Project Document

An assessment of the economic and social impacts of climate change on the energy sector in the Caribbean

Ramón Martín
Charmaine Gomes
Dillon Alleyne
Willard Phillips

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Executive summary

The present report assesses the economic and social impacts of climate change on the energy sector in Antigua and Barbuda, the Bahamas, Barbados, Belize, Cuba, Dominica, the Dominican Republic, Haiti, Grenada, Guyana, Jamaica, Saint Kitts and Nevis, Saint Vincent and the Grenadines, Saint Lucia, Suriname, and Trinidad and Tobago.

In the study, the Artificial Neural Network methodology was employed to model the relationship between climate change and energy demand. The viability of the actions proposed were assessed using cost benefit analyses based on models from the National Renewable Energy Laboratory (NREL) of the United States of America.

Subsequently, future Caribbean energy consumption was forecast, considering the impacts of two scenarios of climate variability. Using forecast prices of oil, the assessed economic impacts ranged from US$ 487 billion to US$ 739 billion 2011 United States dollars during the forty years from 2013-2050, considering the variations given by three discount rates (1 per cent, 4 per cent and 14 per cent) and two oil-price scenarios.

The targets defined and extrapolated to be achieved at the end of the period, with the proposed changes in the structure of the Caribbean energy sector, would achieve a 60 per cent reduction in per capita CO_2 emissions for the Caribbean. Five results were derived from these changes, so that, by 2050, a quarter of the total energy consumption would be electricity consumption, half of the electricity generated would come from renewable sources. Electricity from renewable energy sources would have a price of US$ 0.15 per kilowatt hour or less, national electrification levels would be between 95 per cent to 100 per cent and energy security would be increased by 10 points or more[1]. The second target proposed a Caribbean programme to change 20 million electric light bulbs to compact fluorescent light bulbs.

Finally, the study concluded that the future of the Caribbean energy sector should focus on renewable and affordable localized energy sources. The recommendations for national and international stakeholders, listed below, have been put forward for the acquisition quality of life, economic development and ecological preservation, for a better future for the Caribbean population.

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1 Energy security is defined here as the percentage of energy consumption derived from renewable indigenous sources thus not imported. A full account on the evolution of the term and the reasons as to why this is the definition employed is explored in the report (Sections II.A.1 and IV.C.1. (e)).

a) National and regional energy policies for the Caribbean that encompass energy efficiency and renewable energy need to be completed and updated. These policies must include planning for excess generated capacity, an explicit pro-poor dimension, maximum utilization of renewable energy sources, and the building of reliable statistical databases on the energy sector.

b) The increased use of renewable energy should be part of the development programme of each Caribbean State, concomitant with the appropriate political commitment.

c) Governments should apply specific policy packages and tax incentives to promote energy efficiency and renewable energy projects.

d) Governments should take legislative action to criminalize the theft of electricity, and law enforcement must be aligned with the explicit, pro-poor dimension of energy planning.

e) Studies and projects on biomass applications for electricity generation could be carried out at the domestic level, taking into account possible greenhouse gas emissions, and agricultural and infrastructural development.

f) The transport sector, accounting for nearly half of the energy consumption in the Caribbean, should be addressed separately so that specific climate change impacts, along with the corresponding mitigation and adaptation measures, would be determined.

g) Given its demonstrated feasibility, a project for the replacement of 20 million electric light bulbs with compact fluorescent light bulbs should be carried out in the Caribbean. This project contemplates three cycles covering the whole period considered, in accordance with the devices' lifetimes and usability. Nevertheless, newer technologies such as LED lighting can also be considered in the near future.

h) Campaigns for increasing the awareness of the Caribbean population on energy savings, including the carbon footprint calculation, and the necessity for extensive use of renewable energy sources should be orchestrated at national and subregional levels.

i) Derived results obtained in the present study should be integrated into national energy planning and implemented, given their proven viability.

I. Introduction

The Caribbean[2] is one of the geographical regions most vulnerable to climate (ECLAC, 2009a). It is integrated by low-lying island and mainland States, low coastal zones, depends on precipitation for the provision of water for human consumption and agriculture, and is vulnerable to flooding and forest fires. Most of the Caribbean islands are located within the hurricane belt and although extreme events of this kind have not yet been proven to be linked to climate change, storm damage needs to be considered in assessing the impact of climate change on the economies of these countries.

As the global climate gets warmer, the consumption of energy in climate-sensitive sectors is likely to change. In the Caribbean, energy demand is expected to double in the next 20 years, at a 3.7 per cent average annual rate of increase (Nexant, 2010). Currently, most Caribbean countries are heavily reliant on imported fossil fuels, their energy consumption being based almost solely on oil products, which account for more than 97 per cent of the energy mix. Trinidad and Tobago, Cuba, the Dominican Republic and Barbados cover part of their fuel requirements from their own reserves of oil and natural gas. Nevertheless, only Trinidad and Tobago has significant, proven fossil fuel reserves. Essentially, the Caribbean is highly energy insecure and as such it would be unable to respond to global price shocks, due to its inability to control global fuel prices and supply volumes (Lue, 2011).

Electricity is generated by mostly medium and high speed diesel engines (ECLAC, 2004). The Caribbean is vulnerable to external factors such as volatility in energy prices. Several Caribbean countries spend some 15-30 per cent of their export earnings, inclusive of revenues from tourism, on oil products. This results in high electricity prices, generally between US$ 0.20 and US$ 0.35 per kWh, prices much higher than in the United States of America, or Europe. The small geographical size and population of most Caribbean countries results in diseconomies of scale in generating power on small island developing States (Ehrhardt and Oliver, 2007).

Over the past ten years, there have been some regional and national initiatives aimed at creating, encouraging and enabling an environment that would better prepare the Caribbean for dwindling hard-currency reserves and escalating fossil-fuel prices. These schemes have included the

[2] The Caribbean subregion considered in the present study is integrated by 16 Member States of the United Nations Economic Commission for Latin America and the Caribbean: Antigua and Barbuda, The Bahamas, Barbados, Belize, Cuba, Dominica, Dominican Republic, Grenada, Guyana, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, and Trinidad and Tobago.

PetroCaribe[3] initiative between Venezuela and a number of Caribbean countries, national incandescent light-bulb replacement programmes in a few countries, public sector energy savings and auditing (in Barbados), and projects such as the Caribbean Renewable Energy Development Project (CREDP)[4], a study on energy efficiency in Jamaica[5], and the "Bioenergy in the Caribbean" project.[6]

Moreover, there exist few studies that assess the impact of renewable energy interventions in the Caribbean (Schwerin, 2010). In addition, the Caribbean Community (CARICOM) Secretariat expressed concern that a large proportion of the financial resources provided by the Global Environment Facility (GEF) to the Caribbean for project implementation of climate change initiatives had not been utilized and had had to be returned to the GEF Secretariat (ECLAC, 2009).

Many Caribbean countries are endowed with considerable renewable energy (aeolic, solar, hydropower, geothermal and biomass) resources. Despite this, and except for a few isolated cases (e.g. the use of solar water-heating in Barbados), the impact of renewable energy usage on Caribbean economies has continued to be minimal.

After more than two decades of discussions on including energy efficiency and renewable energy in the energy policies of Caribbean countries, little has been achieved so far. This may be owing to the fact that the Caribbean renewable energy policy has not yet been finalized and is necessary to inform national energy policies. It reflects the failure of public policymaking and international cooperation to implement more sustainable patterns of development.

The objectives of the present report are: (1) to determine the economic and social impacts of climate change on the Caribbean energy sector; (2) to evaluate the goals and strategies of the Caribbean energy sector; and (3) to assess mitigation actions and analyse costs and benefits of selected options, with detailed, project-by-project, financial analysis.

Adaptation strategies will be related to the probable losses in power-generating facilities caused by sea-level rise that might impact existing energy infrastructure (e.g. power plants, transmission lines, refineries, oil and gas pipelines, or liquid natural gas facilities), and to new infrastructural options.

Clearly, an important perspective for the current study has been that, in considering the energy sector in the Caribbean, climate change impacts have a distinctive meaning. Given the current Caribbean development status and the abovementioned objectives of the study, adaptation to climate change would not only result in mitigation, but would also be a step towards resolving the three major challenges that the Caribbean would have to face in the near future as a result of climate change, namely, energy security, economic growth and sustainable development (ECLAC, 2004).

Section I introduces the study and Section II offers a review of the literature focusing on the effects of climate change on energy use and energy production. The main challenges for the energy

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[3] The agreement was initiated with the aim of solidarity with other countries in accordance with ALBA (Bolivarian Alliance for The Americas). The payment system allowed for purchases of oil at market value for 5-50 per cent up front with a grace period of one to two years, the remainder to be paid through a 17-25 -year financing agreement with 1% interest, if oil prices rose above US$ 40 per barrel. The agreement also included social projects in the areas of tourism, education, health, housing, sanitation, roads, sports and agriculture, conducted under the ALBA Caribe Fund, created to finance social and economic programmes (See PetroCaribe, 2012).

[4] The Caribbean Renewable Energy Development Programme (CREDP) is a joint project between the Caribbean Community (CARICOM) and the German International Cooperation (GIZ, formerly GTZ). It is financed by the German Federal Ministry of Economic Cooperation and Development (BMZ) and implemented by the consortium of Projekt-Consult GmbH, Germany and Entec AG, Switzerland, on behalf of GIZ. CREDP seeks to remove barriers for the use of renewable energy and to apply energy efficiency measures in the Caribbean (See CREDP, 2012).

[5] For more information see A. Fitzroy, "Energy efficiency in Jamaica: the current situation: looking to the future", document prepared for the Regional Intergovernmental Conference on Energy Efficiency, United Nations Economic Commission for Latin America and the Caribbean, Santiago, Chile, September, 2009.

[6] For more information see Caribbean Information Platform on Renewable Energy (CIPORE) [online], http://cipore.org/regional-page-3/bioenergy-in-the-caribbean/, 2012.

sector in the Caribbean are also discussed. (See annex 1 for details on the structure of the Caribbean energy sector).

Section III discusses the methodology and the models employed to obtain the results and the building of the corresponding scenarios. Results were achieved primarily by using two methods: Artificial Neural Networks (ANN) and the United States National Renewable Energy Laboratory Decision Support Systems for feasibility studies. The report used the bottom-up approach, analysing and forecasting variables for each country and, from these calculations, deriving the added values for the Caribbean. The Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) A2 (high impact) and B2 (medium conditions as Business as Usual) scenarios were employed to estimate future Caribbean energy demand.

Section IV presents the results. Energy demand forecasts using climate change variables, economic impacts, and mitigation goals and strategies, with cost-benefit and complete financial analysis of actions, are examined in this section.

Finally, Section V draws the conclusions and recommendations of the study. The results of the study, from which conclusions and recommendations were derived, have relied heavily on the data of the annexes. A thorough revision of these annexes would provide a better comprehension of the scope[7] and limitations of the analyses presented in the report.

[7] The time schedule of the current investigation meant that the impacts of climate change on the various sectors were studied in parallel. In consequence, the results from each sector were not available for inclusion in a cross-sectoral analysis.

II. Climate change and the energy sector in the Caribbean: a literature review

A. Energy and climate change

1. Effects of climate change on energy use patterns

There is a large body of literature discussing the contribution of the energy sector to global climate change. There is, however, substantially less literature discussing the inverse relationship, that is, the effect of a changing climate on the energy sector itself (NETL, 2007). In recent years, there has been increased concern related to the magnitude and the way in which climate change may impact the performance of existing and future energy production and consumption trends.

The potential effects of climate change in the Caribbean have implications for energy production and use in the energy-generating sector, as well as in other climate-sensitive sectors (e.g. agriculture, transport, construction and tourism). Wilbanks and others (2008) pointed out that the most important potential effects would be:

a) Increases in the amount of energy consumed in residential, commercial, and industrial buildings for space cooling, because of the drop in thermal comfort (temperature, relative humidity and wind speed);

b) Increases in energy used for residential and commercial refrigeration and industrial process cooling (e.g. in thermal power plants or steel mills);

c) Increases in energy used to supply other resources for climate-sensitive processes, such as pumping water for irrigated agriculture and municipal uses;

d) Changes in the balance of energy use among delivery forms and fuel types, such as between electricity used for air conditioning and natural gas used for heating; and

e) Changes in energy consumption in key climate-sensitive sectors of the economy, such as transportation, construction and agriculture.

De Cian (2007) stated that the relationship between energy demand and temperature depended on the season. Indeed, the same temperature increase typically had distinctive impacts in winter, spring, summer or autumn. There are two clearly-differentiated seasons in the Caribbean, namely the wet and dry. During the wet season, high temperatures have a greater impact on energy consumption increases, due to the use of cooling devices. Temperature increases in the wet season would extend the volume and duration of peak demand, as the extension of the season would cause a probable increase in energy demand, particularly for electricity in residential and commercial sectors.

According to the literature,[8] the most noticeable impact on energy use will be caused by increased temperatures. However, climate change will also impact other sectors and may lead to alterations in the current uses given to energy. The following are some examples of the changes in sectoral energy use.

a) The agricultural sector

The agricultural sector will be one of those affected by climate change and will result in changes in energy usage in that sector. In developing countries and small island developing States in the Caribbean, climate change will cause yield declines for the most important staple crops (UNDP, SRC and CEIS, 2009) Fossil fuels are the main energy source consumed directly by the agricultural sector through transportation, with fertilizer and pesticides accounting for a significant share of indirect energy consumption. Electricity is the main driver of energy consumption through water requirements. So, changes in agricultural productivity would largely influence demand for direct and indirect energy inputs. Other important factors include changes in crop refrigeration requirements, and potential changes in the global flow of agricultural products from areas of higher productivity to ameliorate food shortages in areas where climate changes would have contributed to overall declines in agricultural productivity. Interactions between the agricultural and energy sectors are likely to diverge significantly, between nations and on a regional and global scale (NETL, 2007)

b) Commercial and residential sector

The principal change in the energy use pattern in the commercial and residential sectors in the Caribbean will be the increase in energy demand, attributed primarily to increases in electricity demand for interior cooling. This will be the result of higher temperatures, combined with the changes in other climatic variables. Extreme weather events can be expected to lead to greater risk of damage to residential and commercial buildings. Should building damage increase notably, financial and energy inputs associated with rehabilitation and reconstruction could also be expected to increase (NETL, 2007).

Rising sea levels may contribute to population shifts, as vulnerable coastal areas become less habitable due to inundation and salinization of groundwater resources. Any major population shifts caused by climate change can be expected to have impacts on power demand and requirements. While there is substantial literature describing the potential impacts on human migration qualitatively (IPCC, 2001), far less work has been done to assess these shifts quantitatively, much less their implications for the energy sector. The impacts of sea-level rise will not be uniform among Caribbean States. Some countries are projected to experience severe impacts from a one-metre rise in sea level, and their vulnerability should not be underestimated (UNDP, SRC and CEIS, 2009).

c) Industrial sector

Many of these risks of the industrial sector by climate change may be indirect. Major industries in the Caribbean that will be affected by climate change include food processing, textiles, ore processing and those linked to energy production. Higher temperatures, combined with changes in other climatic variables, may lead to changes in the amount of energy required for industrial, temperature-controlled processes and refrigerated-storage needs. Cooling spaces and cooling devices would also increase in industrial facilities and associated offices and plants. Increases in extreme

[8] De Cian, (2007), United States Department of Energy National Energy Technology Laboratory (2007), Contreras-Lisperguer and de Cuba (2008), Wilbanks and others (2008), United Nations Development Programme, Scientific Research Council and Caribbean Energy Information System (2009), United Nations Advisory Group on Energy and Climate Change (AGECC) (2010), and United Nations Environment Programme (2011).

weather events may lead to structural damage in important industries such as tourism, where energy-intensive demand for building materials and other goods may increase (NETL, 2007).

Sea-level rise may force the relocation of industrial facilities, or the construction of sea walls to protect those facilities. In coastal and low-lying areas, underground water aquifers would become vulnerable to increased saltwater concentrations as sea levels rise. Hence, the need for water treatment may increase, along with the demand for energy to be used in the treatment process (NETL, 2007).

d) The transport sector

Sea-level rise may have potentially significant impacts on transportation infrastructure and, indirectly, on the energy sector. Areas that are hit hardest may need to relocate, reconstruct or rehabilitate roads, highways, bridges, ports, inland waterways and other vital transportation infrastructure. If sufficient land area were lacking for relocation, the result might be an increase in traffic congestion and fuel consumption. Furthermore, the relocation of transportation infrastructure might, in turn, impact energy infrastructure sitting decisions (NETL, 2007).

Higher temperatures, combined with changes in other climatic variables, may have a number of impacts on the transportation sector that, in turn, could indirectly affect the energy sector. Cars, trucks, buses and locomotives would be likely to use more fuel, due to greater air-conditioning usage during the extended Northern-hemisphere summers in the Caribbean.

2. Effects of energy production on climate change

The main source of anthropogenically-induced climate change is the processing of fossil fuels, especially oil.[9] The process of transformation of fossil fuels generates a high volume of carbon dioxide (CO_2). This hydrocarbon is considered to be the main source of emission of greenhouse gases from human activities that contribute significantly to global warming. Scientific studies have advanced to the point where they can now measure the "carbon footprint" or level of greenhouse gas emissions, by individual, by company, and by country. This has provided the opportunity to increase awareness on the subject of climate-change hazards.

The Caribbean has one of the lowest rates of per capita emissions of greenhouse gases, with the exception of Trinidad and Tobago, which has a high index of per capita emissions. Although several fuels generate emissions of greenhouse gases, it is clear that countries that consume more oil and its derivatives have higher emission rates (table 1).

3. Effects of climate change on energy production

a) Impacts due to temperature increases

Increases in temperature result in decreases in the efficiency and capacity of natural gas or oil-fired combustion turbines or steam cycles (NETL, 2005a, 2005b). This is based on the logic that the differential in ambient and combustion temperature will be smaller and, therefore, less energy can be pulled out from steam extraction and condensing processes. While long-term impacts of increased temperature may be mitigated by the use of new technologies, the short-term heatwaves in specific regions can threaten power supply significantly. (Bueno and others, 2008)

[9] There is a body of literature on the subject, written by the scientists who prepare assessment reports on climate change for the Intergovernmental Panel on Climate Change (IPCC), the United Nations Framework Convention on Climate Change (UNFCC) and its Conference of Parties (COP).

TABLE 1
CARIBBEAN REGION: CO_2 EMISSIONS: 2009

Index	Total CO_2 emissions from energy consumption	Consumption of petroleum	Per capita CO_2 emissions from energy consumption
Unit	*Millions of metric tons*	*Millions of metric tons*	*Metric tons*
COUNTRY			
Antigua and Barbuda	0.69	0.69	7.7
The Bahamas	5.24	5.24	16.9
Barbados	1.43	1.43	5.1
Belize	0.98	0.98	3.2
Cuba	30.49	27.95	2.7
Dominica	0.14	0.14	2.0
The Dominican Republic	19.81	16.62	2.0
Grenada	0.30	0.30	2.7
Guyana	1.52	1.52	2.0
Haiti	2.06	2.06	0.2
Jamaica	12.04	11.96	4.2
Saint Kitts and Nevis	0.30	0.30	6.0
Saint Lucia	0.43	0.43	2.7
Saint Vincent and the Grenadines	0.27	0.27	2.7
Suriname	2.03	2.03	4.2
Trinidad and Tobago	47.48	5.28	38.6
Caribbean	125.21	77.20	3.3

Source: Energy Information Administration (EIA), "Countries Data" [online], http://www.eia.gov/countries/data.cfm, 2012

Power lines are also susceptible to higher temperatures. When temperatures exceed optimum conditions, reinforced steel cables in power lines lose their tensile strength, expand, and begin to sag. Sagging lines can come into contact with otherwise out-of-the-way grounded objects, such as tree limbs and may cause electrical shortages. During periods of intense demand typically, when temperatures are higher and transmission systems are operating close to their capacity limit, such shortages can trigger much greater system outages. Similarly, transmission and distribution systems are susceptible to damage from extreme weather events. Increased incidence of hailstorms, tornados, hurricanes, and other powerful storms are potential threats to power system security (NETL, 2007).

b) Impacts due to changes in precipitation

Another impact on energy production results from the decrease in water availability, due to the reduction in the size of freshwater lenses resulting from decreased rainfall and saltwater intrusion (UNEP, 2008). Scarcity of freshwater may lead to increased competition for shared water resources, in different locations and for different purposes, including energy, commercial, residential and agricultural uses and also to increasingly high prices for water.

Approximately 20 per cent of the freshwater resources used in Latin American and Caribbean countries are conducted through hydroelectric and thermal electric plants (IPCC, 2001). Caribbean countries consume approximately 13,872 terajoules of hydropower energy (De Cuba and others, 2008), with Jamaica, Haiti, the Dominican Republic and Suriname representing the bulk of this primary energy use. Extended periods of intense drought may result in severe reductions in water availability for hydropower generation and cooling of thermal electric power plants. Paradoxically, it is precisely in periods of drought that thermal plants are expected to increase their generation output in order to make up for the loss of generation from hydropower plants. Drought also causes increased electricity demand from refrigeration and groundwater pumping and purification activities, thus augmenting the pressure on thermal electric power plants, affecting energy and water supplies, and leading to increases in CO_2 emissions (Contreras-Lisperguer and De Cuba, 2008).

Furthermore, changes in precipitation cycles due to climate change can alter river flow patterns, resulting in longer periods of drought that decrease the minimum water levels of rivers and hence their hydroelectric generation capacity. Another potential consequence of altered river flow patterns is the increased incidence of elevated flow rates and flooding that exceed the safety margins of existing hydropower plants (Contreras-Lisperguer and De Cuba, 2008). Hydropower plants generally are designed to operate within specific river flow parameters, plus or minus a margin of safety. Climate change leading to river flow changes outside the margin of safety can have a negative impact on hydropower generation, regardless of whether the flow rate increases or decreases (IPCC, 2001).

c) Impacts due to sea level rise

The Caribbean is projected to experience greater sea-level rise than most areas of the world. Due to gravitational and geophysical factors, the greatest rise is projected to be along the western and eastern coasts of North America. Sea-level rise in the northern Caribbean may exceed the global average by up to 25 per cent (Simpson and others, 2009).

A significant fraction of Caribbean energy infrastructure is located near the coast, from power plants to oil refineries, to facilities that receive oil and gas deliveries. Rising sea levels are likely to lead to direct losses, such as equipment damage from flooding or erosion, and indirect effects, such as the cost of raising vulnerable assets to higher levels, or building new facilities farther inland, increasing transportation costs (UNEP, 2008).

d) Impacts due to extreme weather events

The impacts of changing climate on Caribbean countries are being manifested increasingly, not only in economic and financial losses, but also in the death toll. According to the International Disasters Database[10], in the decade from 2000 to 2009, the Caribbean suffered US$ 25 billion in economic losses from meteorological events and over 4 000 deaths (EM-DAT, 2012).

In 2005, Hurricanes Rita and Katrina had dramatic impacts on the Caribbean and southern United States energy production and distribution infrastructure and, ultimately, on global energy prices. These impacts included the destruction of 115 oil drilling platforms, damage to over 180 oil pipelines, and direct losses to the energy industry estimated at over US$ 15 billion, with substantial additional restoration and recovery costs (Wilbanks and others, 2008). Future energy projects located in storm-prone areas will face increased capital costs, hardening their assets due to both legislative and insurance pressures.

Energy assets can be protected from these impacts either by protecting the facility or relocating it to a safer area. Protection could include reinforcement to walls and roofs, the building of dykes to contain flooding, or structural improvements to transmission assets. However, the high cost of relocating or protecting energy infrastructure has driven many companies to avoid these costs as compared with potential repair costs should a disaster strike. In addition, the potential impact of severe weather events would not be limited to hurricanes. Severe storms and rains would lead to flooding of plains and riverbeds, make rail and road transportation inaccessible and even damage critical bridges used for fuel transport or distribution. Given the high dependency on oil for electricity generation in the Caribbean, any significant disruption to the transportation infrastructure has serious implications for energy service reliability (Bueno and others, 2008).

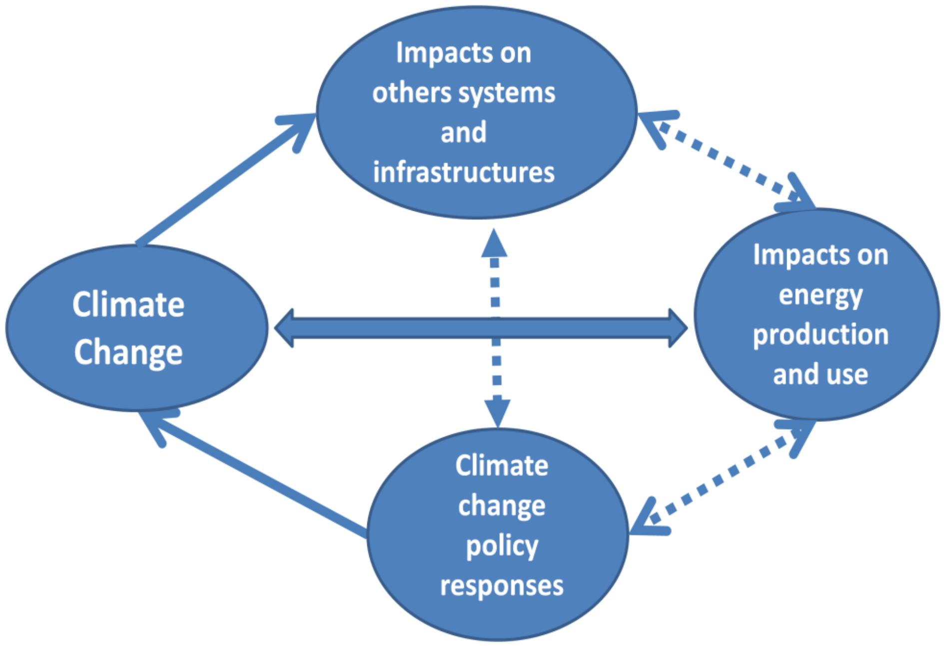
More severe rainstorms might lead to the flooding of rivers that then could wash out, or degrade, the nearby roadbeds. Flooding might disrupt the operation of inland waterways, the second-most important method of transporting coal. With utilities carrying smaller stockpiles and projections

[10] Since 1988, the World Health Organization Collaborating Centre for Research on the Epidemiology of Disasters (CRED) has been maintaining an Emergency Events Database, EM-DAT. EM-DAT was created with the initial support of the Belgian Government.

showing a growing reliance on coal for the majority of national electricity production, any significant disruption to the transportation network has serious implications for the overall reliability of the grid as a whole (Wilbanks and others, 2008). Figure 1 presents a summary of the relationship between climate change and the energy sector.

The filled lines in figure 1 represent direct impacts, and the dashed lines symbolize indirect effects (on energy planning and investments, on technology research and development, on energy supply institutions, on energy prices, on energy security).

FIGURE 1
FLOW DIAGRAM OF CONNECTIONS BETWEEN CLIMATE CHANGE AND ENERGY PRODUCTION AND USE



Source: Wilbanks and others (2008)

B. Overview of concerns and main challenges

1. Energy security

The concept of energy security has evolved over time through three stages (Valentine, 2011) as follows:

a) Availability of sufficient energy supply to meet demand

b) Accessibility

c) Resilience or the capacity to ensure fuel supplies not disrupted by any external or exogenous factor.

During the second stage (from the end of World War II until the 1980s), the same criteria for energy security remained, but strategies to achieve it varied. It was then the era of oil, in which possession of this fossil fuel was the ultimate solution to energy security. Clearly, even today, societies with hydrocarbon deposits are safer than those without these reserves. However, the findings on climate change concerning the pollution generated by burning fuel and subsequent studies in the late twentieth century and early twenty-first century, have predicted humanity facing the fact of its own demise as a species. These findings have increased the interest in presenting solutions to the problem of CO_2 emissions produced by the use of oil. The carbon capture and sequestration technologies are calls to reduce the impact of excessive use of oil. Irrespective of new hydrocarbon reserves discoveries, increasing the production of energy from other sources is not an alternative, but a mandate.

The third stage, the one in which humanity now finds itself, relates to the clear need for a reduction in the consumption of hydrocarbons and their replacement by renewable energy sources that produce minimal, or no emissions. (For example, it is anticipated that some applications of biomass and biofuels energy use generate greenhouse gas emissions). There is widespread agreement that the best way to get safe energy depends on both renewable and local energy resources, at national or integrated, community levels (AOSIS, 2012).

Thus, distinct from developed countries, Caribbean nations should withhold the concept that energy security is "about meeting basic human needs at the household level, where per-capita consumption levels and the quality of energy supplies are often far lower than in Organization for Economic Cooperation and Development (OECD) countries"[11]. This consumption must be secured from the use of affordable, clean, reliable sources which, in many cases, would mean locally-accessible, renewable energy sources, given that an important part of total energy consumption in underdeveloped countries occurs at the household level.

The costs of production and energy generation from fossil-type sources tend to grow, whereas those from renewable sources follow the opposite course. The other aspect of accessibility is that renewable sources offer a real chance of stopping the growth of domestic prices of electricity, so that not only does access to more power mean countries have more available for consumption, but also that power becomes affordable to many more of the population, which is vital to the improvement of quality of life. Accessibility includes the possibility of access to electricity for four-and-a-half million persons in the Caribbean population who have not yet enjoyed this service. This is clearest when analysing the differences in access among countries, and the lower level of consumption of the Caribbean against Latin American and global averages (USEIA, 2012).

Resilience would be enhanced by the use of renewable energy since, in general, these are decentralized technologies that would prevent widespread impacts of any phenomenon, whether climate-indiced or human- induced (such as operator error, for example), by eliminating the possibility of damage from far-away disasters in energy-production plants or energy systems.[12] Caribbean countries have been giving increasing attention to the development of sustainable projects using renewable energy, both from the national and the CARICOM standpoint and, in some cases, with the support of other countries outside the Caribbean, or of international organizations. These projects have been seeking to diversify the sources of supply of fuels, generate beneficial payment conditions, and increase energy security in the Caribbean. However, failure to meet a certain level of excess capacity would be another factor to be included in energy security planning.

One of the most important challenges for each Caribbean country is being subject to volatile oil prices. However, these high prices present new opportunities for the technological development of renewable energy. Tables 2 and 3 present some quantitative and qualitative approaches based on the resources available for independent renewable energy development in the Caribbean.

[11] The Global Network on Energy for Sustainable Development (GNESD), "Energy security theme" [online], United Nations Environment Programme, http://www.gnesd.org/Publications/Energy%20Security%20Theme.aspx, 2010.

[12] For example, on September 9, 2012, a human error at a power plant in the east of Cuba left nearly 60 per cent of the country without electricity, including the city of Havana, almost 600 km. away from the origin of the problem.

TABLE 2
RENEWABLE RESOURCES ESTIMATES FOR SELECTED CARIBBEAN COUNTRIES

Resource	Wind		Geothermal		Hydro		Solar PV		Biomass		Total	
Country	MW	GWH/yr	MW	GWH/yr	MW	GWH/yr	MW	GWH/yr	MW	GWH/yr	MW	GWH/yr
Antigua and Barbuda	400	870					27	30			427	900
Barbados	10	20					26	30			36	50
Dominica			100	700	8	50	45	50			153	800
The Dominican Republic	3 200	7 000			210	1 470	2 899	3 800			6 309	12 270
Grenada	11	20	400	2 800			21	20	1	2	433	2 842
Haiti	10	20			50	350	1 654	2 170			1 714	2 540
Jamaica	70	150			22	150	650	850	40	210	782	1 360
Saint Kitts and Nevis	5	10	300	2 100			16	20	20	100	341	2 230
Saint Lucia			25	170			36	40			61	210
Saint Vincent/Grenadines	2	4			5	30	23	30			30	64
Total	3 708	8 094	825	5 770	295	2 050	5 397	7 040	61	312	10 286	23 266

Source: Nexant, "Caribbean regional electricity generation, interconnection, and fuels supply strategy: final report" [online], CARICOM, http://www.caricom.org/jsp/community_organs/energy_programme/electricity_gifs_strategy_final_report.pdf, March 2010.

TABLE 3
QUALITATIVE LEVEL OF RENEWABLE ENERGY AVAILABILITY IN THE CARIBBEAN

	Renewable energy resources					
Countries	Wind	Solar	Hydro	Biomass	Geothermal	Ocean
Antigua and Barbuda	High	High	Unknown	Unknown	Unknown	Low
The Bahamas	Medium	High	Unknown	Medium	Unknown	Low
Barbados	High	High	Low	Low	Unknown	Low
Belize	High	High	Medium	Unknown	Unknown	Unknown
Cuba	Medium	High	High	Low	Unknown	Low
Dominica	High	High	Medium	Unknown	High	Low
The Dominican Republic	Medium	High	High	Low	Unknown	Low
Grenada	High	High	Low	Low	High	Low
Guyana	Medium	High	High	Low	Unknown	Low
Haiti	High	High	High	Low	Unknown	Low
Jamaica	Medium	High	Low	Low	High	Low
Saint Kitts and Nevis	High	High	Low	Low	High	Low
Saint Lucia	High	High	Low	Low	High	Low
Saint Vincent and the Grenadines	High	High	Medium	Low	High	Low
Suriname	Low	High	High	Low	Unknown	Low
Trinidad and Tobago	Medium	High	Low	Low	Unknown	Low

Source: International Renewable Energy Agency (IREA), "Biomass for Power Generation", *Renewable Energy Technologies: Cost Analysis Series*, vol. 1, No. 1, June 2012.

2. Energy efficiency

Achieving high energy efficiency is another pathway to reducing the impact of climate change on the energy sector. Energy efficiency is compared:

a) Among activities that produce similar results (electricity generation with multiple energy sources or technologies, or passenger-kilometres flown in different modes of transport)

b) The same activity at different times (direct savings retail electricity use, accommodating work hours to reduce demand)

This analysis may be deconstructed into measures that increase energy efficiency from the supply and demand sides.

a) Measures that increase energy efficiency from the supply side

a) Production sectors - increased economic performance with lower power consumption. This can be achieved by changing arrangements, by making a more rational use of lighting (natural and artificial), or by changes in production processes to more energy-efficient technologies.

b) Construction or rehabilitation of buildings with sustainable, efficient criteria.

c) Legislation on mandatory, minimum-efficiency standards for appliances, imported cars, and other items.

d) Rehabilitation of the transmission and distribution of electricity and water, to reduce losses.

e) Promotion of energy audits.

b) Measures that increase energy efficiency from the demand side

a) Use of solar water heaters (instead of electric devices)

b) Bulb programmes - compact fluorescent light bulb (CFL) programmes, LED programmes (substitution of incandescent lighting bulbs).

c) Fuel-efficient tyres.

d) Policy packages and taxes to promote energy efficiency throughout society.

e) Campaigns for increasing awareness on energy savings (including the carbon footprint calculation) among the population.

f) Reduction in consumption (changing even energy sources like wood) and more use of electricity in all social areas.

g) Implementation of mandatory building and office plans to increase energy efficiency. Some studies have shown that energy efficiency in buildings can be raised by over 50 per cent in the Caribbean. (Edwards, 2012)

There have been seminars, campaigns and projects held in Caribbean countries, and some progress towards improved energy efficiency has been achieved. However, losses during the transmission and distribution of electricity have remained fairly common problems among countries of the Caribbean, as shown in table 4.

In brief, the positive impacts of rising energy efficiency relate to decreases in production costs (of interest to the business sector), and to the conscience of society on energy saving, influencing lower demand and lower greenhouse gas emissions.

TABLE 4
LOSSES IN ELECTRICITY TRANSMISSION AND DISTRIBUTION IN THE CARIBBEAN

Countries	Percentage
Antigua and Barbuda	8.3
The Bahamas	7.2
Barbados	6.9
Belize	6.5
Cuba	14.7
Dominica	11.1
The Dominican Republic	14.5
Grenada	10.0
Guyana	15.9
Haiti	53.6
Jamaica	7.9
Saint Kitts and Nevis	7.1
Saint Lucia	5.9
Saint Vincent and the Grenadines	7.7
Suriname	8.8
Trinidad and Tobago	2.3

Source: United States Energy Information Administration (USEIA), "Country data" [online], Washington, D.C., http://www.eia.gov/countries/data.cfm, 2012.

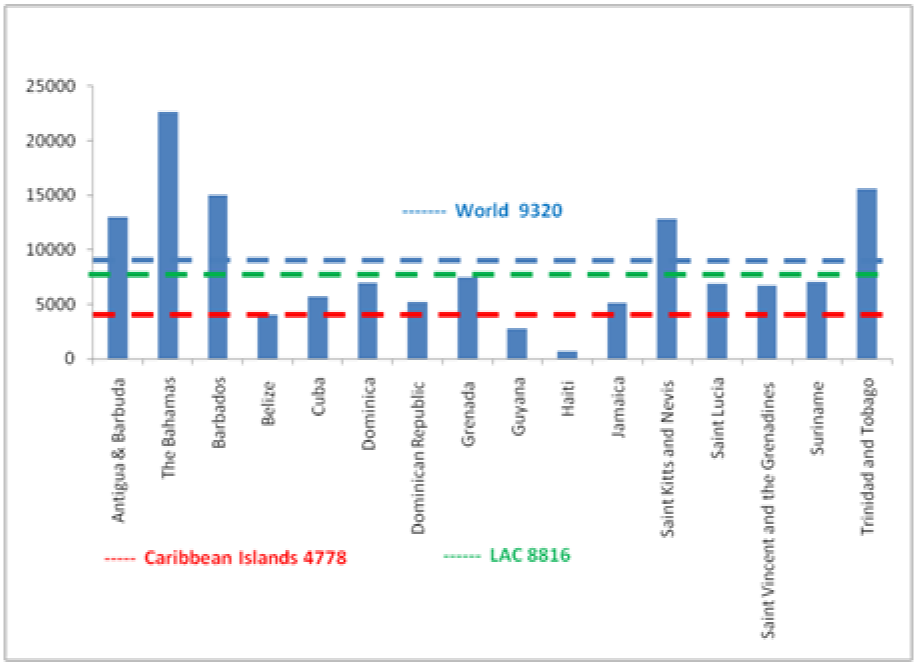
3. Energy and economy

Caribbean countries, despite their efforts towards economic development, were still in 2010 at a level of development lower than the average Latin American gross domestic product (GDP) per capita of US$ 8,816, and even lower than the world average GDP per capita of US$ 9,230 in the same year, as shown in figure 2.

National differences are evident from the GDP per capita indicator. The more affluent countries are the Bahamas, Trinidad and Tobago, Barbados, Saint Kitts and Nevis, and Antigua and Barbuda. At the bottom of the scale are Haiti, Jamaica, Guyana, Belize, the Dominican Republic and Cuba (see annex 2). Another indicator of development is energy intensity, which reflects energy consumption per unit of GDP where a lower index means more efficient use of energy. Moreover, higher levels of industrialization affect energy intensity and in this regard the Caribbean shows an uneven performance (figure 3). Some countries, particularly Trinidad and Tobago, Guyana, Suriname and Jamaica, have high levels of energy intensity, at market prices.

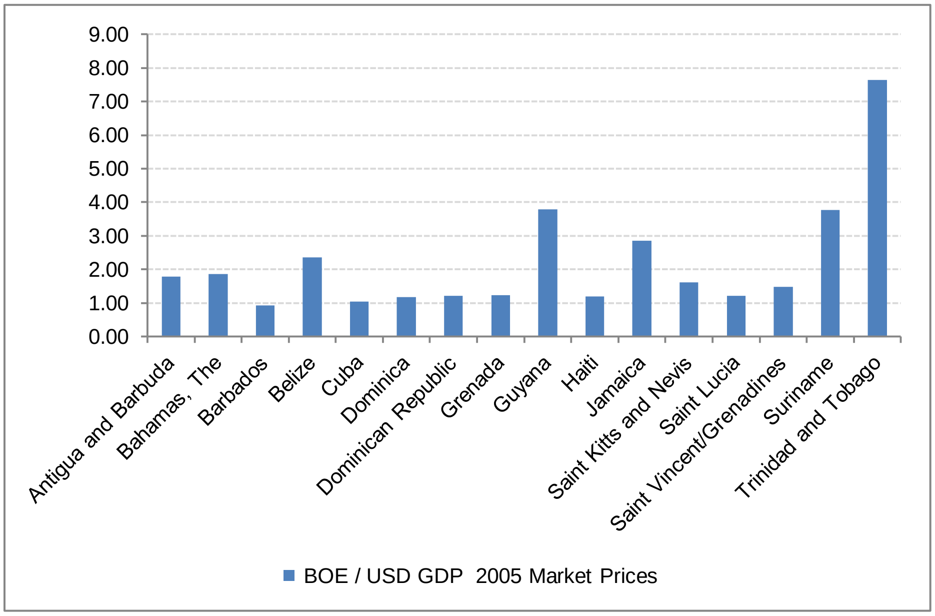
Like most developing economies, Caribbean countries have been increasing their energy consumption since the 1990s. Electricity consumption has increased by 47 per cent globally and by 57 per cent in the Caribbean between 2000 and 2008 (Elliot and others, 2011) Higher global oil prices, therefore, which have been accompanied by an increase in the unit cost of energy, in general, and electricity, in particular, have been of concern to Caribbean countries in recent years, as these may impair efforts to expand economically (USEIA, 2012). This volatility in oil prices (see figure 4) has been of particular concern, mainly because fossil fuels are the primary source of energy for electricity generation in the Caribbean, apart from the implications in terms of levels of harmful emissions, climate change, and foreign reserves.

FIGURE 2
WORLD AND CARIBBEAN GROSS DOMESTIC PRODUCT PER CAPITA, 2010
(United States dollars)



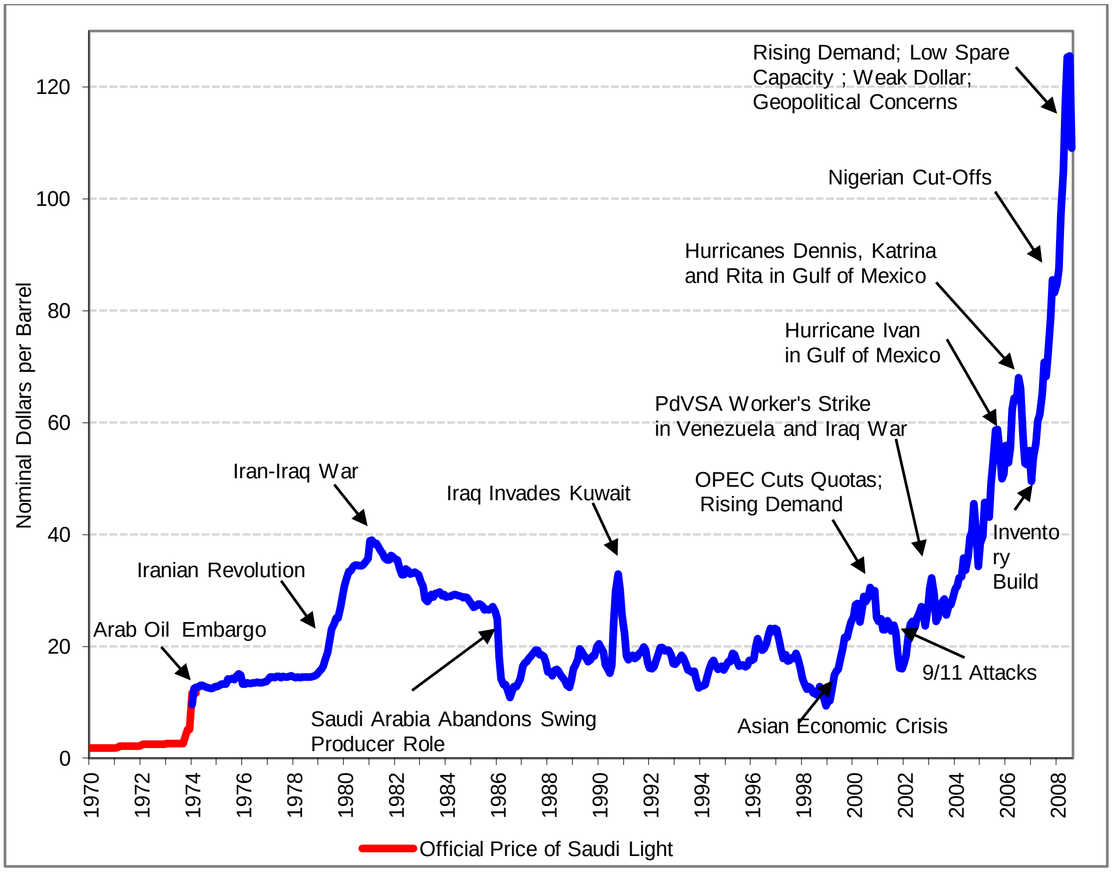
Source: United States Energy Information Administration (USEIA), "Country data" [online], Washington, D.C., http://www.eia.gov/countries/data.cfm, 2012

FIGURE 3
CARIBBEAN ENERGY INTENSITY IN 2009
(Energy consumption per unit of GDP)



Source: United States Energy Information Administration (USEIA), "Country data" [online], Washington, D.C., http://www.eia.gov/countries/data.cfm, 2012

FIGURE 4
OIL PRICES EVOLUTION
(United States dollars per barrel of oil equivalent)



Source: United States Energy Information Administration (USEIA), "Updated capital cost estimates for electricity generation plants" [online], Washington, D.C., Office of Energy Analysis, United.States, Department of Energy, http://www.eia.gov, 2010

The rise in oil prices will have significant negative impacts on:

a) The prices of all products, especially electricity.

b) International food prices (the Caribbean is a net food importer)

c) Transport costs and prices.

d) The value of imports of fuels and possible increases in external debt

These trends will inevitably weaken both the competitiveness of Caribbean countries and the financial well-being of the the population, unless steps are taken to mitigate their impacts. Such measures would be directly related to the increased use of renewable energies which, in turn, would be at the core of mitigation and adaptation strategies to build resilience to climate change.

4. Energy management and social impacts

The uncertainty in technological change is one of the most important issues in assessing the impact of climate change on the energy sector. The following are some priority areas under consideration in current scientific research:

a) The transport sector (not included in the current study, due to lack of data) is committed to increasing the use of mixed fuels and to promoting the use of electricity and has been evaluating new models based on the use of hydrogen.

b) A wide range of technologies could be selected. There is no universal technology for answering the energy needs of all regions

c) The use of solar energy has been directed towards the search for more efficient devices, that is, higher-capacity factors, which are imperative because of the need for lower investment costs in such a clean technology as solar power. Conservation technologies for this type of energy (batteries) have been under development and important results are expected within a period of 5 to 10 years.

d) The use of wind technology (high capacity load) and the search for better combinations of generation (with other fuels, for other purposes).

e) The technologies of efficient use of energy from the oceans.

For the purposes of the present study, energy management includes resource analysis and barriers to their use. To this must be added the social impacts arising from actions, plans and projects. Finally, the general status of regulatory processes to achieve these objectives must be considered.

5. Resource assessment

The availability of fossil fuels in the long term has not been ascertained although it is possible that the twenty-first century may see serious shortages. Therefore, significant international cooperation among those countries with those natural resources and those who do not possess them is required. In the Caribbean, only Trinidad and Tobago has enough hydrocarbon reserves. However, international cooperation has come from Venezuela in the form of the PetroCaribe Agreement,[13] to which Antigua and Barbuda, the Bahamas, Belize, Cuba, Dominica, the Dominican Republic, Grenada, Guyana, Haiti, Jamaica, Saint Lucia, Saint Kitts and Nevis, Saint Vincent and the Grenadines and Suriname of have subscribed.

Given the situation with fossil fuels, the use of renewable energy technologies needs to be encouraged. Economic drivers of renewable energies (Schwerin, 2010) would include economical optimization (a small, off-grid energy supply may often be cheaper than connection to a power grid), security of supply (decreased reliance on fossil fuels), and increased business opportunities. The main environmental driver would be emissions reduction. Social drivers would include the direct and indirect employment opportunities generated and the potential for development in areas formerly less economically attractive.

Renewable energy technologies imply a diversity of solutions based on local characteristics. There is a tendency towards the selection of reliable technologies which represent an improvement over traditional ones, but the development levels of national energy sectors imply disparate needs among Caribbean countries. As a result, some of the technology choices presented in the present study have been designed to cover the real needs of States and localities, even those where poverty was extreme and payment capacity low. The greatest uncertainties lie in the potential for geothermal energy (table 5).

13 The agreement was initiated for the purposes of solidarity with other Caribbean countries, in accordance with the Bolivarian Alliance for the Americas (ALBA). The system allows the purchase of oil from Venezuela at market value for 5-50 per cent downpayment with a grace period of one to two years; the remainder can be paid through a 17-25 year financing agreement with 1 per cent interest if oil prices are above US$ 40 per barrel.

TABLE 5
INTEREST OF CARIBBEAN COUNTRIES IN RENEWABLE ENERGY RESOURCES

Country	Hydro	Wind	Solar	Geothermal	Biomass	Others
Antigua and Barbuda		x	x		Bagasse	
The Bahamas		x	x		Waste-to-Energy	Tidal. Biofuels
Barbados		x	x		Bagasse	Tidal
Belize	x	x	x		x	
Cuba	x	x	x		x	
Dominica	x	x	x	x		
The Dominican Republic	x	x	x		x	
Grenada		x	x	x	x	
Guyana	x	x	x		x	
Haiti	x	x			x	
Jamaica	x	x	x		x	
Saint Kitts and Nevis		x		x	x	
Saint Lucia		x	x	x	x	
Saint Vincent and the Grenadines	x	x	x	x	x	
Suriname	x	x	x		x	
Trinidad and Tobago			x			
Total	9	15	14	5	14	2

Source: Caribbean Information Platform on Renewable Energy (CIPORE) [online], http://www.cipore.org, 2012.

Depending on the natural resources available in each country, wind, solar and biomass energy sources have been the most cited of interest to Caribbean countries. Of these, biomass technologies are the highest emitters of greenhouse gases and, in many cases, rely on the existence of a well-developed local agricultural sector that can ensure production on a seasonal basis, notwithstanding the fact that other forms of biomass energy (municipal waste and landfill gas) require a pre-existing sanitization services infrastructure in towns and cities which are not always present in the area. For this reason, the current report will only consider[4] proposals related to hydropower and wind, solar and geothermal energy, and those biomass projects already in functioning mode.

6. Barriers

The barriers to better use of energy from renewable sources can be grouped, according to their origin as follows:

a) Technological barriers

These include, lack of adequate research and development, insufficient technological development of energy production (low capacity factors) and high technical losses

b) Economic and financial barriers

These include poor industrial facilities for producing renewable energy devices, and high import cost of devices as well as insufficient financial capacity for investment

c) Political, social and human-resource barriers

These include lack of professional and technical capacity (shortages of trained staff), lack of opportunities for the poorer segments of the population, lack of awareness and inadequate policies, plans and other regulatory or legal actions

7. Regulatory processes

One of the first steps to improving energy management is statistical compilation. However, due to lack of reliable data, energy balances for seven of the countries included in the present analysis were unavailable and electricity profiles for five countries were not available (table 6).

TABLE 6
AVAILABILITY OF ENERGY BALANCE

Country	Energy balance	Electricity profile
Antigua and Barbuda		
The Bahamas		
Barbados	1	1
Belize		1
Cuba	1	1
Dominica		1
The Dominican Republic	1	1
Grenada	1	1
Guyana	1	1
Haiti	1	1
Jamaica	1	1
Saint Kitts and Nevis		
Saint Vincent and the Grenadines		
Saint. Lucia		
Suriname	1	1
Trinidad and Tobago	1	1
Total	9	11

Source: Nations Statistics Division (UNSD), "Energy Statistics: Energy Balance and Electricity Profile" [online], New York, United Nations, http://unstats.un.org/unsd/energy/balance/, 2012.

Caribbean Governments have made considerable efforts to improve the regulatory framework of the energy sector, with varying degrees of success, as shown in table 7. However, the laws, regulations, and economic instruments used by Governments to direct policies could be improved to encourage the use of renewable energy. Policies for the increased use of renewable energy should be part of the development programmes of Caribbean States, raising the level of political commitment for their promotion. It would require more political will and commitment to achieve the successful implementation of these energy plans.

TABLE 7
NATIONAL ENERGY POLICIES AND REGULATIONS IN THE CARIBBEAN

Country		National energy policy and plans				Renewable energy policy				
	Regulations and Acts	Draft	Task force	Vision/Project	Approved	Draft	Vision	Task Force	Approved	IRENA Member
Antigua and Barbuda		2009	2010							2010
The Bahamas				2008	2011					
Barbados	1996 a/				2007			2009 b/		
Belize			1999	2003						
Cuba	c/				2006 c/			2007		2012
Dominica	2006 d/	2009				2003				
Dominican Republic	e/				2004					2010
Grenada		2009			2011	2003				2011
Guyana					1994					
Haiti		2008								
Jamaica	f/				2009	2010 g/			2005	
Saint Kitts and Nevis	h/								2007 i/	
Saint Lucia				2004	2010		2001 j/		2005 j/	
Saint Vincent and the Grenadines					k/					2010
Suriname										
Trinidad and Tobago	l/									

Source: International Renewable Energy Agency (IRENA), "Renewable Energy Country Profile" [online], Abu Dhabi, United Arab Emirates, http://www.irena.org/menu/index.aspx?mnu=cat&PriMenuID=47&CatID=99, 2012.

a/Sustainable Energy Framework for Barbados
b/ Tax deductions for solar heaters reinstated solar water heaters
c/ Energy Revolution and other regulations
d/ Electricity Supply Act Amended
e/ General Electricity Act 2001; Decree 566-05 on liquid biofuels 2005; Law 57-07 Renewable energy incentives 2007; Decree implementing Law 57-07 2008
f/ Centre of Excellence for Renewable Energy created 2006; Roll-out of 10% bio ethanol blend 2009
g/ Draft National Renewable Energy Policy; Draft National Biofuels Policy; Draft National Waste-to-Energy Policy
h/ Nevis Geothermal Resources Development Ordinance 2010; Tax Exemptions for Renewable Energy Equipment 2012
i/ National Action Programme for Combating Desertification and Land Degradation
j/ National Sustainable Energy Plan 2001; Sustainable Energy Plan 2005
k/ National Energy Policy approved by Cabinet 2009; Energy Action Plan approved in Cabinet 2010
l/ Renewable Energy Committee created 2008

8. Social impacts

In 2010, the Caribbean had a per capita electricity consumption equivalent to 64 per cent of the average per capita electricity consumption of Latin America. The ratio to average global electricity consumption was 46 per cent, distributed differently in the countries studied, as shown in table 8.

TABLE 8
ENERGY AND ELECTRICITY CONSUMPTION IN THE CARIBBEAN 2010
(Thousands of barrels of oil equivalent and millions of kilowatt hours)

Country	Energy consumption	Per capita energy	Electricity consumption	Per capita electricity
	Thousands BOE	BOE	Million kWH	kWH
Antigua and Barbuda	1 837.0	20.9	110	1 252
The Bahamas	13 676.4	40.4	1 810	5 349
Barbados	2 202.6	10.7	960	3 519
Belize	3 053.7	9.1	290	870
Cuba	64 057.6	5.7	14 650	1 300
Dominica	427.0	6.3	80	1 177
The Dominican Republic	38 738.8	3.0	9 880	1 018
Grenada	537.3	5.2	180	1 729
Guyana	6 032.9	8.0	680	903
Haiti	17 715.7	1.8	320	32
Jamaica	19 656.4	7.3	480	178
Saint Kitts and Nevis	778.6	15.0	130	2 512
Saint Lucia	1 168.8	6.8	120	696
Saint Vincent and the Grenadines	820.0	7.5	320	2 928
Suriname	4 539.2	8.7	1 460	2 808
Trinidad and Tobago	90 148.9	67.5	7 100	5 313
Caribbean	265 390.9	7.0	38 570	1 251

Source: Developed by author based on data from ECLAC, the United States Energy Information Administration (USEIA) and World Bank Database

A more serious situation is that of the unequal access to electricity in Caribbean countries. Table 9 shows the relative, or absolute, delay in electrification level of some Caribbean States in 2009.

There are almost four and a half million people in the Caribbean who have no access to electricity, for reasons as diverse as distance from main networks, geographical inaccessibility, or poverty, or all of these together. The use of renewable technologies can alleviate such situations, as there are solutions to local points of low demand that have no need for grid connections.

Another important issue is the affordability of high electricity prices (see annex 3). This is a direct consequence of the high prices of fossil fuels. Expansion in the use of renewable energy technologies will benefit all of society, including its poorest segments. At the same time, it would contribute to the market competitiveness of Caribbean States.

The lack of reliable datasets on electricity use among the poor is another area that needs to be addressed. Another consideration is that any power sector reforms, or new investments in renewable energy, need an explicit, pro-poor dimension: otherwise, electrification of the poor could be forgotten.

Successful renewable energy policy implementation that addressed social impacts would require the participation of local communities and the fostering of income-enhancing activities. Renewable energy in electricity production can be a source of local employment. Lack of data on employment impedes a deeper analysis of this topic.

All social aspects mentioned must be brought into building population awareness: there will always be a higher understanding of the importance of these measures once they can be clearly translated into individual, and communal, benefits.

TABLE 9
CARIBBEAN COUNTRY ELECTRIFICATION LEVELS 2009
(Percentage)

Country	Population	Electrification level *(Percentage)*	Population without electricity
Antigua and Barbuda	87 500	99.0	900
The Bahamas	342 877	90.0	34 300
Barbados	274 000	95.0	13 700
Belize	345 000	89.9	34 800
Cuba	11 257 979	97.0	337 700
Dominica	67 757	87.6	8 400
The Dominican Republic	9 877 000	95.9	405 000
Grenada	104 487	86.4	14 200
Guyana	754 493	77.5	169 800
Haiti	9 993 247	38.5	6 145 800
Jamaica	2 702 000	92.0	216 200
Saint Kitts and Nevis	52 000	94.0	3 100
Saint Lucia	174 000	94.2	10 100
Saint Vincent and the Grenadines	109 000	93.0	7 600
Suriname	524 636	84.0	83 900
Trinidad and Tobago	1 341 465	99.0	13 400
Caribbean	38 007 441	88.3	4 442 100

Sources: World Bank Database (2012), United States Energy Information Administration (2012), Renewable Energy and Energy Efficiency Partnership (2012)

III. Methodology

A. General description of the methodology

A system of relationships adapted to the economy of the energy sector in relation to climate change in the Caribbean is presented here. At the core of the processes diagram lie the goals, strategies and targets described in the present study (see figure 5). A description of the steps followed in the general procedure is provided here.

Step1: Literature review: This step provided the necessary basis of the relationship between energy and climate change. It defined the complexities sought in the data, and the variables to be employed in the analysis, providing a foundation for the rest of the procedure here described.

Step 2: Completion of the dataset employed: This step proved to be a challenge, although it was essential in the subsequent outcome of the study. There were small, incomplete sets of data from each country involved in the study, requiring a great deal of time and effort for their completion—as much as was possible, using the variables derived from the literature review.

Step 3: Energy consumption modelling and forecast: This step was carried out through extensive computing time, after the functional relation to be modelled was defined for each country. More than 122 different artificial neural networks were run in this process.

Step 4: Determination of mitigation and adaptation targets: This step was defined by a thorough analysis of the environmental, social and economic conditions and prospects of the countries studied, as well as of the Caribbean as a whole. Targets were established that took all these dimensions and their interrelationships into account, on a country-by-country basis.

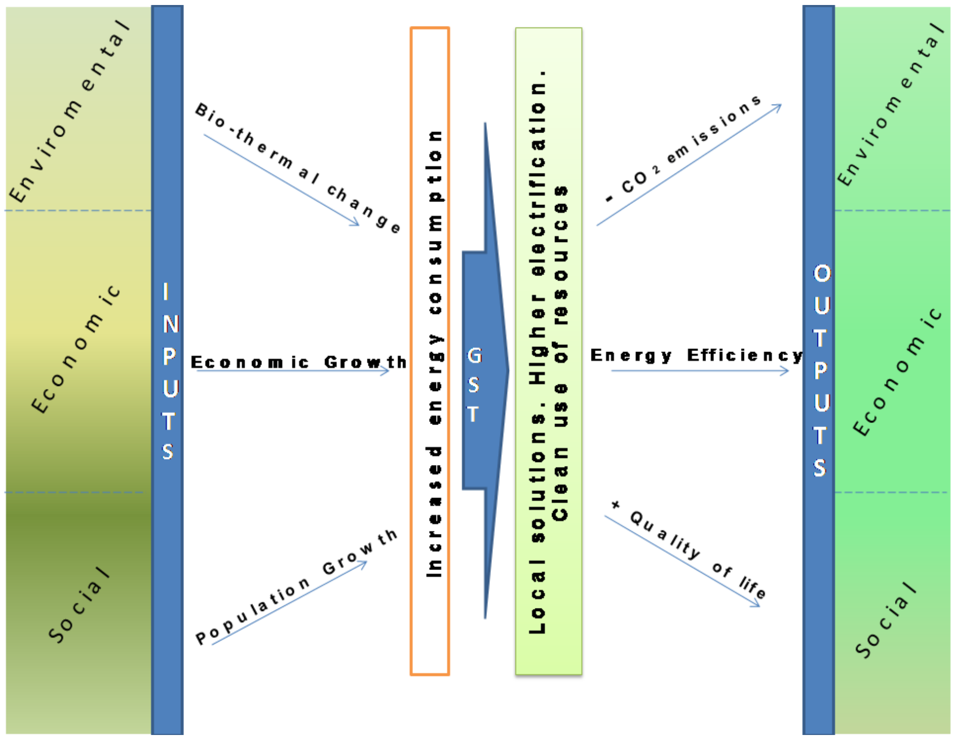
Step 5: Design of mitigation and adaptation actions: This step was completed through extensive analysis of national and Caribbean Community energy policies, plans, visions, reports, studies and outlooks. National-level actions were proposed and the composite outcomes re-analysed from a Caribbean perspective.

Step 6: Complete financial evaluation of proposed mitigation and adaptation actions: Cost-benefit analyses for the designed actions at country level were carried out, including the calculations of the avoided costs from non-imported fuels derived from the installation of renewable energy technologies. A complete financial evaluation of projects derived from proposed actions was conducted, including scenarios of plant size, discount rates, equity and debt management and the definition of levelised cost of electricity (LCOE) for each project. Spreadsheets for these calculations were provided by the National Renewable Energy Laboratory (NREL) of the United States of America, which has proved, through usage of its services, to be accurate and to provide a high level of detail.

Step 7: Caribbean results analysis: An analysis of the results obtained was conducted and aggregated to outline the principal consequences and impacts of climate change on the energy sector for the whole Caribbean, with special emphasis on the shared commonalities between countries.

Step 8: Country results analysis: Finally, a special report that is available separately was constructed for each country, with the analysis of the results obtained and their implications for national stakeholders.

FIGURE 5
PROCESS FLOWCHART OF CLIMATE CHANGE IMPACTS ON THE ENERGY SECTOR



Source: Developed by the author

From the literature review, the demand model of energy consumption (EC) (dependent variable) for each country was constructed as a function of the following (taken as independent) variables, namely, Mean Temperature (MT), Relative Humidity (RH), Wind Speed (WS), GDP and Population (P). The exception was those countries for which there were no GDP and population projections from the IPCC.[14] In those cases, only the relation between climate variables and energy consumption was modelled. Not all variables were used at the same time in the forecasts, and they differed in the sources from which they were taken. Data for the variables selected with the models were analysed in search of outliers and other error-generating causes.

[14] Antigua and Barbuda, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, and Saint Vincent and the Grenadines. See subsection on sociodemographic variable analysis, and table 11.

B. Data collection and analysis

The data-collection process was conducted by national data collectors and was based on data series for each sector, as requested. Despite the efforts of data collectors, data series reflected the lack of some important and meaningful information. These gaps were corrected by consulting alternative sources of information from entities such as: the United Nations Economic Commission for Latin America and Caribbean (ECLAC), the Latin American Energy Organization (OLADE), the Caribbean Community (CARICOM) Secretariat, the Caribbean Energy Information System (CEIS), the Intergovernmental Panel for Climate Change (IPCC) Projections, the Caribbean Information Platform on Renewable Energy (CIPORE), the Renewable Energy and Energy Efficiency Partnership (REEEP), the World Bank Database, the United States Energy Information Administration (EIA) and the Providing Regional Climates for Impacts Studies (PRECIS) Regional Climate Model (RCM) for the Caribbean. Although data for the Caribbean countries were scarce, a dataset covering annual data from 1970 to 2010 was completed and employed.

1. Temperature, relative humidity and wind speed

Mean temperature has been rising increasingly in the Caribbean. This is entirely consistent with both global and regional observations, following Simpson and others (2009). As noted by Sookram (2010), Peterson and others (2002) reported that the percentage of days with cold temperatures had decreased since the middle of the twentieth century, while the ratio of days with very warm maximum, or minimum, temperatures to the general account of days had increased significantly. In Trenberth and others (2007), it was made clear that temperatures in the Caribbean have been increasing from 0.0^{0} C to 0.5^{0} C per decade in the years considered (1971-2000). The PRECIS RCM brought a complete dataset of projections for a grid comprising all countries involved in the analysis, with the exception of Suriname, for which a grid point practically at the border with Guyana (for which data existed) was selected.

Rising temperatures were expected to reach the 1.5° C mark by 2050 under the SRES A2 scenario. Projected values of local minima were expected to increase by at least by 1° C in the best-case scenario. Nonetheless, locally intensifying phenomena, such as ocean acidification, which were likely to affect coastal lowlands, in countries such as those in the Caribbean, might even give rise to temperature increases of 3° C in some places.

Relative humidity and wind speeds, which are also related to energy consumption, were expected to stay unchanged, or decrease slightly, in most Caribbean countries, associated mostly with local decreases in total rainfall. Wind speeds were projected to fall marginally from actual ranges, with some pointed decreases in specific countries in the Caribbean, mostly under SRES A2. Table 10 depicts the change from historical values for climate variables in the projections for B2 and A2 SRES in the considered countries, from PRECIS RCM. Negative values denote decreases.

Individual values for mean temperature looked relatively worse for SRES B2 projections, yet there was nothing wrong with the estimates. The worst case scenario remained SRES A2, when the combined relative variation of the three variables was taken into account. Temperature increased slightly less for SRES A2, relative humidity stayed mostly the same and was higher than in SRES B2 in most countries, and wind speeds dropped below past levels, being lower in SRES A2 in every case. These variables have a combined effect, implying therefore that cooling needs, which are at the core of climate change impacts on energy use, would be higher in the scenario with the worse combined values, namely, SRES A2. The manner of these combinations and their effect on energy demand has been modelled in the following sub-sections. In addition, the effects of the SRES A2 storyline increased and became more clearly worse after 2050, at dates beyond the scope of the present study.

TABLE 10
PROJECTED CARIBBEAN CLIMATE VARIATIONS UNDER SRES A2 AND B2: 2010 TO 2050

Country	Projected climate variations (2010 - 2050) SRES A2			Projected climate variations (2010 - 2050) SRES B2		
	Temperature (º C)	Humidity (%)	Wind speed (m/s)	Temperature (º C)	Humidity (%)	Wind speed (m/s)
Antigua and Barbuda	1.8	0.6	-0.2	2	-0.5	-0.6
The Bahamas	1.4	0.3	0.4	1.5	-1	0.4
Barbados	1.6	1.4	-0.4	1.7	-3.1	0.4
Belize	1.9	-1.3	0.1	2.3	-1.1	0.2
Cuba	1.85	-2.4	0.18	1.9	-2.5	0.15
Dominica	1.7	1	-0.3	1.8	0	-0.1
The Dominican Republic	1.5	2.1	-0.2	2.1	2.1	-0.7
Grenada	1.7	0.5	-0.2	1.8	-1	0.6
Guyana	2.2	-1.8	0.4	2.5	-4.2	1.4
Haiti	1.6	1.5	-0.1	2	2.2	-0.3
Jamaica	2.1	-1.6	-0.1	2.3	-0.2	0
Saint Kitts and Nevis	1.8	0.4	-0.2	2.2	-0.5	-0.7
Saint Lucia	1.7	1	-0.4	1.6	0.4	0.1
Saint Vincent and the Grenadines	1.7	1	-0.5	1.6	0.8	0.3
Suriname	2.3	-2.9	0.5	2.8	-6.7	1.4
Trinidad and Tobago	1.9	0	-0.2	2.3	-3.8	0.9

Source: Economic Commission for Latin America and the Caribbean (ECLAC), based on figures from providing regional climates for impacts studies (PRECIS) and the Regional Climate Model (RCM) for the Caribbean

2. Socio-demographic variables

The economic and social aspects of future energy demand have been covered in the present study through the use of gross domestic product (GDP) and population data for each country. These projections were made from the SRES storylines by IPCC, and have been employed here in order to provide a consistent outlook of the future, from a single point of view, using a single methodology.[15]

Unfortunately, IPCC projections did not include the six smaller island countries of Antigua and Barbuda, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, and Saint Vincent and the Grenadines. In the countries for which data existed, GDP was forecast to grow the same for every country under study within each SRES except Jamaica, which had a notably steeper increase under SRES B2. In contrast, population was expected to grow in the Caribbean with the exception of Cuba and Guyana. In Cuba, population was expected to decrease under SRES B2, but the trend between the two scenarios remained unaltered. However, in the case of Guyana, it was found that population growth was lower under SRES A2 as compared with 2010. This proved to be determinant in the modelling of future energy demand for Guyana. Table 11 shows the entire set of variations, which, in the case of GDP, have been expressed for the year 2050 in terms of 2010 values i.e. the projected value of GDP for the Bahamas in SRES A2 for the year 2050 will be 3.6 times that of 2010.

[15] While this can be criticized, the author preferred the use of a reliable, widely-used source over the hazards of multiple criteria use or self-made forecasts. Moreover, the future climate values themselves that have been employed in the study were a direct result of IPCC GDP and population schematics. Therefore, use of one or more sources for those variables, in departing from the basis from which CO2 emissions and, ultimately, temperature, relative humidity and wind speeds, were estimated would render the whole modelled projection inconsistent.

TABLE 11
GROSS DOMESTIC PRODUCT AND POPULATION VARIATIONS IN THE CARIBBEAN UNDER SRES A2 AND B2: 2010 AND 2050

Country	Variations (2050 / 2010) SRES A2		Variations (2050 / 2010) SRES B2	
	GDP	Population (%)	GDP	Population (%)
Antigua and Barbuda	-	-	-	-
Bahamas (the)	3.6	70	5.3	30
Barbados	3.6	13	5.3	11
Belize	3.6	88	5.3	61
Cuba	3.6	11	5.3	-2
Dominica	-	-	-	-
Dominican Republic (the)	3.6	61	5.3	35
Grenada	-	-	-	-
Guyana	3.6	-8	5.3	28
Haiti	3.6	86	5.3	84
Jamaica	4.3	73	5.3	35
Saint Kitts and Nevis	-	-	-	-
Saint Lucia	-	-	-	-
Saint Vincent and the Grenadines	-	-	-	-
Suriname	3.6	40	5.3	23
Trinidad and Tobago	3.6	28	5.3	23

Sources: Intergovernmental Panel on Climate Change (IPCC), *Special Report on Emissions Scenarios*, 2000

3. Energy variable

The sole energy variable employed in the model was energy consumption, since the purpose of the exercise was to estimate future energy demand, both in the Caribbean and within each country. It is on the demand side of the energy sector on which the main foreseeable impacts from climate change are to occur, according to the literature review.

Energy consumption in the Caribbean has seen a disparate growth in the years from 1970 to 2010. While some countries have grown to high relative values like Trinidad and Tobago, and Saint Vincent and the Grenadines, which have multiplied tenfold their energy consumption in 40 years others have shown only modest increases, for example, Jamaica and Suriname, which have grown approximately 15 per cent since the 1970s. Cuba, with a practically null increase in energy consumption, has been a special case (see table 12).

Table 12 shows data for energy consumption in Caribbean countries for the years 1970-2010. Not only has growth in energy consumption been unequal in the Caribbean, so has the rate of growth in energy consumption been unequal. Most countries have had an unstable growth curve, which can be derived from the mean and standard deviation values.

C. Methods and models: cost-benefit analysis and financial analysis

There is a growing volume of literature on the best methods of producing accurate forecasts, both in economics as well as in other fields. Qualitative methods, usually based on the experience and expertise of individuals, have been in use for quite some time, the Delphi method being one of the most commonly employed. Quantitative methods generally can be divided into three major areas, which differ in the mathematical and statistical nature of their approaches: time series, econometric (causal), and artificial intelligence methods. The forecast methods employed in the present study were all quantitative.

TABLE 12
GROWTH IN ENERGY CONSUMPTION FOR SELECTED CARIBBEAN COUNTRIES, 1970-2010

Country	Energy consumption		
	Percentage growth (2010/1970)	Thousands of barrels of oil equivalent (BOE)	
		Mean	Standard deviation
Antigua and Barbuda	78.5	1 098.4	292.3
Bahamas (the)	118.5	8 137.5	2 551.8
Barbados	87.8	1 523.9	378.5
Belize	371.5	1 241.4	888.8
Cuba	0.1	64 515.8	16 795.5
Dominica	381.4	189.7	103.6
The Dominican Republic	208.5	24 206.8	10 322.7
Grenada	400.4	275.5	150.1
Guyana	38.4	5 251.1	1 053.1
Haiti	98.4	11 455.7	3 390.1
Jamaica	15.5	16 501.3	5 168.6
Saint Kitts and Nevis	546.2	232.3	149.5
Saint Lucia	392.3	487.2	208.8
Saint Vincent and the Grenadines	931.8	297.2	208.8
Suriname	16.4	3 837.0	800.3
Trinidad and Tobago	1 324.7	32 846.4	27 416.4

Source: Economic Commissionf or Latin America and the Caribbean (ECLAC), based on official data and data from the United States Energy Information Administration (USEIA), and study data.

The first area of quantitative methods, time series, deals with methods which consider the variable itself in its historical development only. Relying on the chronological behaviour of the variable, these methods establish the main components of time series (i.e. trend, cycle, seasonality, etc.) and then forecast the future values of the variable in a definite time frame. Examples of these methods are: naive, exponential smoothing, and the ARIMA (autoregressive integrated moving average) family.

The second area of quantitative methods comprises the most-used methods in economic variables forecasting, those that establish causality between variables described through unknown functions which, in this case, are called demand functions. Thus, an econometric model of demand (or demand model) fixes a variable describing the demand (energy consumption, for example) as a function of a number of other variables that have a direct causal relation to the first. The former is called the dependent variable, the latter are called independents and the mathematical expression of the function, which is generally unknown, is approximated through specific methods. Examples of these methods range from simple regression to the statistically sophisticated Time Varying Parameters (TVP), Computable General Equilibrium (CGE) and panel data models, among others. (Kulendran and Witt, 2001).

The third, and last, area of quantitative methods is populated by the comparatively more recent approaches generally classified as artificial intelligence. These methods, based on results that mathematically model processes in natural and human development, are being used increasingly in demand forecasting, with more significant outcomes in comparison to the previous two methods. Among these methods, fuzzy logic, artificial neural networks (ANNs), genetic algorithms (GAs), and combinations of these, have been some of the most widely employed (Mazanec, 1992; Law and Au, 1999; Law, 2000; Wang, 2004; Bigne and others, 2008; Delgado and Fernandez, 2010; Delgado and Abreu, 2010).

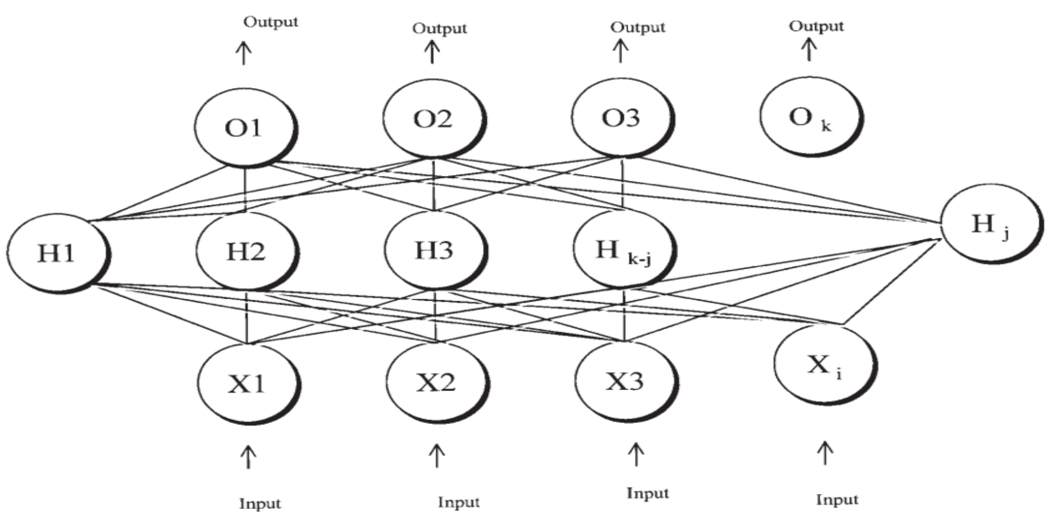
1. Artificial neural networks

In recent years, there has been an emerging interest in artificial intelligence (AI) forecasting models. Research has indicated that these AI forecasting methods including neural networks, rough sets theory, fuzzy time-series theory, grey theory, genetic algorithms, and expert systems sometimes have outperformed conventional forecasting methods (Wang, 2004). Wang, and other studies, found that neural networks were more accurate than regression and time-series models.

The ANN model was introduced in the early 1960s by Mclloach-Hopfield (cited in Simpson, 1990) but has developed from about 1985 (Ripley, 1994). Today, ANNs are used widely. The model consists of a set of nodes (i.e. neurons) for processing input data, and a set of connections, for "memorizing" information (Simpson, 1990; Ripley, 1994).

Thus, a neural network model learns from examples, and provides desired results by generating new information. The typical architecture of neural network models includes one input layer, one or two hidden layers, and one output layer (NeuralWare, 1993; Simpson, 1990). Figure 6 depicts a general neural network model. Each layer can have numerous processing nodes that are connected. The input layer receives stimuli from the outside world that are analogous to independent variables in regression models. The output layer can be thought of as the dependent variable (i.e. energy consumption, oil prices). The hidden layer contains nodes that serve as filters that rescale the input data onto the output data.

FIGURE 6
GENERAL NEURAL NETWORK ARCHITECTURE



Source: J. Jeng and D.R. Fesenmaier, "A Neural Network Approach to Discrete Choice Modeling", *Journal of Travel and Tourism Marketing*, vol. 5, No. 1/2, 1996.

ANN models are basically derived from two learning methods, supervised and unsupervised, and two architectures, feedforward recall and feedback recall (Simpson 1990; Ripley 1994; Jeng and Fesenmaier, 1996). An unsupervised learning method, on the one hand, relies on internal control, and data are organized by computing the degree of similarity between two objects in order to group the respective objects. A supervised learning method, on the other hand, is defined by outputs, and the weights are adjusted corresponding to the difference between desired output and actual output (Nelson and Illingworth, 1991). Supervised learning implies that the input categories already have been identified, and the labels for each input class known. Feedforward recall refers to unidirectional flow and information processing, in which each node is allowed only to receive information from the preceding neuron. Feedback recall is a bidirectional information-processing method, in which each node receives information from the preceding layer and allows the feedback to subsequent layers. A multilayer perceptron indicates that the input layer is indirectly connected to the output layer through the hidden layer.

A final point on ANN architecture is the choice of the construct of the hidden layer. Although there have been some attempts, in several studies, to develop guidelines for deciding on the optimal number of hidden layers and nodes (Lippmann, 1987; Gorr, Nagin, and Szczypula, 1994), so far, no established procedures are available and it is still being subject to trial and error (Jeng and Fesenmaier, 1996). This is a critical issue, since the consequence of a bad decision regarding the hidden layer construct may cause overfitting, that is, the model could get caught in a local, rather than a global, minimum. The problem is that the rationale of back-propagation is the minimization of the least square error if the model is not trapped in a local minimum (Hill and Remus, 1994). The general rule of thumb, however, is to increase the number of hidden layer nodes. This has to be accompanied by an increase in the sample size, since the model consumes more degrees of freedom as the number of hidden nodes in the middle layer is expanded. Otherwise, the model will lose the generalization power and will start to memorize rather than learn (Hill and Remus, 1994). Also, the excessive use of this rule-of-thumb may cause the model to learn from unnecessary noise in training patterns which, again, may deteriorate its generalization power (Lee and Lee, 1994). The final limitation on this rule is that the model may get confused, and be unable to estimate reliably the many weights required by a larger number of hidden units (Lippmann, 1987)

2. Generalized regression, probabilistic and linear neural networks

Estimating probability density functions from data has a long statistical history (Parzen, 1962), that, in this context, fits into the area of Bayesian statistics. Conventional statistics can, given a known model, inform the chances of certain outcomes (e.g. an unbiased die has a 1 in 6 chance of coming up with a six). Bayesian statistics turns this situation on its head, by estimating the validity of a model given certain data. More generally, given the available data, Bayesian statistics can estimate the probability density of model parameters. To minimize error, the model whose parameters maximized this probability density function would be selected.

An alternative approach to probability density function estimation is kernel-based approximation (see Parzen, 1962; Speckt, 1990; Speckt, 1991; Bishop, 1995; Patterson, 1996). It can be reasoned loosely that the presence of a particular case would indicate some probability density at that point: a cluster of cases close together would indicate an area of high probability density. Close to a case, there can be high confidence in some probability density, with a lesser and diminishing level of confidence moving further away. In kernel-based estimation, simple functions are located at each available case, and are added together to estimate the overall probability density function. Typically, the kernel functions are each Gaussians (bell-shapes). If sufficient training points are available, these will, indeed, yield an arbitrarily-good approximation to the true probability density function.

This kernel-based approach to probability density function approximation motivates the probabilistic neural network (PNN) and generalized regression neural network (GRNN), both devised by Speckt (1990, 1991). These two types of network are really kernel-based approximation methods cast in the form of neural networks. In the PNN, there are at least three layers: input, radial, and output layers. The radial units are copied directly from the training data, one per case. Each model is a Gaussian function centred at the training case. There is one output unit per class. Each is connected to all the radial units belonging to its class, with zero connections from all other radial units. Hence, the output units simply add up the responses of the units belonging to their own class. The outputs are each proportional to the kernel-based estimates of the probability density functions of the various classes, and these are normalized to sum to 1.0 to produce estimates of class probability.

Generalized regression neural networks (GRNNs) work in a similar fashion to PNNs, but perform regression, rather than classification, tasks (Speckt, 1991; Patterson, 1996; Bishop, 1995). As with PNN, Gaussian kernel functions are located at each training case. Each case can be regarded, in this case, as evidence that the response surface is a given height at that point in input space, with progressively decaying evidence in the immediate vicinity. GRNN copies the training cases into the network to be used to estimate the response on new points. The output is estimated using a weighted average of the outputs of the training cases, where the weighting is related to the distance of the point from the point being estimated (so that points nearby contribute most heavily to the estimate).

The first hidden layer in the GRNN contains the radial units. A second hidden layer contains units that help to estimate the weighted average. This is a specialized procedure. Each output has a special unit assigned in this layer that forms the weighted sum for the corresponding output. To get the weighted average from the weighted sum, the weighted sum must be divided through by the sum of the weighting factors. A single special unit in the second layer calculates the latter value. The output layer then performs the actual divisions (using special division units). Hence, the second hidden layer always has exactly one more unit than the output layer. In regression problems, typically only a single output is estimated, and so the second hidden layer usually has two units. The GRNN can be modified by assigning radial units that represent clusters rather than each individual training case: this reduces the size of the network and increases execution speed. Centres can be assigned using any appropriate algorithm (i.e. sub-sampling, K-means or Kohonen).

A general scientific principle is that a simple model should always be chosen in preference to a complex model (if the latter does not fit the data better). In terms of function approximation, the simplest model is the linear model, where the fitted function is a hyperplane. In classification, the hyperplane is positioned to divide the two classes (a linear discriminant function); in regression, it is positioned to pass through the data. A linear model is typically represented using an NxN matrix and an Nx1 bias vector.

A neural network with no hidden layers, and an output with dot product synaptic function and identity activation function, actually implements a linear model. The weights correspond to the matrix, and the thresholds to the bias vector. When the network is executed, it effectively multiplies the input by the weights matrix then adds the bias vector.

Finally, the performance of a regression network can be examined in a number of ways:

a) The output of the network for each case (or any new case chosen to be tested) can be submitted to the network. If part of the data set, the residual errors can also be generated.

b) Summary statistics can be generated. These include the mean and standard deviation of both the training data values and the prediction error. It would generally be expected that a prediction error mean would be extremely close to zero. The most significant value is the prediction error standard deviation. If this is no better than the training data standard deviation, then the network has performed no better than a simple mean estimator. A ratio of the prediction error SD to the training data SD significantly below 1.0 indicates good regression performance, with a level below 0.1 often said (heuristically) to indicate excellent regression. This regression ratio (or, more accurately, one minus this ratio) is sometimes referred to as the explained variance of the model. The regression statistics may also include the Pearson-R correlation coefficient between the network's prediction and the observed values. In linear modelling, the Pearson-R correlation between the predictor variable and the predicted is used often to express correlation - if a linear model is fitted, this is identical to the correlation between the model's prediction and the observed values (or, to the negative of it). Thus, this gives a convenient way of comparing the neural network's accuracy with that of the linear models.

c) A view of the response surface can be generated. The network's actual response surface is, of course, constructed in N+ 1 dimension, where N is the number of input units, and the last dimension plots the height. It is clearly impossible to visualize this surface directly where N is anything greater than two (which it regularly is).

3. Model specifications

For the abovementioned reasons, ANN modelling was employed for all necessary projections in the present study. Different types of neural networks, such as those described above, were experimented with in the model selection processes.

For a better understanding, the interpretation of specific model architectures and performance is explained below. First line:

Profile	MLP s7 1:7-8-8-1:1

The first line of the model explains that a Multilayer Perceptron was employed, which had 7 nodes in the first layer, 8 nodes in the first hidden layer, 8 nodes in the second hidden layer and also, naturally, a single output node. This is explicitly stated in lines 6, 7 and 8. ANNs work by dividing the data into three independent sets: Training, Selection and Test Errors committed by the network are presented in lines 2, 3 and 4. Training/Members (BP100, CG12b) are the code of optimization algorithms. Statistica software codes for optimization methods are shown in figure 7.

FIGURE 7
STATISTICAL SOFTWARE CODES FOR ARTIFICIAL NEURAL NETWORK OPTIMIZATION METHODS

BP	Back Propagation
CG	Conjugate Gradient Descent
QN	Quasi-Newton
LM	Levenberg-Marquardt
QP	Quick Propagation
DD	Delta-Bar-Delta
SS	(sub)Sample
KM	K-Means (Centre Assignment)
EX	Explicit (Deviation Assignment)
IS	Isotropic (Deviation Assignment)
KN	K-Nearest Neighbour (Deviation Assignment)
PI	Pseudo-Invert (Linear Least Squares Optimization)
KO	Kohonen (Centre Assignment)
PN	Probabilistic Neural Network training
GR	Generalised Regression Neural Network training
PC	Principal Components Analysis

Source: StatSoft, Statistica: user guide and documentation, version 7.0, Tulsa, OK, 2004.

The terminal codes are:

b Best network: the network with lowest selection error in the run was restored

s Stopping condition: the training run was stopped before the total number of epochs (iterations) elapsed as a stopping condition had been fulfilled.

c Converged: the algorithm stopped early because it had converged, that is, reached and detected a local or global minimum. (Note that only some algorithms can detect stoppage in a local minimum, and that this is an advantage, not a disadvantage!)

Thus, line 5 (BP100, CG12b) states: "Two optimization algorithms were employed, Back-Propagation (BP) with 100 epochs and Conjugate Gradient (CG) with 12 epochs, of which the latter turned out to be the best (CG12b), i.e., the one determining a network which had the lowest error on selection subset."

D. Cost benefit analysis and financial evaluation inputs

There is a growing volume of literature on the best methods of producing accurate forecasts, both in economics as well as in other fields. Qualitative methods, usually based on the experience and expertise of individuals, have been in use for quite some time, the Delphi method being

The results of the cost benefit analysis (CBA) for each of the targets and detailed explanations of the targets are presented in chapter IV Effectively, the core of the analysis lay in the first target, from which five subsequent, important results were derived. Proven the economic viability by, and of, themselves for each of the 89 projects[16] considered, the aforementioned results followed. The exception was the self-contained light-bulb-replacement project, which comprised the second target. That is, the derived results (that "a quarter of total energy consumption was electricity consumption," and so on) were the numerical, aggregate outcomes of the implementation of the projects, and thus, were not subject to their own cost benefit analyses.

It can be argued that, along with the social benefits, merely those benefits accruing due to greater accessibility to electricity (local, affordable and efficient) should be accounted in a comprehensive cost benefit analysis for each derived result. This approach faces two important obstacles, which find their origin in the very nature and use of cost benefit analysis, and for which the reasoning on the manner in which they have been treated in the current study follows. Firstly, elements such as the improvement in the general quality of life for the Caribbean population have to be considered to be beyond measure in numerical or financial terms.[17] Secondly, cost benefit analysis has been employed to appraise the viability of the economic endeavour, by balancing the two corresponding features of costs and benefits. Projects proposed were already financially viable without considering other associated benefits which have not been numerically expressed in the analysis. Since those were benefits additional to the ones taken into account, the purpose of the CBA was considered to be already accomplished, without the inclusion of artificial numerical measures for the elements mentioned in the first obstacle.

Finally, considerations of the inputs which were to be provided to the NREL spreadsheets, mentioned above, are placed here.[18] Wind turbines of 1.5 MW were the preferred aero generation technology, 20 MW and 30 MW nameplate capacity plants were selected for geothermal and hydroelectric generation, respectively, while 500 kW solar photovoltaic facilities were considered for solar power generation. Table 13 summarizes the costs that were fed into the financial model, so that different scenarios were obtained upon the variation of these figures.

Additionally, corporate tax rates used in the analysis have been displayed in table 14. These rates proved to be crucial in the financial analysis, indicating that tax incentives from Governments may prove to play a key role in the implementation of successful renewable energy projects.

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[16] A project is defined in the present study as the total amount of specific renewable energy technology (whether it be solar, wind, hydro or geothermal) to be installed in a given year for a given country. See tables 21, 22 and 23 for details.

[17] Consider, for example, the relatively complex question "What is the value of a human life?" For a thorough analysis of the limitations on the use of cost benefit analysis, see Ackerman (2009).

[18] Examples of those spreadsheets can be found at the NREL website. Please visit [Online] https://financere.nrel.gov/finance/content/crest-cost-energy-models

TABLE 13
COSTS PER ENERGY SOURCE AND TECHNOLOGY
(United States Dollars)

Renewable energy technology	Capital costs 2009 US$		Capacity	Min	Max	Capital costs Mill $/MW		Capital costs Mill $/MW yr		Plant life
	$/KW		MW	Mill. US$		Min	Max	Min	Max	Years
Wind	1 250	1 500	1.5	1.9	2.3	1.3	1.5	0.042	0.050	30
Hydro	2 000	2 800	30	60.0	84.0	2	2.8	0.067	0.093	30
Geothermal	2 800	3 400	20	56	68	2.8	3.4	0.093	0.113	30
Solar	5 200	7 200	0.5	2.6	3.6	5.2	7.2	0.260	0.360	20

Source: Nexant, "Caribbean regional electricity generation, interconnection, and fuels supply strategy: final report" [online], CARICOM, http://www.caricom.org/jsp/community_organs/energy_programme/electricity_gifs_strategy _final_report.pdf, March 2010.

TABLE 14
COUNTRY CORPORATE TAX RATES EMPLOYED

Countries	2011 corporate tax rates
Antigua and Barbuda	26%
The Bahamas	33%
Barbados	24%
Belize	25%
Cuba	35%
Dominica	26%
The Dominican Republic	22%
Grenada	28%
Guyana	24%
Haiti	24%
Jamaica	26%
Saint Kitts and Nevis	32%
Saint Lucia	26%
Saint Vincent and the Grenadines	30%
Suriname	28%
Trinidad and Tobago	22%

Sources: International Finance Corporation and World Bank

IV. Results

A. The energy sector in the Caribbean

1. Energy supplies

The economies of Caribbean countries have evolved in recent years towards greater dependence on supplies of oil and its derivatives, as shown in table 15 below.

TABLE 15
TOTAL OIL AND NATURAL GAS PRIMARY ENERGY SUPPLY IN THE CARIBBEAN, 2000 AND 2009
(Percentage)

Country	2000	2009
Antigua and Barbuda	100	100
The Bahamas	99	99
Barbados	81	89
Belize	61	77
Cuba	62	76
Dominica	89	92
The Dominican Republic	81	65
Grenada	92	93
Guyana	54	52
Haiti	23	28
Jamaica	84	83
Saint Kitts and Nevis	84	88
Saint Lucia	98	98
Saint Vincent and the Grenadines	91	94
Suriname	90	87
Trinidad and Tobago	100	100

Source: International Renewable Energy Agency, "Biomass for Power Generation", *Renewable Energy Technologies: Cost Analysis Series*, vol. 1, No. 1, June 2012.

However, this dependence on hydrocarbons is not supported by a sufficient level of production. Five Caribbean countries produced an aggregate volume of 176.2 thousand barrels per day of crude oil in 2009, and imported 158.1 thousand barrels per day. This volume was mostly refined in nine refinery plants in five countries (Cuba, the Dominican Republic, Jamaica, Suriname, and Trinidad and Tobago). The total consumption of petroleum products in the Caribbean amounted to 506.5 thousand barrels per day, implying imports of 171.9 thousand barrels per day. The main features of the petroleum sector in Caribbean countries are shown in table 16. (See more details of the Caribbean petroleum sector in annex 1).

Caribbean power generation using renewable energy sources in 2009 was based on the thermal plants that used fossil fuels to operate at a level of 86 per cent, or some 26.5 thousand barrels of oil equivalent (BOE) from 31.0 thousand BOE (OLADE, 2010). Capacity-building for generating electricity using renewable energy sources has lagged in the Caribbean compared to countries like Germany, or Spain. Ten of the studied countries have an installed generating capacity of less than 10 MW from renewable energy, as shown in table 17. Hydropower generation (883 megawatts, mainly from the Dominican Republic and Suriname) is the main source of renewable energy in the Caribbean, representing 89 per cent of the electricity generation capacity from renewable energy sources.

TABLE 16
MAIN FEATURES OF CARIBBEAN PETROLEUM SECTOR, 2009

Country	Crude oil producer *(thousand barrels per day)*	Number of oil refineries	Total refinery output *(thousand barrels per day)*	Total petroleum consumption *(thousand barrels per day)*
Antigua and Barbuda				4.8
The Bahamas				35.0
Barbados	0.77			8.5
Belize	3.99			7.4
Cuba	48.24	4	105.2	154.0
Dominica				1.0
The Dominican Republic		2	33.8	125.0
Grenada				2.1
Guyana				10.0
Haiti				17.1
Jamaica		1	22.8	82.0
Saint Kitts and Nevis				2.0
Saint Lucia				3.0
Saint Vincent and The Grenadines				1.6
Suriname	16.00	1	7.4	13.0
Trinidad and Tobago	107.2	1	165.1	40.0
TOTAL	176.2	9	334.3	506.5

Source: International Renewable Energy Agency (IRENA), "Biomass for Power Generation", *Renewable Energy Technologies: Cost Analysis Series*, vol. 1, No. 1, June 2012**.**

2. Energy consumption in the Caribbean

Total energy consumption in the Caribbean in 1970 amounted to 130 million barrels of oil equivalent (figure 8). Between the years 1970 and 2009, total consumption rose to 267 million BOE, that is, total energy consumption grew at an annual rate of 1.7% over the period of 39 years.

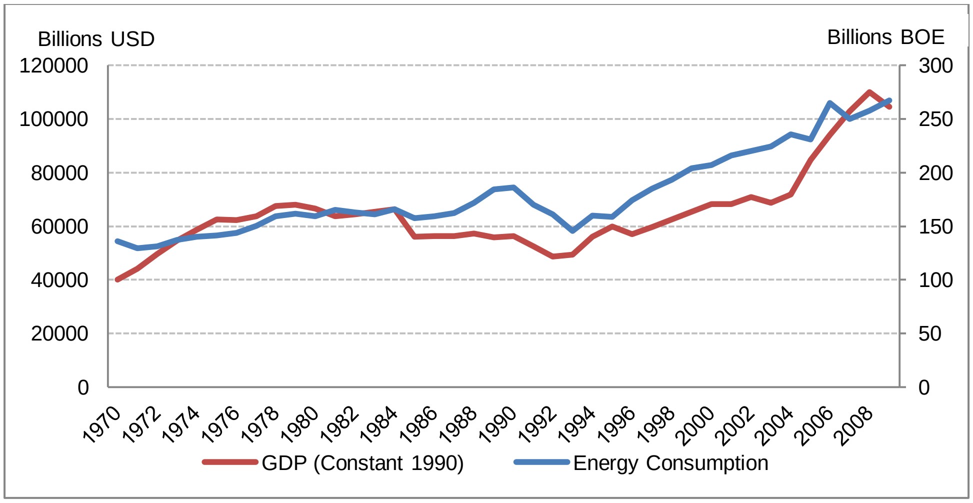
One demonstration of macroeconomic efficiency is that the growth of total energy consumption be less than the growth of gross domestic product. In the Caribbean, GDP grew by 2.7 times over the same period 1970 to 2009, at an annual rate of 2.6 per cent (at constant 1990 prices).

TABLE 17
ELECTRICITY GENERATION CAPACITY FROM RENEWABLE ENERGY SOURCES IN THE CARIBBEAN, 2010

Country	Hydropower *Mw*	Wind *Mw*	Solar *Mw*	Geothermal *Mw*	Biomass *Mw*	Total *Mw*
Antigua and Barbuda	0	0	0	0	0	0
Bahamas, The	0	0	0	0	0	0
Barbados	0	0	0	0	0	0
Belize	40	0	0	0	30	70
Cuba	60	10	0	0	0	70
Dominica	6	0.2	0	0	0	6.2
The Dominican Republic	494	0.2	0	0	10	504.2
Grenada	0	0	0	0	0	0
Guyana	1	0	0	0	0	1
Haiti	62	0	0	0	0	62
Jamaica	22	50	0	0	6	78
Saint Kitts and Nevis	0	0	0	0	0	0
Saint Lucia	0	0	0	0	0	0
Saint Vincent and the Grenadines	9	0	0	0	0	9
Suriname	189	0	0	0	0	189
Trinidad and Tobago	0	0	0	0	5	5
Total	883	60.4	0	0	51	994.4

Source: United States Energy Information Administration (2012)

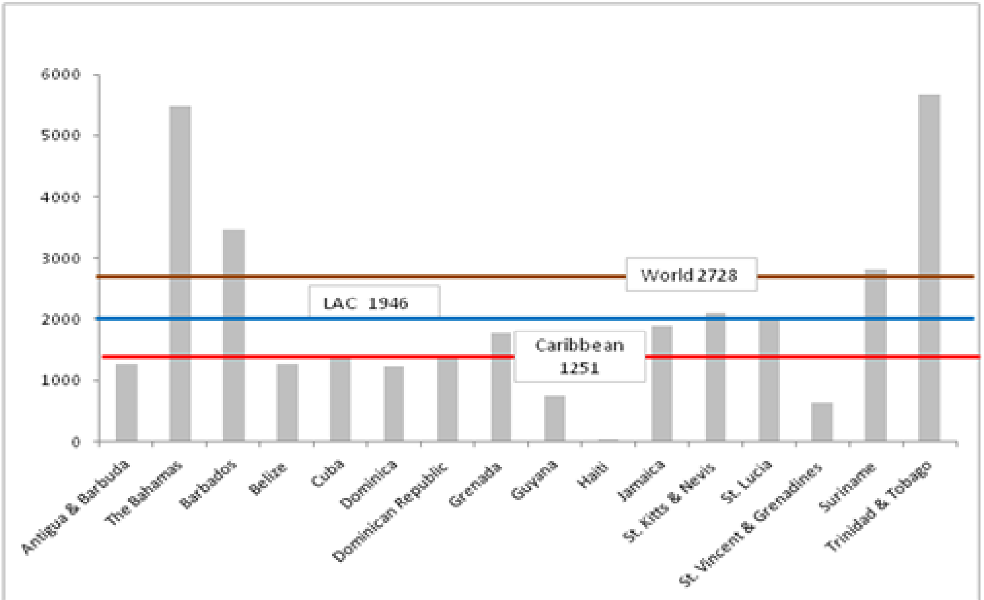
FIGURE 8
ENERGY CONSUMPTION AND GROSS DOMESTIC PRODUCT IN THE CARIBBEAN, 1970-2009
(Billions of barrels of oil equivalent and billions of United States dollars at 1990 prices)



Sources: United Nations Economic Commission for Latin America and the Caribbean (ECLAC), based on official figures and data from the World Bank and the United States Energy Information Administration (USEIA).

In 2009, the level of electricity use in the Caribbean (1,251 kWh per capita) was still far below the average for both the Latin American subcontinent (1,946 kWh per capita) and global electricity consumption (2,728 kWh per capita), as shown in figure 9.

FIGURE 9
WORLD AND CARIBBEAN ELECTRICITY USE PER CAPITA IN 2009
(Kilowatt-hours)



Source: International Renewable Energy Agency (IRENA), "Biomass for Power Generation", *Renewable Energy Technologies: Cost Analysis Series*, vol. 1, No. 1, June 2012**.**

Four countries in the Caribbean had average annual power consumption per capita higher than the global average of 2728 kWh in 2009. These countries were the Bahamas, Barbados, Suriname, and Trinidad and Tobago. Grenada, Jamaica, Saint Kitts and Nevis, and Saint Lucia were close to, or exceeded, the average electricity consumption per capita for Latin America and the Caribbean in 2009. Antigua and Barbuda, Belize, Cuba, Dominica, and the Dominican Republic had a level of per capita electricity use that approximated the average for the Caribbean in 2009. Guyana, Haiti, and Saint Vincent and the Grenadines had very low levels of per capita electricity consumption in 2009.

B. Energy demand forecast using climate change variables

Energy demand forecasts for the Caribbean for 2020-2050 are shown in table 18.

TABLE 18
FORECAST ENERGY CONSUMPTION IN THE CARIBBEAN UNDER EMISSIONS SCENARIOS A2 AND B2, 2020-2050
(Thousands of barrels of oil equivalent)

	2020	2030	2040	2050	Total
SRES A2	362 662	441 949	479 766	517 223	1 801 600
SRES B2	305 266	315 514	334 176	353 677	1 308 634
Difference	57 396	126 434	145 590	163 546	492 967

Source: Developed by the author.

Energy consumption would almost double (1.98 times) over the forecast period 2013-2050 under SRES A2, with an annual mean growth rate of 1.7 per cent, higher than the mean growth rate of the population (1.02 per cent). Under SRES B2, energy consumption would increase by a factor of 1.35 at an annual mean growth rate of 0.74 per cent, lower than the annual mean rate of population growth.

Energy consumption was projected for every country within the Caribbean, for the period 2013-2050. Forecasts showed that energy demand would increase in all cases, although this growth, like historical records, would be different across countries. As expected, energy demand grew faster, and to a greater extent, under SRES A2 with respect to B2, except in the case of Guyana, where population increased more under SRES B2 (and actually decreased under A2), thus driving the model towards a greater increase in energy demand under SRES B2. Projected growth in energy consumption for both scenarios is displayed in table 19.

TABLE 19
FORECAST GROWTH IN ENERGY CONSUMPTION IN THE CARIBBEAN UNDER EMISSIONS SCENARIOS A2 AND B2, 2010 TO 2050
(Percentage)

Country	Energy consumption	
	Growth (2050 / 2010 SRES A2	Growth (2050 / 2010) SRES B2
Antigua and Barbuda	37.4	21.8
Bahamas, The	98.6	40.9
Barbados	54.2	26.5
Belize	144.8	101.1
Cuba	51.3	26.8
Dominica	29.7	14.1
The Dominican Republic	16.4	9.0
Grenada	43.2	17.7
Guyana	-1.1	4.5
Haiti	34.0	25.4
Jamaica	62.9	41.1
Saint Kitts and Nevis	121.6	15.9
Saint Lucia	99.1	32.2
Saint Vincent and the Grenadines	29.1	16.8
Suriname	47.5	38.5
Trinidad and Tobago	189.6	85.3

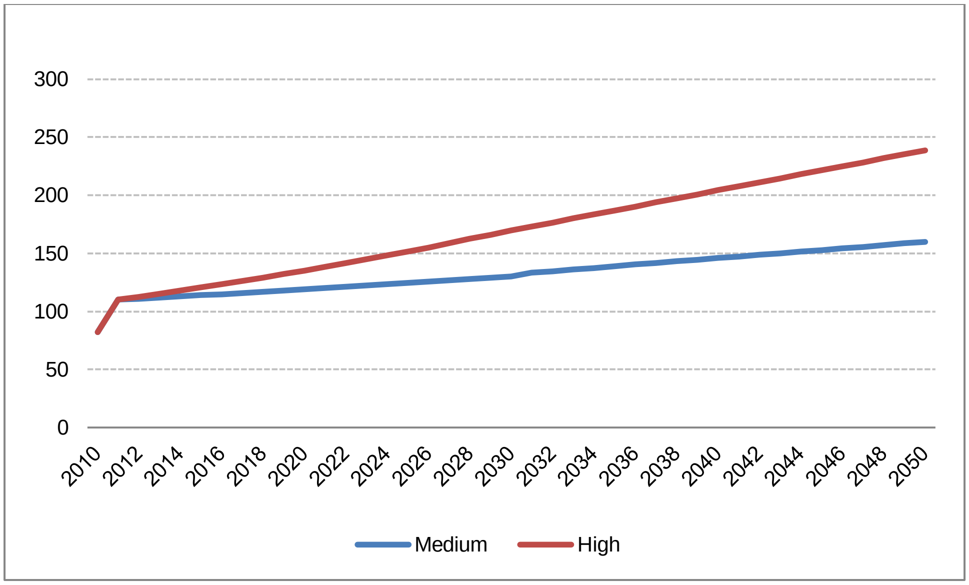
Source: Developed by the author.

1. Oil price forecast

Oil price forecasts employed in the present study were taken partially from the Department of Energy and Climate Change (DECC) of the United Kingdom. These forecasts have been made following multiple-criteria decision analysis (DECC, 2011). Oil prices were extended lineally beyond the forecast, original scope (2035) to reach the end year for the current study (2050). DECC divided their forecast in three central trends, defined as the low, central and high price scenarios. Medium and high prices have been employed in the study, as shown in figure 10.

Finally, by applying these oil prices to the energy consumption forecast, and taking into account the differences between SRES A2 and B2, a general measure of the economic impacts of climate change on the energy sector was obtained, which was divided into the medium and high emissions projections according to the oil prices forecast. Results were found for each country, and table 20 shows the aggregate values for the Caribbean.

FIGURE 10
OIL PRICE FORECASTS: MEDIUM- AND HIGH- PRICE SCENARIOS, 2011-2050
(USD per barrel)



Source: Author's calculations, based on data from United Kingdom Department of Energy and Climate Change (DECC), "Review of the generation costs and deployment potential of renewable electricity technologies in the United Kingdom", Study Report, REP001 United Kingdom, Ove ARUP & Patterns Ltd, October 2011.

TABLE 20
FORECAST PRESENT VALUE OF ECONOMIC IMPACTS OF CLIMATE CHANGE ON THE ENERGY SECTOR IN THE CARIBBEAN DISCOUNTED AT 1%, 4% AND 14%
(Billions of 2011 United States dollars)

Forecast period	Discount rate 1%		Discount rate 4%		Discount rate 14%	
	Medium prices	High prices	Medium prices	High prices	Medium prices	High prices
2012-2020	43	46	41	45	38	41
2021-2030	118	146	115	142	105	130
2031-2040	185	250	179	242	163	221
2041-2050	205	297	199	288	181	263
Total impact	550	739	534	718	487	655

Source: Developed by the author

Differences in energy consumption between the SRES A2 and B2 (with B2 taken as BAU), were multiplied by the forecast oil prices (up to 2035) and projected for the period 2035-2050. The series of values for economic impacts of climate change on energy consumption for the Caribbean obtained were discounted using three different discount rates. The discount rates of 1 per cent and 4 per cent represent a social approach to the importance of these impacts. The third discount rate of 14 per cent introduces a market approach, following agreements reached at ECLAC meetings held during the course of this research.

C. Mitigation and adaptation goals, strategies and targets

Table 21 shows the definition of the goals and consequent strategies to achieve them in the range of years considered, following the flowchart outlined in section 3A. Based on these strategies, targets and the actions to reach those targets were defined.

TABLE 21
ENERGY POLICY GOALS AND STRATEGIES

Nº	Goal	Nº	Strategy
1	Pursuing a low-carbon economy	1.1	Encourage the use of renewable energy resources
		1.2	Increase the awareness of society of the impacts of climate change on energy sector (workshops, campaigns, the way to calculate carbon footprint)
		1.3	Achieve international support for investing in coping with climate change
		1.4	Improve or implement regulations - such as building standards and vehicle emission limits - and demand clean energy certification of appliance-, technology- and vehicle imports.
2	To improve energy security	2.1	Less reliance of oil fuel imports
		2.2	Develop energy saving programmes
		2.3	Deployment of solar water heaters
		2.4	Design national assessment studies on decreasing energy peak demand through changes in daily schedules for industries and commerce.
		2.5	Develop an international project on light bulb energy savings
3	Improve access to electrification and its affordability	3.1	Assess local solutions for physical access
		3.2	Decrease expenditure of household economies, particularly slum dwellers

Source: Developed by the author

From the outlined strategies, the following two targets were defined and scaled to be achieved by the year 2050:

a) First target**:** A 60 per cent decrease in per capita CO_2 emissions is accomplished through the development of a total of 89 projects for electricity generation from renewable sources in the Caribbean.

b) Second target**:** A total of 20 million electric light bulbs are changed to compact fluorescent light bulbs.

TABLE 22
NUMBER OF RENEWABLE ENERGY PROJECTS AND INSTALLED CAPACITY IN THE CARIBBEAN

Country	Wind		Solar		Hydro		Geothermal		Total	
	Total number of evaluated projects	Total installed capacity MW	Total number of evaluated projects	Total installed capacity MW	Total number of evaluated projects	Total installed capacity MW	Total number of evaluated projects	Total installed capacity MW	Total number of evaluated projects	Total installed capacity MW
Antigua and Barbuda	4	141	4	135					8	277
The Bahamas	4	926	4	277					8	1 203
Barbados	3	27	3	36					6	64
Belize	4	310	3	1 558					7	1 868
Cuba	4	4 980	4	4 010					8	8 990
Dominica							1	20	1	20
The Dominican Republic	2	1 967	2	947					4	2 914
Grenada							2	40	2	40
Guyana					4	551			4	551
Haiti	3	290	4	4 497	2	117			9	4 904
Jamaica	1	107	2	530	3	878			6	1 515
Saint Kitts and Nevis			3	26			4	145	7	171
Saint Vincent and the Grenadines			3	30			1	20	4	50
Saint Lucia			3	32			1	20	4	52
Suriname					3	1 089			3	1 089
Trinidad and Tobago	4	2 817	4	195					8	3 012
Total	29	11 565	39	12 273	12	2 634	9	245	89	26 718

Source: Developed by the author

1. First target

The 89 renewable energy projects considered in the present report are shown in table 22. These projects can be summarized by electricity generation and nameplate capacities, as shown in table 23.

TABLE 23
SUMMARY OF ELECTRICITY GENERATION AND NAMEPLATE CAPACITIES IN THE 89 RENEWABLE ENERGY PROJECTS, 2020-2050

Electricity by renewable energy technology	Units	2020	2030	2040	2050
Wind	GWH	1 631	3 902	6 785	11 632
Solar	GWH	1 620	3 499	8 395	13 894
Geothermal	GWH	434	666	874	1 052
Hydro	GWH	924	1 818	4 313	5 244
Total	GWH	4 608	9 885	20 368	31 822
Capacity					
Wind	MW	186	445	775	1 328
Solar	MW	185	399	958	1 586
Geothermal	MW	49	76	100	120
Hydro	MW	105	208	492	599
Total	MW	526	1 128	2 325	3 633

Source: Developed by the author

The investment costs of the projects were also summarized by renewable energy technology (table 24).

TABLE 24
INVESTMENT COST BY CATEGORY FOR THE 89 RENEWABLE ENERGY PROJECTS 2013-2050
(Millions of United States dollars)

Investment costs	2013-2020	2021-2030	2031-2040	2041-2050
Wind	256	613	1 065	1 826
Solar	1 147	2 476	5 942	9 834
Geothermal	153	236	309	372
Hydro	253	498	1 182	1 437
Total	1 809	3 823	8 498	13 469

Source: Developed by the author

Total investment costs amount to US$ 27.6 billion. Nevertheless, decadal investment costs correspond to a small but incremental fraction of the present economic performance of the Caribbean. In effect, total investment per decade corresponds to 1.5 per cent, 3 per cent, 6.8 per cent and 10.8 per cent of 2010 GDP for the countries considered. The financial benefit of avoided costs from non-imported fuels which, in many cases, balance and even outweigh the investment costs themselves should not be overlooked.

All options were evaluated at the proposed social 1 per cent and 4 per cent discount rates and at the current market rate of 14 per cent. At national levels, these rates could be introduced into local policies promoting the use of renewable energy resources. However, this evaluation takes into account only the economic viability of renewable energy resource utilization. Other external factors, such as the avoided cost from non-imported fuels due to the increase in renewable energy market share, may alter for the better the overall feasibility of each endeavour. The following results would be achieved through the implementation of these 89 renewable energy projects:

a) A quarter of the total energy consumption is electricity consumption.

b) Half of the electricity generated comes from renewable sources.

c) Electrification levels are between 95 per cent and 100 per cent in the Caribbean.

d) Electricity from renewable resources is at a price of US$ 0.15 /KWh or lower.

e) Energy security increased in 10 points or more.

a) A quarter of the total energy consumption is electricity consumption

The study proposes the following schedule to increase the participation of electricity within total energy consumption. A greater electricity share can be achieved by a number of measures, mainly by increasing the use of electricity in the residential and commercial sector. Table 25 shows the progression in electricity share from year 2009 to 2050. On average, electricity represented 13 per cent of energy consumption in 2009, the proposed share being a 12 per cent increase by 2050.

TABLE 25
CHANGE IN ELECTRICITY SHARE OF TOTAL ENERGY CONSUMPTION, 2009-2050
(Percentage)

Country	2009	2020	2030	2040	2050	2050-2009
Antigua and Barbuda	4	9	14	19	20	16
The Bahamas	5	10	15	20	20	15
Barbados	26	27	28	29	30	4
Belize	8	10	12	16	20	12
Cuba	14	15	16	18	20	6
Dominica	14	16	18	21	25	11
The Dominican Republic	21	24	27	30	34	13
Grenada	20	24	28	33	39	19
Guyana	6	10	14	18	22	16
Haiti	1	6	12	20	29	28
Jamaica	16	17	18	20	22	6
Saint Kitts and Nevis	11	13	15	17	20	9
Saint Lucia	19	21	24	27	30	11
Saint Vincent and the Grenadines	11	13	15	17	20	9
Suriname	20	21	23	25	27	7
Trinidad and Tobago	10	10	10	11	11	1

Sources: Authors calculations, based on data from Latin American Energy Organization (OLADE) and Renewable Energy and Energy Efficiency Partnership (REEEP).

b) Half of the electricity generated comes from renewable sources

The present study proposes the following schedule to increase the participation of electricity from renewable energy sources in total electricity consumption. A greater renewable energy share would be achieved by making use of the renewable energy resources available in each country, most of which are currently in exploration phase, or not tapped at all. Table 26 shows the forecast progression in renewable energy share from year 2009 to 2050. On average, electricity from renewable sources represented 8 per cent of electricity in 2009, the proposed share being a 42 per cent increase by 2050.

TABLE 26
CHANGE IN RENEWABLE ENERGY SHARE OF TOTAL ELECTRICITY CONSUMPTION IN THE CARIBBEAN, 2009-2050

	UNIT	2009	2020	2030	2040	2050
Percentage of renewable energy	%	8	14	23	36	50
Total renewable electricity	GWH	3 544	9 651	19 621	32 362	47 870

Source: Developed by the author

c) Electrification levels are between 95 to 100 per cent in the Caribbean

The study proposes to increase the level of electrification in every Caribbean country. A greater electrification level is achieved by making use of the available renewable energy resources, which bring the benefits of local power generation and lower prices. Table 27 shows electrification levels for each Caribbean country in 2009 and 2050. An 8% average increase in electrification levels is forecast to be achieved by 2050.

d) Price of electricity from renewable energy source of US$ 0.15 per kWh or less

Prices for electricity could be lowered from current values on par with the increase in electricity supply from renewable energy sources. Cost benefit analyses for the Caribbean show the economic viability of these prices. In fact, those analyses show that, with the exception of solar power, electricity from renewable energy sources can be priced at a range from US$ 0.07 to US$ 0.10 per kilowatt hour (KWh), depending on the source. As usual, the discount rates play an important role in the aforementioned viability, as do tax rates. Table 28 illustrates the example using solar power, different tax and discount rates, yielding variable results in the evaluation.

TABLE 27
CHANGE IN ELECTRIFICATION LEVELS IN THE CARIBBEAN, 2009 AND 2050
(Percentage)

Country	Electrification level	
	2009	2050
Antigua and Barbuda	99.0	100.0
Bahamas, the	90.0	95.0
Barbados	95.0	100.0
Belize	89.9	95.0
Cuba	97.0	100.0
Dominica	87.6	95.0
The Dominican Republic	95.9	100.0
Grenada	86.4	95.0
Guyana	77.5	95.0
Haiti	38.5	95.0
Jamaica	92.0	95.0
Saint Kitts and Nevis	94.0	95.0
Saint Lucia	94.2	95.0
Saint Vincent and the Grenadines	93.0	95.0
Suriname	84.0	95.0
Trinidad and Tobago	99.0	100.0
Caribbean	88.3	96.6

Source: Developed by the author

TABLE 28
VARIATIONS ON THE NET PRESENT VALUE OF SOLAR POWER PER DISCOUNT AND TAX RATES
(Millions of United States dollars)

Price ¢/KWh	Tax rate 30% Net present value			Tax rate 15% Net present value			Tax rate 5% Net present value		
	1%	4%	14%	1%	4%	14%	1%	4%	14%
7	604	75	−632	1.025	369	−508	1.306	565	−425
10	1.446	663	−383	2.048	1.084	−205	2.449	1.364	−87
15	2.850	1.644	32	3.752	2.274	299	4.353	2.695	476

Source: Developed by the author

e) Energy security has increased in 10 points or more

Energy security, as the percentage of energy consumption derived from renewable indigenous energy sources thus, not imported is one of the most important issues for the majority of Caribbean countries.[19] Table 29 shows the progression of the share of renewable energy sources in total energy consumption from 2009 to 2050. At the end of the forecast period, energy from renewable sources is 38 times that of the year 2009.

TABLE 29
CHANGE IN RENEWABLE ENERGY SHARE OF TOTAL ENERGY CONSUMPTION IN THE CARIBBEAN, 2009-2050
(Percentage)

	Unit	2009	2020	2030	2040	2050
Energy consumption	kBOE	218 151	362 738	441 951	479 788	517 341
Share of renewable energy	%	1	2	4	7	12

Source: Developed by the author

Government involvement in the development of projects using renewable energy resources is crucial to their viability. Not only can taxes play an important role in the financial feasibility of investments, but so can other forms of Government involvement: legislation, grants and public campaigns can prove to be fundamental to the success of such endeavours.

The investment costs in the renewable energy projects in the Caribbean are US$ 27.6 billion for the considered period, 2013-2050, a significant sum that should decrease as technologies improve. These projects include little or no biomass or biofuels production. The avoided cost from non-imported fuels, computed using the oil prices in section IV, were treated separately for a clearer view of the amounts involved, which could function as aids in the decision-making process, incorporated into national visions and outlooks to 2050. Tables 30a and 30b show these avoided costs, evaluated in the medium- and high- oil-price scenarios.

[19] Although most of the time this item is measured as the ratio between imported energy and total consumption, the author holds that the form of evaluation here employed represents the real energy security level in the long run, due to the eventual unavailability of fossil fuels.

TABLE 30a
AVOIDED ENERGY COSTS (MEDIUM OIL PRICES) FOR THE CARIBBEAN TO 2050
(Millions of United States dollars)

	2020	2030	2040	2050	Total
Wind	109	1 935	3 453	6 529	12 027
Solar	109	1 893	3 295	8 032	13 327
Geothermal	29	486	565	799	1 879
Hydro	62	1 066	1 708	3 950	6 785
Total	309	5 379	9 021	19 309	34 019

Source: Developed by the author

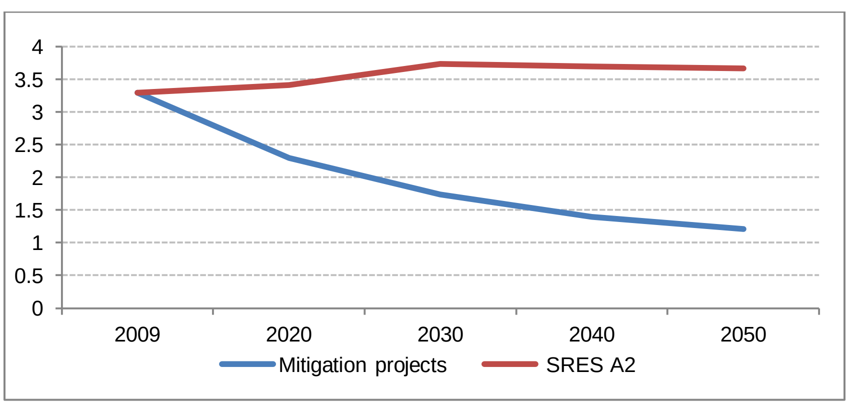
TABLE 30b
AVOIDED ENERGY COSTS (HIGH OIL PRICES) FOR THE CARIBBEAN TO 2050
(Millions of United States dollars)

	2020	2030	2040	2050	Total
Wind	116	2 322	4 679	9 443	16 560
Solar	115	2 269	4 473	11 615	18 471
Geothermal	31	580	765	1 154	2 530
Hydro	66	1 276	2 319	5 705	9 365
Total	327	6 447	12 236	27 917	46 926

Source: Developed by the author

In summary, an investment of US$ 27.6 billion which would be totally (and for the better part, quickly) recovered in the projects financially assessed would achieve greenhouse gas emission abatements of 108.8 million tons of CO_2 equivalent by the year 2050, a reduction in per capita emissions[20] of 60 per cent from 2009 figures, as shown in figure 11. This would represent an improvement in energy efficiency, energy security and quality of life for the Caribbean population.

FIGURE 11
PER CAPITA EMISSIONS IN THE CARIBBEAN UNDER SRES A2 AND WITH MITIGATION, 2009-2050
(Tons of CO_2 equivalent)



Source: Developed by the author

[20] Population estimates are taken from the ones employed in the forecasts made for energy demand. The estimates for those countries, for which there were no IPCC data, were made by the author following historical growth rates.

2. Second target: 20 million electric light bulbs are replaced with compact fluorescent light bulbs

The present study proposes to increase the number of compact fluorescent light bulbs employed in the Caribbean. Compact fluorescent light bulbs provide more luminosity than traditional electric bulbs, while helping considerably to save energy. The cost benefit analysis for the change of 20 million of these electric light bulbs showed that this would be a remarkable investment, in terms of both payback period and energy savings. Table 31 shows the economic assessment for electric light bulb replacement. Some replacement programmes have been carried out already in the Caribbean, hence the relatively low proposed number (one CFL per pair of inhabitants) of replacement light bulbs.

TABLE 31
ELECTRIC LIGHT BULB REPLACEMENT PROGRAMME IN THE CARIBBEAN
(Millions of United States dollars)

	Unit	Total	D. Rate 1%	D. Rate 4%	D. Rate 14%
CFL Units	Million	80			
Investment costs	Million US$	800			
Energy savings	GWH	51 246			
Energy savings	KBOE	31 751			
Energy savings	Million US$		4 137	3 224	1 519
Net present value	Million US$		3 393	2 414	933
Payback period	Years		3	3	3

Source: Developed by the author

V. Conclusions and recommendations

A. Conclusions

The results have allowed many conclusions to be drawn. These are summarized below. Some of them pertain to Government actions in the drafting and updating of national energy policies and regulations. Others confirm the necessity of using renewable energy sources, both to reduce CO_2 emissions and thus mitigate anthropogenic effects on climate change and to adapt to the impacts of a changing climate.

These conclusions are based on perspectives on the economic and financial feasibility of individual projects. They also address the concerns of energy security, energy efficiency, and accessibility. Thus, the final conclusions for the present study are, as follows:

a) The energy sector is, perhaps, an exception in the individual sectoral relationships to climate change. Insights into the study of the energy sector should avoid the dangers of falling into a vicious circle.

b) Economic growth will demand more energy, and Caribbean countries need to achieve higher levels of development. The Caribbean consumes more than 99% of its energy needs from non-renewable sources nowadays. The goals, strategies and targets contained in the present report would reduce that figure considerably.

c) Differences with other studies and reports occur, habitually, in the assessment made of the contribution of each energy source to the achievement of energy goals.

d) The use of simulation models showed several scenarios that could be considered, to produce fewer impacts (emissions) while achieving social and economic development.

e) Regarding economic issues, larger discount rates could be used in the cost benefit analysis, and renewable energy sources could still be efficiently and financially tapped.

f) Any protocol or agreement after 2012 would allow a Clean Development Mechanism (CDM).[21]

g) Technology issues (the short, medium, and long term technological challenges) are to be taken into account.

h) Opportunities related to greenhouse gas management, including energy efficiency, gas flaring and venting reduction, and carbon capture and storage, should be included in national energy plans.

i) The energy study considers a range of policies that cope with increased energy use and encourage total emissions reduction.

j) Well-documented mitigation actions at both national and Caribbean subregional levels are developed and presented.

The future of the Caribbean energy sector lies with localized energy provision, which is for the better part both renewable and affordable.

B. Recommendations

Energy policy objectives should be incorporated into national energy policies. These objectives can be condensed to: reducing CO_2 emissions; improving energy independence, energy security and energy efficiency; promoting competition in energy markets; working towards accessibility of energy prices to the public and the economy; and, increasing public awareness of a number of the topics addressed in the present report.

For possible investors, the development of renewable energy sources is an economically and financially viable option. The study of those options should be continued at specific points where renewable energy sources are available within each country, which is consistent with the bottom-up approach declared in chapter I. This is important, for it should take into account local wages, local imports and insurance costs, special tax policies, among other factors.

The efficient use of, and improvement in, current channels of cooperation between affiliated nations of regional organizations and institutions is of the utmost importance. The Caribbean, per its characteristics, now needs and would need increasingly in the future not only the support of international organizations (for the important role they play in the development of studies of this kind), but also (in the search for external financial aid and project investments), the continuation of necessary technology transfers, and the establishment of frameworks within which to cooperate rather than to compete, in this crucial aspect of Caribbean development. This, in turn, would strengthen both the negotiating capacity of the associated Caribbean States, and the efforts to increase awareness of the obstacles ahead and the ways in which those obstacles could, and should, be dealt with for the attainment of a better future, in which quality of life, economic development and ecological preservation are at the centre of everyday life.

[21] The Clean Development Mechanism (CDM), defined in Article 12 of the Protocol, allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol (Annex B Party) to implement an emission-reduction project in developing countries. Such projects can earn saleable certified emission reduction (CER) credits, each equivalent to one tonne of CO2, which can be counted towards meeting Kyoto targets. The mechanism is the first global, environmental investment and credit scheme of its kind, providing standardized emissions offset instrument, CERs. A CDM project activity might involve, for example, a rural electrification project using solar panels or the installation of more energy-efficient boilers. The mechanism stimulates sustainable development and emission reductions. See [online], http://unfccc.int/kyoto_protocol/mechanisms/clean_development_mechanism/items/2718.php

The recommendations are as follows:

a) National energy policies need to be completed and updated for every country. In particular, renewable energy policies are to be concluded for each country, and a Caribbean subregional renewable energy policy finished along those lines. These policies must include planning for excess capacity, an explicit pro-poor dimension, the projection to maximize the utilization of renewable energy sources, and the building of reliable statistical databases.

b) The increased use of renewable energy should be part of the development programme of each Caribbean State, raising political commitment to its promotion. It will require more political will, and commitment, to achieve the successful implementation of these energy plans.

c) Governments should apply specific policy packages and tax incentives to promote energy efficiency and renewable energy projects.

d) Governments should take legislative action to criminalize the theft of electricity, in those countries affected by this problem. To be fair, law enforcement must be aligned with the explicit, pro-poor dimension to be included in energy planning.

e) Studies and projects on biomass applications for electricity generation could be carried out at the domestic level, taking into account possible GHG emissions, and agricultural and infrastructural development.

f) The transport sector, accounting for nearly half of the energy consumption in the Caribbean, requires a study of its own, in which climate change impacts, along with the corresponding mitigation and adaptation measures, would be determined.

g) A project for the replacement of 20 million electric light bulbs with compact fluorescent light bulbs should be carried out in the Caribbean, given its demonstrated feasibility. It contemplates three cycles covering the whole period considered, in accordance with the devices' lifetimes and usability. Nevertheless, newer technologies such as LED lighting can also be considered in the near future.

h) Campaigns for increasing the awareness of the Caribbean population – on energy savings, including the carbon footprint calculation, and the necessity for extensive use of renewable energy sources – should be orchestrated at national and Caribbean subregional levels.

i) Derived results obtained in the present study should be integrated into national energy planning and its fulfilment implemented, given its proven viability. Renewable energy management through projects, although detailed by country, can be summarized in the following:

- A quarter of the total energy consumption is electricity consumption.
- Half of the electricity generated comes from renewable sources.
- Electrification levels are between 95 to 100 per cent in the Caribbean.
- Electricity from renewable energy sources is at a price of 15 cents per kWh or lower.
- Energy security is increased in 10 points or more.

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Annexes

Annex 1
Energy sector structure

The energy sector has a complex structure and yet must be seen as a whole, although it must be divided for better understanding in the present study. Figure 1 is a plot of the fundamental components of the energy sector.

This diagram has been prepared from the classification between fossil fuels and renewable energy, which is the most convenient for the purposes of this study. However, another important classification is the process of production and consumption of energy. In this way of classification, energy is classified as primary when taken directly from nature. It receives a production process, or processing, (called generation in the case of electric power) and then exists in the main forms that allow consumption. This does not mean that the primary energy cannot be consumed, but merely that it is mostly processed in some way to facilitate consumption. Crude oil, for example, can be used for direct consumption in boilers, while cement plants use refined products (gasoline, kerosene, etc.)

FIGURE A1
DIAGRAM OF ENERGY SECTOR STRUCTURE

Fossil Fuels	Coal	Coal Mining	Electric power and fuels	DEMAND
	Crude Oil	Petroleum		
	Natural Gas			
Renewable Energy	Wood	Wood-derived fuels		
	Biomass – Biofuel	Fuel		
	Hydropower	Electricity		
	Wind			
	Geothermal			
	Ocean			
	Solar	Heating		

Source: Developed by the author
Note: Nuclear energy is not included because it's not an energy resource in the Caribbean subregion.

Nuclear energy has not been included in the diagram because it has not been used as an energy resource in the Caribbean.

The following definitions and concepts have been taken and summarized from the Energy Glossary of the United States Energy Information Administration.

A. Fossil fuel

Fossil fuel is the generic name for fuels that are inside the planet Earth that have been formed over millions of years. It includes natural coal, crude oil and natural gas. These fossil fuels are subject to removal and transformation processes (coal mining, oil drilling) to achieve their industrial, commercial and domestic use.

Petroleum products

- Liquefied natural gas (LNG): natural gas (primarily methane) that has been liquefied by reducing its temperature.
- Liquefied petroleum gases: a group of hydrocarbon-based gases derived from crude oil refining or natural gas fractionation.
- Derivatives: refined products obtained from the processing of crude oil
- Sometimes petroleum is defined to include crude oil.

Manufactured gas

- A gas obtained by destructive distillation of coal or by the thermal decomposition of oil, or by the reaction of steam passing through a bed of heated coal or coke. Examples are coal gases, coke oven gases, producer gas, blast furnace gas, blue (water) gas, carburetted water gas. BTU content varies widely.

Rest of oil-derived fuels

- Production to meet the demands of the transportation sector, end-use in machinery.

B. Renewable energy resources

Energy resources that are naturally replenishing but flow-limited. They are virtually inexhaustible in duration, but limited in the amount of energy that is available per unit of time. Renewable energy resources include biomass, hydro, geothermal, solar, wind, ocean thermal, wave action, and tidal action.

Biomass: Organic non-fossil material of biological origin

- Biomass gas: A medium BTU gas containing methane and carbon dioxide, resulting from the action of micro organisms on organic materials such as landfills. The methane in landfill gas may be vented, flared, or combusted to generate electricity or useful thermal energy on-site, or injected into a pipeline for combustion off-site.
- Biomass waste**:** Organic non-fossil material of biological origin that is a by-product or a discarded product. Biomass waste includes municipal solid waste from biogenic sources, landfill gas, sludge waste, agricultural crop by-products, straw, and other biomass solids, liquids, and gases; but excludes wood and wood-derived fuels (including black liquor), biofuels feedstock, biodiesel, and fuel ethanol.
- Biodiesel: A fuel typically made from soybean, canola, or other vegetable oils; animal fats; and recycled grease. It can serve as a substitute for petroleum-derived diesel or distillate fuel.
- Biofuels: Liquid fuels and blending components produced from biomass food stocks, used primarily for transportation.

Wood energy*:* Wood and wood products used as fuel, including round wood (cord wood), limb wood, wood chips, bark, saw dust, forest residues, charcoal, pulp waste, and spent pulping liquor, bought or gathered, and used by direct combustion.

Hydroelectric power: The use of flowing water to produce electrical energy through conventional hydroelectric plant (a plant in which all of the power is produced from natural stream flow as regulated by available storage) and small hydropower stations.

Wind energy Kinetic energy present in wind motion that can be converted to mechanical energy for driving pumps, mills, and electric power generators. It is common to name WECS (Wind energy conversion system to a device or an apparatus for converting the energy available in the wind to mechanical energy that can be used to power machinery (grain mills, water pumps) and to operate an electrical generator or wind turbine (device that produces electricity; typically three blades rotating about a horizontal axis and positioned up-wind of the supporting tower) in a wind power plant. A group of wind turbines interconnected to a common utility system through a system of transformers, distribution lines, and (usually) one substation is called a Wind Farm.

Geothermal energy: Hot water or steam extracted from geothermal reservoirs in the Earth's crust. Water or steam extracted from geothermal reservoirs can be used for geothermal heat pumps, water heating, or electricity generation.

Ocean energy systems: Energy conversion technologies that harness the energy in tides, waves, and thermal gradients in the oceans. The process or technologies for producing energy by harnessing the temperature differences (thermal gradients) between ocean surface waters and that of ocean depths is named Ocean thermal energy conversion (OTEC).

Solar energy: The radiant energy of the sun, which can be converted into other forms of energy, such as heat or electricity by using Concentrating Solar Power (CSP) or Photovoltaic (PV) systems.

Electric power sector: An energy-consuming sector that consists of electricity only and combined heat and power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public and Independent Power Producers (IPP) using fossil fuels or renewable energies.

Annex 2

ENERGY PRODUCTION AND CONSUMPTION IN CARIBBEAN COUNTRIES

TABLE A2
GROSS DOMESTIC PRODUCT PER CAPITA AND ELECTRICITY USE PER CAPITA IN CARIBBEAN COUNTRIES, 2009

(2010 United States dollars and kilowatt hours)

Country	GDP per capita *(2010 US$)*	Electricity use per capita 2009 *(kWh)*
Antigua and Barbuda	13 006	1 264
The Bahamas	22 665	5 493
Barbados	15 035	3 481
Belize	4 064	1 276
Cuba	5 704	1 348
Dominica	6 964	1 229
The Dominican Republic	5 195	1 398
Grenada	7 500	1 777
Guyana	2 750	749
Haiti	664	36
Jamaica	5 133	1 902
Saint Kitts and Nevis	12 847	2 095
Saint Lucia	6 890	2 040
Saint Vincent and the Grenadines	6 712	634
Suriname	7 018	2 814
Trinidad and Tobago	15 614	5 662
Latin America and the Caribbean	8 816	1 946
Caribbean Islands	4 778	1 251
World	9 230	2 728

Source: International Renewable Energy Agency

Annex 3

ELECTRICITY PRICING

TABLE A3
PRICE OF ELECTRICITY TO THE CONSUMER IN THE CARIBBEAN

Country	Consumer electricity price
Antigua and Barbuda	US$ 0.15 /KWh (Average)
The Bahamas	US$ 0.18 /KWh (Average) + Fuel charge (variable unit includes price of fuel)
Barbados	Not available
Belize	US$ 0.42 /KWh (Average)
Cuba	US$ 0.44 /KWh (Average)
Dominica	Fuel surcharge: US$ 0.088 /KWh (Average) (non price)
The Dominican Republic	US$ 0.69 /KWh (Average) + fixed charge US$ 2.01
Grenada	US$ 0.35 /KWh (Average) + fuel surcharge 0.18 US$ /KWh
Guyana	US$ 0.285 /KWh // 0.59 $/KWh (Average) (including fuel surcharge)
Haiti	US$ 0.3 /KWh
Jamaica	US$ 0.14 /KWh
Saint Kitts and Nevis	Not available
Saint Lucia	US$ 0.28 /KWh (Average) + fuel surcharge US$ 0.066 /KWh
Saint Vincent/The Grenadines	Not available
Suriname	US$ 0.07 /KWh
Trinidad and Tobago	US$ 0.31 /KWh (Average)

Source: Economic Commission for Latin American and the Caribbean (ECLAC), based on official figures.