize grid access and integration procedures. An impartial policy or regulatory body would help create a more enabling environment. The government of Curacao recently developed an Energy Policy and the government of Aruba recently announced a partnership with the Carbon War Room to transition the island to 100% renewable energy. The partnership is in early stages but could hold much promise for government support of wind development in the Netherland Antilles (Carbon War Room, 2012).

3. Cost benefit analysis

3.1. Direct costs and benefits

In this section we explore the costs and benefits related to renewable energy technologies being introduced into the Caribbean as described above. To compare the investments we calculate the Levelized Cost of Electricity (LCOE) for each technology along with emissions reduction and green job estimates. We also calculate estimates of wholesale generation costs and report on current utility rates[2] (see Tables 2–4). We find renewable technologies to be cost effective in the Caribbean showing the potential for development, given the current expensive and fuel oil biased fuel mixes of the islands (see Fig. 2).

The LCOE of wind generation in Jamaica is based on data provided by Wigton Wind farms on investment and operations costs.[3] The LCOE of $0.078 USD/kW h is lower than the domestic and net billing rates in Jamaica (even at higher discount rates, according to sensitivity analysis). A clearer picture comes from comparison to avoided costs of current electricity generation.[4] The Long Run Incremental Cost is currently $0.10 USD/kW h and is used as the base for contracting guaranteed capacity (OUR, 2008). Where capacity cannot be guaranteed price is based on the short term avoided cost, which is the variable fuel cost. This rate is roughly $0.088 USD/kW h. Wigton Wind Farm receives $0.10 USD/kW h, a 15% premium over this avoided cost. The LCOE of wind energy in Jamaica is lower than each of the OUR's reported costs and is well within the range of costs experienced in other international wind developments (Cory and Schwabe, 2009; Wiser and Bolinger, 2010). However when compared to countries such as Germany, Switzerland and Australia where purchase agreements allow for the sale of wind power above even $ 0.20 USD/kW h (Myers, 2008), Wigton's selling price translates into a very low rate of return and may be partially responsible for the dearth of international investor interest that Wigton has been able to attract - hence still being wholly owned by the PCJ.

High capacity factors and subsidies allow the LCOE of wind energy both in Aruba and Curacao to be less than $0.03/kW h.[5] This is lower than the avoided cost of electricity and the IPP 'take or pay' contract price allowing NuCapital to make a significant return on investment. This rate may be an underestimate given future operation and maintenance (OM) cost increases, as suggested by the difference in OM costs between the older wind farms in Curacao and the new wind farm in Aruba. Nevertheless Antillean wind developers are able to provide a significant amount of electricity production at low cost, attracting investment to the resource. The LCOE for GRENSOL solar systems is lower than the domestic rates charged and net metering rates offered in Grenada but still much higher than the fuel and short run avoided cost of current electricity production.[6] Again, this may be in part due to the shipping costs that are incurred from importing small orders for panels. According to sensitivity analysis, the LCOE of photovoltaics with an install cost of $3.00 USD/$W_{installed}$ would much better align with current avoided cost estimates, showing the potential for commercial markets (see Fig. 3). For SWH we derive a Levelized Cost of Electricity Displacement[7] of $0.05 USD/kW h and find that payback on SWHs can be 2 years. The cost effective nature of SWH with or without subsidies is clear when compared to the avoided costs of electricity in Barbados, and even when compared to the $0.088 USD/kW h for non-firm capacity energy rates offered in Jamaica. This highlights the potential benefits that could come to the Barbados government or utility from helping families and businesses to finance the upfront payment for such systems. This is currently a barrier given that electric water heaters are less than half the price of SWHs.

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[2] The utility domestic rates are taken from CARILEC Technical Reports (CARILEC, 2010).

[3] The current wind farm was built at an average capital cost of $2–3 million USD/MW installed and the 18 MW project, which was recently commissioned in March 2011, cost US$49 million. Wigton operation costs include financing and sales, labour, electricity, repair and maintenance operations and depreciation and insurance expenses. These operating costs were estimated at US$4.258 million for 2008 (E. Barrett—General Manager, Wigton, 2010).

[4] According to the OUR in Jamaica the Long Run Incremental Cost (LRIC) of generation represents the incremental cost of provided electrical power over a 20 year period discounted to present value by the opportunity cost of capital (12%) attributable to new plants to be added over the planning horizon divided by the expected capacity to be supplied by these plants.

[5] Based on installation costs of $2.4million USD/MW for both Vader Piet and Playa Canoa. Annual production output and associated OM costs for both projects were provided by NuCapital. Fuel costs based on Curoil (local gas and oil distribution company) diesel prices for both Aruba and Curacao and assuming a Heavy Fuel Oil engine heat rate of 13.6E3 kJ/kW h.

[6] The cost of a system includes a lifetime guarantee, including maintenance and inverter replacement costs. There are thus very few additional costs that an owner would have to pay for the system. We assume a marginal degradation rate of 0.005%. The LCOE of photovoltaics is estimated at roughly $0.28 USD/kW h (Barbose et al., 2010). This is much higher than the average US LCOE of around $0.16 USD/kW h, however there are a few things to note. First, according to GRENSOL the installation price decreases the larger the system purchased so that $6.17/$W_{installed}$ is a conservative estimate of the installation costs for their systems. Furthermore, the US LCOE includes an Investment Tax Credit (ITC) of 30%. Without this tax credit, the cost of PV would be much higher in the states.

[7] Approximately 0.11 kW h are needed to heat a gallon of water given the ambient temperature in the tropics and the theoretical heat capacity of water. Assuming electric water heaters are about 90% efficient, assuming that an average household uses approximately 10,000 gal of hot water a year and given that the electrical fuel efficiency of the BL&P Co. generator fleet is roughly 30%, the amount of electricity that a standard 65 gal SWH can displace per year is 3700 kW h.

Table 2
LCOE of renewable energy technologies compared to other electricity cost estimates (US Dollars).

Renewable energy technology costs					Generation rates					
Country	**Technology**	**Installation cost (\$/W)**	**O&M cost (\$/kW/yr)**	**LCOE @ r=7% (\$/kW h)**	**Cost of fuel (\$/kW h)**	**Avoided cost of electricity (\$/kW h)**	**Fuel surcharge (\$/kW h)**	**Domestic retail rate (\$/kW h)**	**Net metering payment (\$/kW h)**	**IPP contract rate (\$/kW h)**
Jamaica	Wind	2.50	210	0.078	0.219	0.225	0.233	0.265	0.225	0.101
Aruba	Wind	2.40	36	0.013	0.329	0.336	0.160	0.260		0.092
Curacao	Wind	2.40	53	0.028	0.352	0.358	0.211	0.355		0.092
Grenada	Photovoltaics	6.17	0.010	0.283	0.146	0.154	0.213	0.341	0.341	
Barbados	SWH			0.051	0.228	0.235	0.227	0.294	0.227	

Table 3
Green house gas emissions savings.

Country	Technology	Project size (MW)	Annual generation (GW h/yr)	Current generation CO_2 intensity (kg CO_2/kW h)	Total annual CO_2 savings (′000 MT/yr)
Jamaica	Wind	38.70	115	0.944	120
N. Antilles	Wind	39.00	132	0.944	125
Grenada	Photovoltaics	0.12	0.237	0.66	0.16
Barbados	SWH		185.5	1.106	200

Table 4
Estimates of direct employment benefits.

Energy technology	Source of numbers			Employment components		Cap factor	AVG (person-years/GW h)
	Project	**Project size**	**Equipment lifetime (years)**	**CIM (jobs/$MW_{installed}$)**	**O&M (jobs/MW_{actual})**		
Wind	Wigton Wind farm	20.7 MW	25	3.88	0.59	0.34	0.17
Wind	Nu Capital, Curacao	12 MW	25	1.50	1.43	0.35	
Wind	NuCapital, Aruba	30 MW	25	1.50	0.85	0.47	
Solar PV	Grensol Ltd	65 kW	25	0.00	30.77	0.22	16.19
SWH	Solar Dynamics Ltd	140,000 MW h saved	20	0.59		0.22	0.31

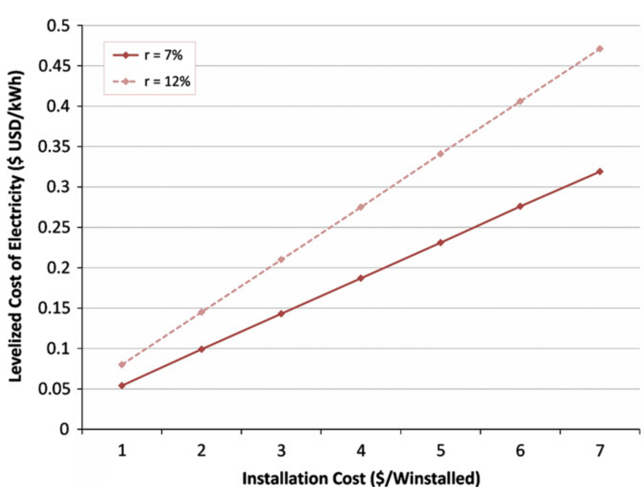

Fig. 3. Sensitivity of PV LCOE to installation cost, Grenada.

3.2. Indirect costs and benefits

Here we estimate the indirect benefits that renewables have had on job and carbon emissions abatement. Data for job estimates came directly from the number of people employed by these companies in different stages of the operation process and reflect only direct jobs created, not indirect or induced jobs. Tables 3 and 4 show that Wigton requires 0.17 person-years/GW h (roughly 20 full time jobs per year) while saving 20,000 t of CO_2/year. GRENSOL requires 16.19 person-years/GW h (although this is likely to decrease in the near future as the number of installations increases) and saves 160 t CO_2/year. In Barbados the high penetration of SWH has led to energy savings of 185 GW h/year and a total savings of 200,000 t CO_2/year, highlighting the indirect benefits of energy efficiency technology. As can be seen from these case studies there are a number of successful wind, solar and SWH projects that have been deployed in the region within recent times. Other notable wind projects have been developed in Guadeloupe. Photovoltaics have been introduced in St. Lucia and St. Vincent. Geothermal energy is also proving successful as a base load substitute for fossil fuels in Dominica, St. Lucia and Guadeloupe.

4. Discussion and case study highlights

4.1. Lessons from island case studies

In this analysis we have explored the history of energy policy and the cost of renewable energy technology in the Caribbean (see Table 5). We do not perform a comprehensive survey of all islands where renewable energy has been deployed but instead

Table 5
Summary of energy sector policy in the case study countries.

	Grenada	Barbados	Jamaica	Aruba	Curacao
Monopoly utility	Grenada Electric Services Ltd (GRENLEC)	Barbados Light and Power Company (BL&P)	Jamaica Public Services Company (JPS Co)	W.E.B. ARUBA N.V.	Aqualectra
Utility ownership	50% foreign, 25% state, 25% local investor	37% Foreign, 23% state, 35% local investor	80% Foreign, 20% state	100% State holding company	25% Foreign, 75% state
Utility exclusive rights	Generation, Transmission, Distribution	Generation, Transmission, Distribution	Transmission, Distribution	Generation	Generation, Transmission, Distribution
Regulatory agency	None	Fair Trading Commission	Office of Utility Regulation	None	None
Energy legislation	1994 Electricity Supply Act	1907 Electricity Supply Act 1951 Public Utilities Act 1974 Fiscal Incentives Act	1958 Electricity Development Act 1995 Office of Utilities Regulation Act 2001 All Island Electricity License	None	None
Government energy policy	None	2007 Barbados National Energy Policy	2009 Jamaica National Energy Policy	None	None
RPS goal	None	20% by 2020	20% by 2030	None	None
Net metering policy	Max 10 kW, retail rate, cap 1% installed capacity	Max 50 kW, fuel adjustment rate cap 1600 kW	Max 100 kW, avoided cost, cap 3% installed capacity	None	None
Financial incentives	5% Duty Concession for PV (since 2005)	Consumption Tax on EWH (1974), Inc Tax Deduction for SWH (1980)	None	None	None
RE pilot projects to date	Small Scale Solar	Bagasse, WTF, Wind, Small Scale Solar, SWH, LFG	Bagasse, Hydro, Wind	Large Scale Wind	Large Scale Wind

provide a sense of the variation that exists. Even though such a small region, there are significant differences among Caribbean islands in the scale of industry, the type of utility ownership, the level of regulation and government involvement in the energy sector, presenting a number of considerations that should be addressed in creating an enabling environment. History shows that socio-technical transitions take time and involve systemic changes. Because infrastructure favours the currently dominant fuels, renewable energy deployment will be most effective in a flexible environment. An enabling environment for renewable energy involves policy that addresses a number of domains with different configurations of interaction depending on country context (Mitchell et al., 2011).

We observe that GRENLEC is a predominantly foreign owned and privatized company. WRB owns majority shares in a number of other US and Caribbean utility companies (bNET, 2004) but has not ventured into alternative technologies. This historical lack of experience coupled with GRENLEC's sole supplier status and an absence of utility regulation, creates an environment that constrains the introduction of new technologies and the potential growth of new industry. However recent moves to introduce regional regulation are promising. Since 2009 the Grenadian government along with the other Eastern Caribbean States (Dominica, St. Lucia and St. Vincent and the Grenadines) has been planning a regional regulatory authority that oversees energy providers within the sub-region. The Grenadian government has recently approved a National Energy Policy (Government of Grenada, 2011) and in collaboration with the United Nations also produced a road map for sustainable development in its smaller islands (UNDESA, 2012).

In Barbados we note the number of experiments with renewable energy that the state controlled utility has made thus far, highlighting government interest in energy security. However this intention is not supported by significant legislative or policy backing. This may be part of the reason that, aside from SWH technology, it has been difficult to integrate other technologies into the Barbadian market. There needs to be more structured near and long term planning and more consistent provision of incentives. A structured plan of action and implementation would support exploration of other alternative technologies.

In Jamaica we find similar governmental support of new technologies through PCJ. However securing continued and expanded investment for projects is proving difficult. Thus while government interest in indigenous resources is expanding, it is important that the government continue to seek expressions of interest from local and foreign investors. Financial incentive or security must be availed to lower the threshold for investment (Loy and Manilo, 2005). This can be achieved by developing standardized protocol for contractual arrangements and by working with local financing institutions. Jamaica should also implement interconnection standards that would allow greater access to the transmission and distribution grid. This effort has already begun through the pilot net billing program. Similar efforts would provide support for the growing local energy industry. Aruba and Curacao show a successful wind energy industry that developed in a fairly ad-hoc manner driven by powerful Antillean winds. There is significant investor interest and utility amenability. An official energy policy and government process would direct and stream-line interactions between state, utility and project developers.

4.2. Considerations for regional energy policy

Nuances among island needs and contexts may be part of the reason that inter-island policy is so difficult to develop. They should be well understood for a regional direction and implementation mechanisms to emerge. There are already institutions that are concerned with regional energy policy. The Caribbean Community (CARICOM) has created assistance programs such as the Caribbean Renewable Energy Development Program (CREDP) through collaboration with international agencies such as the Alliance of Small Island Developing States (AOSIS) and the Inter-American Development Bank (IDB). CREDP prepared the 2007 CARICOM Energy Policy Paper. These agencies create a forum for discussion on energy issues amongst the region's political leaders but have contributed little to actual policy development or implementation.

Our study highlights the need for enabling policy which acknowledges and addresses the varying needs of different island. Enabling policy will involve non-governmental stakeholders in formulation and implementation; will support the burden of financial and investment risk; will place focus on infrastructure and network development; will encourage technology transfer and will be designed to be complementary to policy in transportation, agriculture, water management and related sectors (Mitchell et al., 2011). We have shown how focus on different policy domains in various island types might lead to the design of such an enabling policy environment. Arguments are also often put forward for liberalization and free competition on the basis that state owned enterprises are intrinsically inefficient and mismanaged. However practice shows that ownership regime is far less important than the context within which the enterprise operates (Gabriele, 2004). The dynamics of contract negotiations in the face of uncertainty is also critical to investment decisions (Barradale, 2010; Wolf Heinrich Reuter, 2012). Longevity should thus be explicitly considered when designing incentives for the Caribbean.

There are a few island regions where energy policy has already helped to promote the growth of a renewable energy industry, such as Cape Verde, Crete and the Hawaii Islands (Weisser and Garcia, 2005). In 2011 renewables supplied a quarter of retail electricity in Hawaii (Hawaii Electricity Company, 2011). This penetration has been supported by a number of initiatives implemented by the major utility holding company and the public utility commission. Since the 1990s Hawaii has seen the introduction of a Renewable Portfolio Standard, net metering programs, a feed-in tariff, a competitive generation bidding process, grid interconnection standards and state and federal rebate schemes all tailored to each island (DSIRE, 2010). These cases highlight the potential success that can come from a complementary policy portfolio. Other Caribbean islands are also experimenting with investment incentives. The Cayman Islands for instance recently approved a limited feed-in-tariff (FiT) pilot program for renewable generation of less than 50 kW (Alliance for Renewable Energy, 2011).

5. Conclusion

CARICOM, CARILEC, international investors and national regulatory agencies will be key players in the development of future Caribbean energy policy. Sensitization to power sector dynamics and a working knowledge of the success that can come from small scale energy technologies will support these groups. From our analysis, Grenada needs a greater degree of government involvement in power sector regulation. Barbados, with a regulatory structure in place, needs to harness that capacity by create more binding policies that take advantage of local market potential. Utilities often need to be provided with the security of government support to explore the risky realm of renewables and creating a supportive legislative and policy backbone is a crucial step for energizing the local market. Jamaica, with more sophisticated legislation, needs a more enabling market environment and should put incentives in place to attract investment beyond state financing while the Netherland Antilles would benefit from a more structured energy sector.

As our cost analysis has shown, there are many scenarios in which renewable energy technologies already provide significant social benefit and are cost competitive with short run avoided costs. This indicates the potential for small scale resource development and profitability that can be precipitated by local innovation, local investment and local market interest. It would be useful to explore potential regional institutional regimes through feasibility and barrier assessments to determine solutions appropriate for the Caribbean. In this way enabling regional policy mechanisms can be guided by national energy plans allowing the islands to pursue their individual and collective energy security and sustainability goals within a collective context.

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