The Potential Impact of Climate Change on the Energy Sector in the Caribbean Region

An effort to understand how climate change may impact the productivity of existing and future energy production systems in the Caribbean

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Abstract

The Caribbean region faces a unique and challenging situation with respect to energy for sustainable development. Climate change is expected to have great environmental and socio-economic consequences for the Caribbean countries, where changes in temperature and precipitation patterns, and changes in the intensity and frequency of extreme weather events are already observed (IPCC, 2007). Some of these effects have tangible and increasing implications for the region's energy security, particularly with regard to energy production and use.

Currently there is a clear consensus that fossil fuel based energy production systems are among the main causes of climate change. Ongoing discussions in the scientific community (IPCC 2001 and 2007) are focused on how to drive the energy sector towards the use of cleaner, or renewable, energy production systems. However, little reference is made of the potential effect of climate change on existing and/or future conventional and non-conventional energy production systems.

This paper discusses some of the concerns surrounding the effects of climate change on the performance of current and future energy production systems in the Caribbean countries, with a particular emphasis on the impact of climate change on Renewable Energy (RE) project appraisal and development.

1. INTRODUCTION

There is a clear consensus within the scientific community and the public that traditional fossil fuel based energy production systems are key contributors to global climate change. However, the impacts of climate change and, in particular, weather variability on the energy production sector have been underestimated. In recent years, there has been an increased concern related to the magnitude and the way in which climate change may impact the performance of existing and future energy production systems. For example, changes in precipitation patterns can affect energy generation projections of hydropower dams and crop farms for bio-fuels production either positively or negatively, depending on the location and the type of precipitation change. Increases in intensity and frequency of extreme weather events in the Caribbean seriously affect energy production and distribution, leading to impacts on local, regional and global energy markets (e.g., disruption of, or damage to, oil platforms, gas pipelines, electrical grids or fuel transport). The extreme impact of weather on the local energy sector also leads to the further weakening the Caribbean region's capacity to recover from natural disasters (IPCC, 2001).

In this paper the concerns about the potential impact of climate change on current and future performance of the energy sector are discussed. Although more research is needed in this field, it is expected that new findings may lead to a change in perception and valuation of energy technology alternatives (in particular renewable energy systems highly dependent on climate conditions such as solar or wind energy technologies). If this change in appraisal or valuation is effected, it may alter energy policies and decision making processes, including plans of action and development of appropriate strategies for energy sector development in the Caribbean region.

The following chapters describe the changes in climate observed in the Caribbean and the wider region of the Americas, the impacts of climate change on conventional and renewable energy production systems and what impacts climate change may have on renewable energy project appraisal and development.

It is necessary to clarify that this paper depicts general data and provides a regional overview and does not represent local or specific conditions. The reader should note that any single country may show substantial differences in spatial variations and characteristics of climate, and that climate changes over time because of natural patterns or due to anthropogenic influence. The data released in this paper, should *not* be construed as to represent the climate of a specific country or sub-region without specific reference. If climate data are required for specific a country or sub-region, inquiries must be made to the National Meteorological Agency of the country or sub-region in question.

2. CLIMATE CHANGE IN THE CARIBBEAN

The Caribbean region is a unique climatic and geological area in the world, where climate variability is influenced by many physical and atmospheric interactions such as the convergence zone of trade winds, El Niño-Southern Oscillation (ENSO),[1] [2] or variations in Sea Surface Temperatures (SST) caused by surface and deep water currents among many other atmospheric teleconnection patterns. All these occurrences are the perfect ingredients for the incidence of extreme weather events. If we add to

[1] El Nino-Southern Oscillation (ENSO), is an oscillation of the ocean-atmosphere system in the tropical Pacific having important consequences for weather around the globe.
[2] National Oceanic and Atmospheric Administration; ENSO Web Page, http://www.pmel.noaa.gov/tao/elnino/el-nino-story.html

this the effects of human induced climate change, the results obtained by atmospheric-oceanic numerical models are alarming.

Figure 1 depicts increases in temperatures in the Northern and Southern Hemisphere over the past decade.[3] Global temperatures increased by about 0.74˚C (0.56˚C to 0.92˚C) since the 19th century (IPCC, 2007). A similar trend was observed for the Caribbean over the period 1950-2000 (Peterson et al., 2002), (Taylor et al, 2007). Higher ambient or surface water temperatures contribute to increased intensity of weather related events.

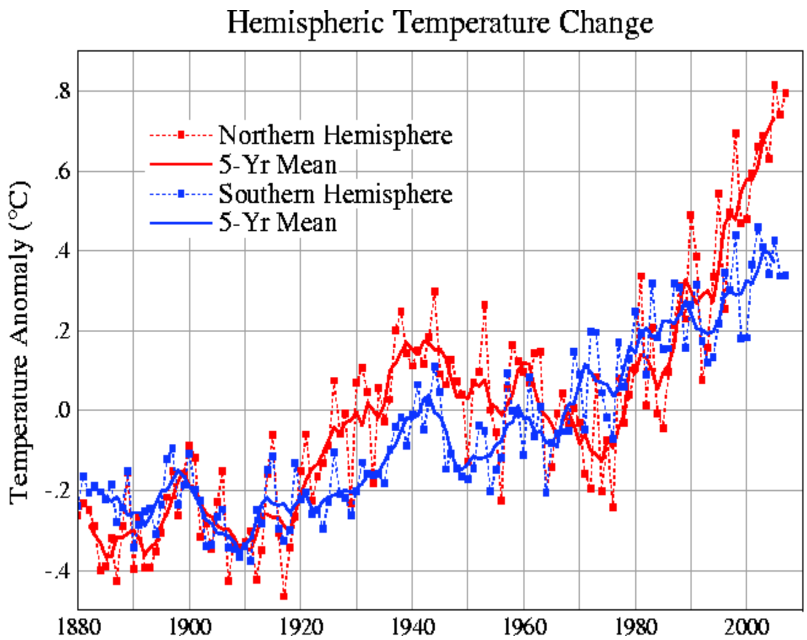

Figure 1

In the last three decades, the Caribbean and Latin American region was affected by several extreme weather events, including two Mega-ENSOs (1982-83 and 1997-1998). A mega-ENSO is an event that has severe implications for regional and even global atmospheric processes and lead to more intense draught or precipitation trends.

Over the last decades, wind storms, floods and droughts have been the most significant and frequent natural disasters occurring in the Caribbean (see figure 2 for a schematic overview).[4]

[3] NASA web site, http://data.giss.nasa.gov/gistemp/
[4] EM-DAT : The OFDA/CRED International Disaster Database ; http://www.cred.be

Distribution of natural disasters by country and type of phenomena in the Caribbean (1975-2001)

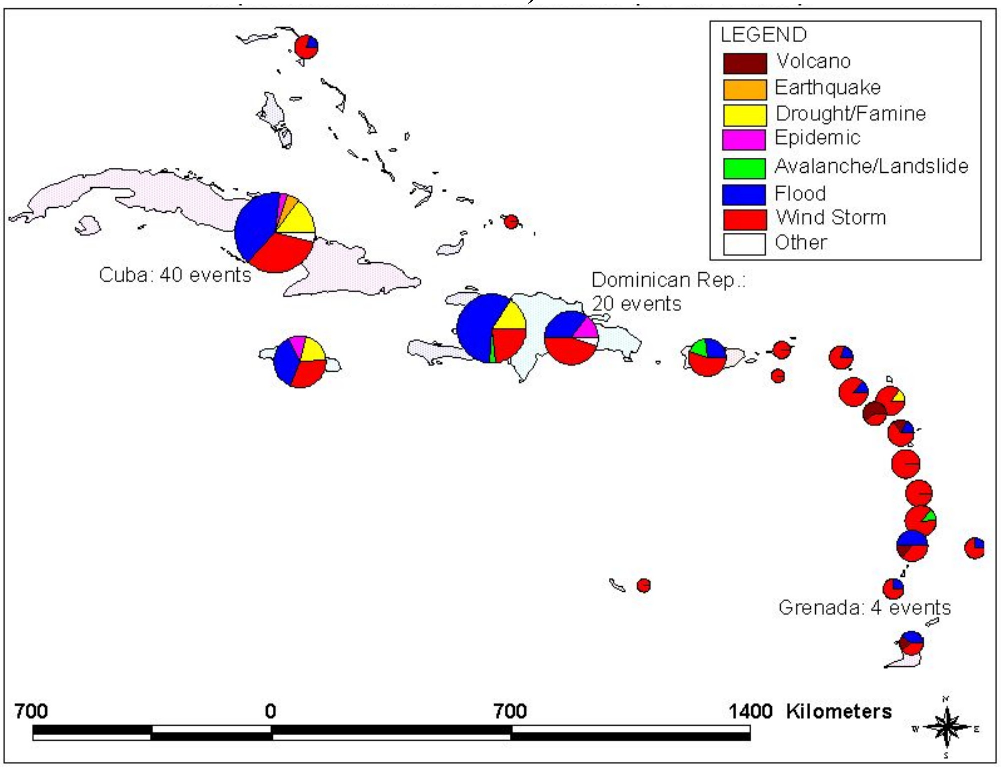

Figure 2

In recent years, a more complex reality can be observed where a higher frequency and wider variety of natural disasters took place in the region over the period 2006-2007.[5] Table 1 provides an overview of the most common cases of disasters such as hurricanes, tropical storms or droughts that are linked, related to, or triggered by, ongoing climate change and climate variability.

Natural Disaster Occurrences in LAC 2006-2007

Variable	Event Type	Caribbean	México y Centro America	**Total in the Region**
Number of Event	Drought	5	13	30
	Flood	23	47	166
	Wind-Storm	53	40	113
Event Quantified in % of total	Drought	40%	38%	30%
	Flood	17%	15%	16%
	Wind-Storm	19%	18%	18%
Damages in million of $US\$_{2006}$	Drought	9	351	830
	Flood	1,305	146	3,641
	Wind-Storm	10,490	2,198	13,048

Table 1

[5] ibid. 4 and 5

In sum, according to table 1, weather related calamities account for 86% of total disasters that occurred over the period 2006-2007 and is anticipated to increase.[6]

Some projections of climate change scenarios for the Caribbean are summarized in table 2 below (IPCC, 2001). In the short, medium and long term, several climate centers,[7] come to the same prediction: climate change will result in the increased incidence of extreme weather events (Kerry, 2005; Trenberth et al, 2006). Even though more hurricanes are expected take place as a consequence of climate change, longer periods of droughts are anticipated, leading to particular impacts on the supply of water resources in the wider Caribbean.

Period	**Region**	**Temperature (Δ in ºC)**	**Precipitation (Δ in %)**	**Some Effects**	**Extreme Events**	**SLR**
2015 To 2025	Caribbean	+0.5 – 1.1	-7 – +14	Supplies water resources have severe decreases. Desertification affects most of the Caribbean Areas.	It is high probable to expect that have an increasing effect on the intensity of the most severe storms, both in tropical and extra-tropical regions.	7 - 9
2040 To 2060	Caribbean	+0.8 –+2.3	-40 – +30	.		12 - 15
2070 To 2090	Caribbean	+1.0 –+4.0	-60 – +20	Shortages in water affect most of the Caribbean, Venezuela, and Guyana.		22 -37

Table 2 (IPCC, 2001-2007)

The potential effects described above have implications for energy production and consumption in the energy generation sector as well as in other climate-sensitive sectors of the Caribbean (e.g. agriculture, transport and tourism). Possible effects include increased amounts of energy consumed for cooling in residential, commercial, and industrial buildings and industrial process cooling. In the following sections an overview is provided of the potential impact of climate change on energy production sectors that are based on conventional and/or renewable energy generation systems.

3. CLIMATE CHANGE IMPACTS ON TRADITIONAL ENERGY SYSTEMS

The energy sector is vulnerable to the effects of climate change in several ways, as many different aspects of the energy industry are directly affected by environmental and climatic conditions. Some of these interactions are described below (DOE/NETL, 2007):

- Seasonal and daily temperatures and precipitation changes affect the timing of peak electricity demands and the size of these peaks;
- Extended periods of drought lead to reduced water availability for hydropower generation;
- Changes in temperature and precipitation affect water availability for cooling power generators;
- Changes in cloud cover, temperature and pressure patterns directly affect wind and solar resources (affecting resource availability or productivity);

[6] CRED International Disaster Database, Université catholique de Louvain, Brussels, Belgium; http://www.emdat.be/Database/terms.html

[7] World Data Center for Climate Max-Planck-Institute for Meteorology, www.wdc-climate.de: Hadley Centre, http://www.metoffice.gov.uk/research/hadleycentre/index.html

- Increased intensity and frequency of severe weather events impacts on energy infrastructure, for instance power plants, transmission lines, refineries, oil and gas drilling platforms, pipelines and power lines in and around the Caribbean. These weather-related supply disruptions result in higher energy prices;
- Increased intensity and frequency of severe weather events impact design and safety requirements of future energy infrastructure and other capital investments;
- Increased occurrence of blackouts may be observed as a result of higher electricity demand for cooling and refrigeration caused by higher temperatures.

3.1 Effects on energy production due to changes in water availability

Approximately 20% of the freshwater used in the Latin American and Caribbean countries runs through hydroelectric and thermal electric plants (FAO, IPCC 2001). In the Caribbean, approximately 13,872 TJ of hydropower energy is consumed (de Cuba, et. al., 2008), with Jamaica, Haiti, the Dominican Republic and Suriname representing the bulk of this primary energy use. Extended periods of intense droughts may result in severe water availability reduction for hydropower generation and cooling of thermal electric power plants. Conversely, it is precisely in periods of draught 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 for cooling or refrigeration and ground water pumping activities, thus augmenting the pressure on thermal electric power plants, affecting energy and water supplies, and leading to increases in CO_2 emissions.

Furthermore, changes in hydrological cycles, particularly in small island states, trigger serious issues related to water availability and use. Most small island states have limited fresh water resources because of the limited availability of surface for groundwater aquifer formation or regeneration and the intrusion of salt or brackish sea water. Scarcity of fresh water may lead increased competition for shared water resources in different locations and for different purposes including energy, commercial, residential and agricultural uses. This potential increase in competition may negatively affect the energy sector, especially when considering the existing conventional fossil fuel based power plants that are dependant on quality water for their cooling systems to function appropriately (DOE/FE Energy-Water RD&D Programs, 2005).

3.2 Effects on energy production due to changes in temperature and humidity

In the Caribbean region temperatures show an upward trend. An environment with higher ambient air temperatures will decrease the efficiency and capacity of natural gas or oil fired combustion turbines or steam cycles (DOE/FE Energy-Water RD&D Programs, 2005). This is based on the logic that the differential in ambient and combustion temperature will be smaller and therefore less energy can be 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 heat waves in specific regions can significantly threaten power supply. For example, during the 2003 and 2006 heat waves in Europe, severe decreases in availability of cooling water for electricity generation lead to blackouts and other supply disruptions (Carey, 2006).

3.3 Effects of extreme weather events on the energy production and distribution

Extreme weather events caused by climate change have a strong impact on the production and distribution of energy resources such as petroleum, gas and electricity. The energy infrastructure is very vulnerable to these extreme climatic events. For example, under strong winds with speeds over 100km/hr, electric wires and other electricity distribution components can easily collapse.

In the 2008 summer season alone, in a timeframe of only 3 weeks (August 25 to September 14, 2008) the Caribbean, an in particular poorer island nations without proper infrastructure, suffered extensive damages from hurricanes Gustav, Hanna and Ike. These not only impacted residential infrastructure but also damaged energy infrastructures and facilities. In September 2008, hurricane Ike caused considerable damage to the islands of Turks and Caicos. As many as 95 percent of the buildings on Grand Turk were severely damaged, flattened, or demolished; houses collapsed and the hospital sustained major damages. Hurricane Ike moved over Cuba and finally caused damages to off-shore oil platforms in the Gulf of Mexico.

To provide an example of the estimated costs that come about with such events, hurricanes Rita and Katrina in 2005 had dramatic impacts on the Caribbean and southern United States' energy production and distribution infrastructure, and ultimately on global energy prices. These impacts include the destruction of 115 platforms, damages to over 180 pipelines,[8] and direct losses to the energy industry estimated at over US$15 billion with substantial additional restoration and recovery costs.

In addition, the potential impact of severe weather events is not limited to hurricanes. Severe storms and rains, lead to flooding of plains and riverbeds, make rail and road transportation inaccessible and even deteriorate critical bridges used for fuel transport or distribution. Given the Caribbean region's high dependency on oil for electricity generation, any significant disruption to the transportation infrastructure has serious implications for energy service reliability.

Modeling tools that integrate climate change factors into natural hazard adaptation measures should be utilized in project design, appraisal and implementation. This approach ensures the full effectiveness and reliability of energy technologies as well as adequate water resource management. These actions will in turn help prevent increases in fossil fuel prices caused by climate-related events.

4. CLIMATE CHANGE IMPACTS ON RENEWABLE ENERGY SYSTEMS

Most Caribbean countries are net energy importers highly dependent on fossil fuel to meet their energy demand. Petroleum accounts for an estimated 93 percent of energy consumption. In this scenario, renewable energy accounts approximately for only 2 percent of the total energy generation in the Caribbean region.[9] But the 2008 spike in fossil fuel prices is expected to accelerate the deployment of new renewable energy systems throughout the Caribbean region.

An aspect challenge which may pose a challenge in the future is the fact that most Renewable Energy Technologies (RETs) are dependant on meteorological and climatic variables and patterns such as hydrological resources, wind patterns and solar radiation, and they therefore tend to be very vulnerable to climate change and variability. If the hydrological cycle, the atmospheric conditions, or the solar distribution changes, alterations in the availability of RE resources can be expected. Depending on the specific location and time a renewable energy system is established, changes in wind, solar or hydro energy potential may determine the viability of these specific RE projects.

Furthermore, RE systems are not immune to damages caused by extreme weather events. Nevertheless, in order to achieve long term climate change mitigation efforts, increasing renewable energy

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[8] US Department of the Interior Minerals Management Service. "Impact Assessment of Offshore Facilities from Hurricanes Katrina and Rita." January 2006. MMS Press Release. Available at: http://www.mms.gov/ooc/press/2006/press0119.htm

[9] United Nations Development Programme Global Environment Facility, 2004, project document; Caribbean Renewable Energy Development Programme, Number: RLA/00/G31/A/1G/99 (PIMS 1437). http://www.caricom.org/jsp/projects/CREDP_Project_Document.pdf

production capacity is essential. It is widely recognized that to combat climate change it is important to reduce energy-related greenhouse gas emissions. Renewable energy resources are therefore linked to climate change in a very complex manner. By a simple scale analysis,[10] RE has a negligible effect on climate change, whereas climate change can have a serious effect on RETs.

4.1 Climate change impact on hydro power systems

According to data from OLADE, in Latin America and the Caribbean the regional potential for hydroelectricity was of 582,033 MW in 2005 (Rios, A., 2006). Of this potential, only 139,688 MW (about 24%) are being exploited with a gross output of 3,153,804 GWh per year. In the Caribbean, hydropower only represents a small fraction of the primary energy consumption, where large areas have still not been exploited and may be an option for some countries of the region.

Multiple reports have identified hydroelectric generation around the world as highly vulnerable to climate change (Whittington, H.W & Gundry, S.W, 1998), (Mimikou, M.A & Baltas, E.A, 1998), (Garr, C.e.& Fitzharris, B.B., 1994). Hydroelectric power potential depends on stream flow, which depends directly on precipitation, temperature levels and potential evapotranspiration. Precipitation directly impacts runoff levels and stream flows which then determine the amount of water available for hydroelectric generation.

Annual changes in precipitation and temperature obtained from four Global Climate Models (GCMs) (GFDL-R30, GISS, GISSA, and CCCM) (IPCC, 2007; Climate Change 2007: Synthesis Report), consistently show decreases in runoff in the Caribbean region (Yates, D. 1997) and an ensemble[11] of climate models project the same run-off decreases for the Caribbean, Mexico and Central America (see figure 3).

Potential changes in annual runoff by 2041-60 relative to 1900-70, in percent, under the SRES A1B emissions scenario and based on an ensemble of 12 climate models

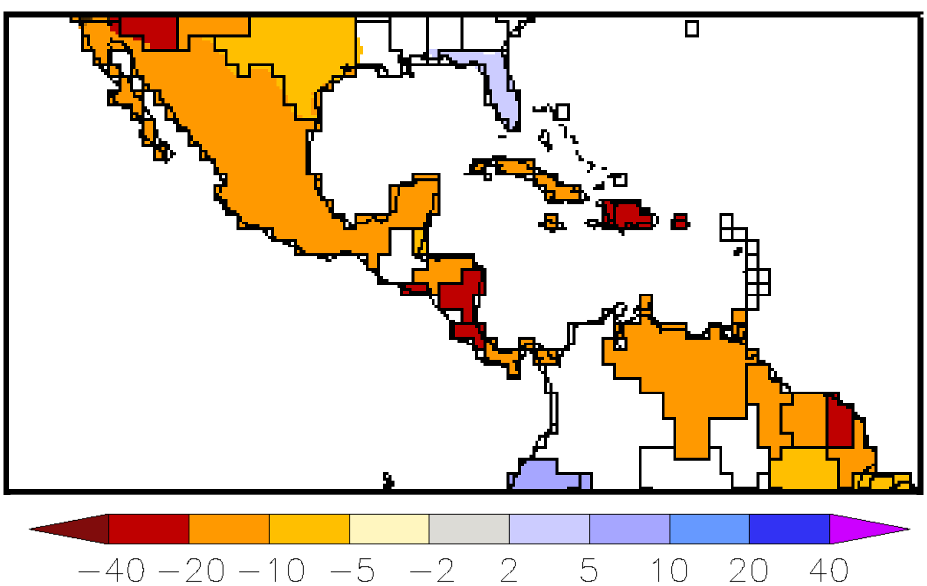

Figure 3

[10] Compare the order of magnitude of each effect.

[11] Ensemble forecasting is a method used by modern operational forecast centers to account for uncertainties and errors in the forecasting system which are crucial for the prediction errors due to the chaotic nature of the atmospheric dynamics (sensitive dependency on initial conditions).

The UKMO HadGEM1 model that includes direct effects of CO_2 under scenarios A1b and A2 (Marengo J., 2006), shows that the Caribbean, Mexico and Central America are among the areas where water resources stress may increase. The most affected countries and sub-regions will be the Dominican Republic, Haiti, the Eastern Caribbean small island states, Mexico, and Guatemala (Barnett TP et al. 2005), (Bradley RS et al. 2006). These effects are clearly visible in figure 3 (Kundzewicz, Z.W., et.al, 2007).

Changes in precipitation cycles due to climate change can alter river flow patterns, resulting in longer periods of drought, thus causing water levels to decrease and affecting 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 hydro plants. On the other hand, increased flow rates, if timed and managed correctly, may result in increased hydropower generation. For example, a shift in higher stream flow rates from dry to wet season (e.g., changes to less frequent rains but with higher quantities of rain at a particular moment) may increase hydropower generation more in the wet season than it is reduced in the dry season.

However, there remain questions as to whether existing hydropower plants would be able to take full advantage of increased flows, and whether storage systems would be adequate to deal with such flows. Hydropower plants are generally 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, W.G II).

The precipitation and temperature trends (figures 4a and 4b) [12] are useful to get a regional overview of water resources. For example, in areas where precipitations tend to decrease and temperatures tend to increase, the flow of the rivers can be expected to decrease and may eventually lead to a diminished ability for energy production. On the other hand, the reverse situation would increase the potential hydro-energy production. Although these assumptions are hypothetical, they give an idea of this complex issue.

Figure 4; 4a, Precipitation and 4b, Temperature trends in the last century (1900-2000).

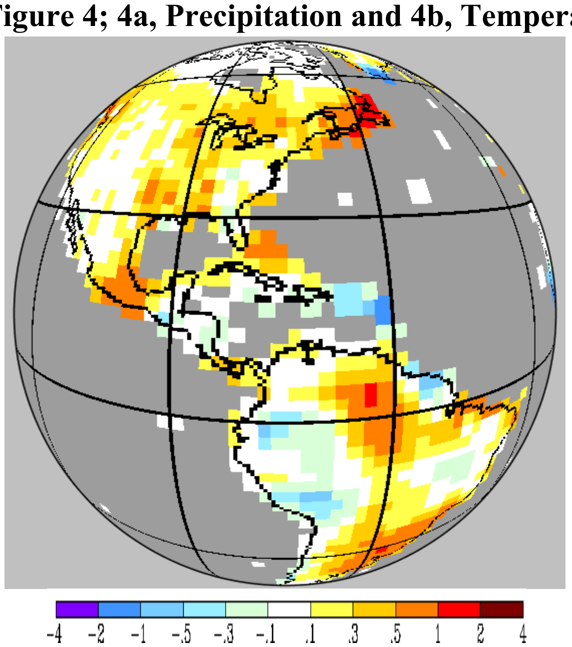

Figure 4a

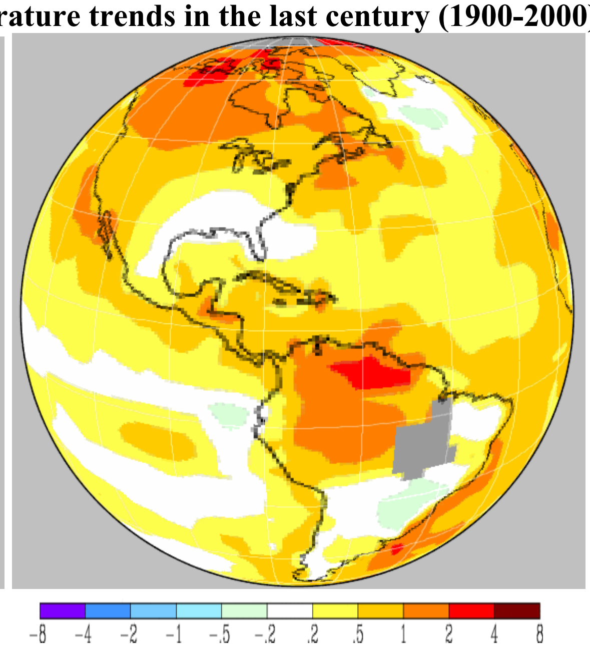

Figure 4b

[12] Maps calculated using NASA information and Tyndall Centre for Climate Change Research, http://www.cru.uea.ac.uk/~timm/data/index.html

In recent years the Caribbean region has been experiencing many severe and long-term droughts that may have an effect on regional power generation capacity and plant operation. Anticipated effects of prolonged drought in the electricity sector in the Caribbean region reveal the vulnerability not only of hydropower producers, but also of industries dependent on low-cost hydropower. At the beginning of the past decade, drought conditions in the region resulted in a reduction of hydropower generation, which in turn led to higher fuel and electricity prices. This highlights the need to include assessments of future climate change scenarios in project appraisal procedures, instead of the conventional approach of extrapolating historical climatological data.

4.2 Climate change impacts on biofuels production systems

In Latin America and the Caribbean (LAC), especially in Brazil, biofuels are among the most promising types of biomass energy systems in place given their ability to replace oil imports by using indigenous resources. Several Caribbean nations possess relatively large agricultural lands for the cultivation of bio-energy dedicated crops. Current biofuel production is not significant in the Caribbean, but there are several ongoing efforts in the development, or conversion, of sugarcane lands for ethanol production. Previous experience has revealed the need to implement sustainable biofuels production systems in such a manner as to avoid a food versus fuel dilemma. This entails the need to develop modern biofuels systems based on cellulosic ethanol.

Classic energy-crops, dedicated biomass for fuel production, such as grain, oilseed crops, grasses and fast-growing trees will be directly affected by climate change because their yield is mainly dependant on climatological and agronomical conditions. Agricultural productivity is generally influenced by many factors, including changes in temperature, humidity, precipitation, atmospheric CO_2 concentrations and the impact of extreme weather events, all of which will affect directly and/or indirectly energy consumption and production of the agricultural sector at the local level.

For example, temperatures are linked with the real evapotranspiration of sugarcane plants in semi-arid conditions (Fonseca, J. 1984), (Carrera, Luis, A.; R.1995), therefore, an increase in temperature and a decrease in rainfall will cause increased evapotraspiration, resulting in lower production of sugarcane and thus lower bio-fuel production.

Cellulosic feedstock may replace grain and oilseed crops for biomass-based transportation fuel production. To a certain degree crop residues such as corn stover, wheat straw and other biodegradable waste from forestry or agriculture considered as potential cellulosic feedstock may also be affected by climate change since they are linked to classic energy dedicated-crops. But cellulosic ethanol feedstock may also originate from municipal solid or liquid waste that is less dependant on climatological conditions.

4.3 Climate change impacts on wind energy generation systems

In Latin America and the Caribbean, wind energy currently accounts for less than 0.4% of renewable energy generation. However, this source of energy has a tremendous potential given its cost-competitiveness with regard to fossil fuel power plants for utility-scale generation or in decentralized configurations.

Wind energy is not affected by shifting water supplies as opposed to fossil-fuel based power systems or other alternative energy systems. Nevertheless projected climate change impacts are likely to have significant positive or negative impacts on wind energy generation given that it depends strongly on climatic and environmental conditions at a particular site. Wind is caused by the uneven heating of the earth's surface by the sun. Since the earth's surface is made of very different types of land cover and water, it absorbs the sun's heat at different rates; this generates temperature gradients and is the reason of why wind flow. Therefore, if temperature gradients changes it can be argued that wind patterns may also changes.

In 2006 Latin America and the Caribbean region experienced an encouraging development with the deployment of new wind turbine installations summing up to 296 MW of installed capacity. During the period 2007-2010 the market is expected to grow in Brazil and Mexico. Smaller developments will also take place in some Caribbean countries. Despite its large potential, the Caribbean region will remain a small market until the end of this decade, progressing towards a more significant development in the next decade (Global Wind 2006 Report).

In order to ensure the sustainability of future wind energy projects, the identification of locations where deep changes in global atmospheric circulation are expected is critical. It is in such locations that radical changes in wind patterns will occur, thus leading to changes in wind space, time dynamics and scale that may have consequences with regard to wind energy potential at locations that may currently be under consideration as suitable sites. It is important to enhance meteorological services in the region in order to better assess the present and future potential of RE resources. For a detailed study at the local or regional level or any area in particular, it is necessary to use meso-scale models[13] which include the topography and other variables linked to meso-scale.

Overall, when considering the potential impact of climate change on wind energy potential, investing in wind energy systems presents significant challenges to local governments and investors. It is recommended to execute climate change projection modeling and economic assessment studies in order to understand to which extent climate change may affect a wind energy project and what its long term financial viability will be. Even changes in the solar intensity may impact the viability of projects in the long run.

To give an example, if solar incidence decreases as predicted by NASA,[14] average wind speeds may suffer a significant decrease of 10%–15% (which entails 30%–40% decrease in potential wind power generation) by 2040-2050[15] (Pan, Z. T., et al., 2004). Changes in diurnal wind patterns can also lead to significant challenges in matching wind power production with daily load, thus demonstrating the atmosphere's high sensitivity to solar variations.

4.4 Climate change impact on solar energy production systems

Earth systems have internal and external sources of energy, both of which create heat. The sun is the major external source of energy and internally there exist two primary sources of energy; the first is the decay of radioactive isotopes and the second is the gravitational energy from the earth's original formation (Houghton, J., 2002), (Hagan, M.E. et. al 2003). However, heating of the earth's surface and atmosphere by the sun drives convection within the atmosphere and ocean, producing winds and ocean

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[13] Using high-speed computer to tackle the computational demand, numerical weather prediction (NWP) is the technique used to forecast weather by solving a set of equations within a numerical model that describes the evolution of meteorological variables representing the atmospheric state. These variables include temperature, wind, pressure and moisture content. Model simulations rely on descriptions of the land surface characteristics, which must be developed from geographic databases. To get a better resolution (more details) and accuracy of the information.

[14] Long Range Solar Forecast; http://science.nasa.gov/headlines/y2006/10may_longrange.htm

[15] Atmospheric processes are not linear; therefore we believe that the certainty of these facts can not be extrapolated beyond 2050.

currents, and resulting in global climate being determined by energy transfer from the sun at, and near, the earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover, earth's rotation, and static conditions such as the position of mountain ranges and oceans.

The use of solar energy in the Caribbean is widely known and disseminated, but only on a local scale or for domestic uses. Photovoltaic (PV) electricity generation, solar water heating and efficient solar stoves are suitable for much of the Caribbean region, with current deployment primarily in off-grid locations.

At first glance, the best location to use solar energy seems to be near the equator given the high solar radiation. The current state of solar energy in the Central American and Caribbean region is shown in figure 5.[16]

Caribbean and Central American Annual Average Global Horizontal Solar Radiation Map

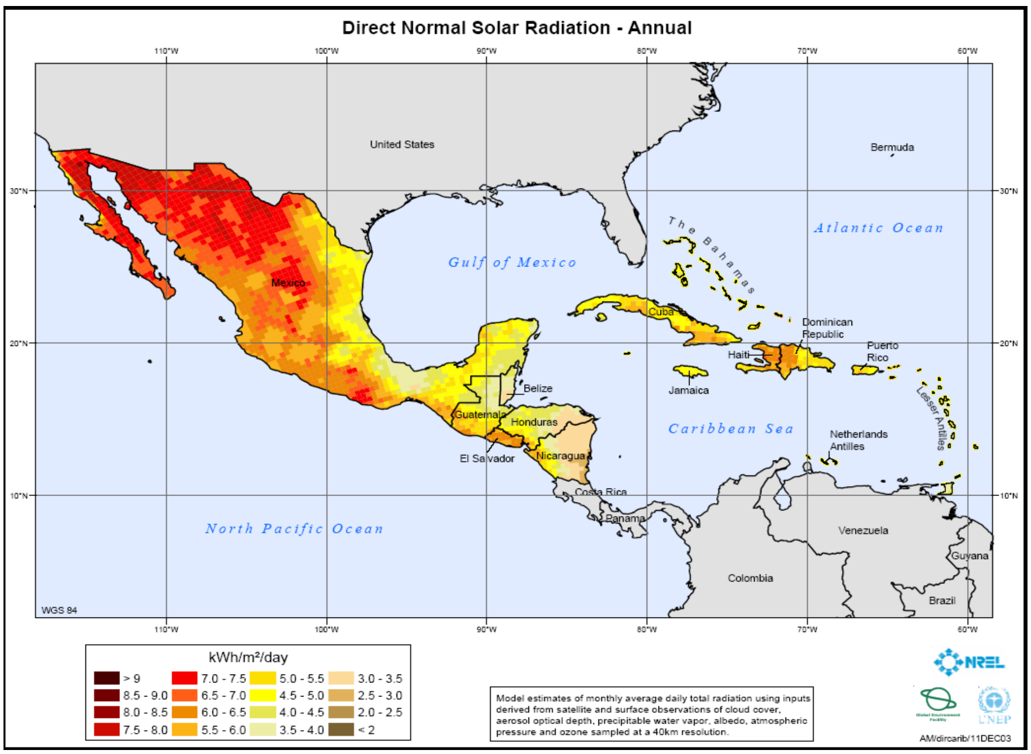

Figure 5

In figure 5 the highest potentials for solar energy generation are represented in red. There are many hot-spots for solar energy extraction in islands. These are located between 10 and 30 degrees north latitude and 70 degrees west longitude.

Some international research focused on using numerical simulations to investigate solar activity oscillations (Pan, et al., 2004). Based on these simulations, changes to global solar radiation were modeled up to the 2040s based on the Hadley Center circulation model. The study showed a 20% reduction in solar radiation seasonally, presumably from increased cloud cover.

Furthermore, increased temperatures can also reduce the effectiveness of PV electrical generation and solar thermal energy collection. A 2% reduction in global solar radiation will reduce solar PV cell

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[16] Sources of map: http://swera.unep.net/index.php?id=solar_map

output by 6%, these projections significantly impact solar energy generation and cost-effectiveness (Audun Fidje. et. al, 2006). The use of aerosols can also reduce average solar radiation, especially regionally and locally. Integrating solar activity variations to solar energy project development may also benefit from further analysis regarding the nexus between anthropogenic aerosols, climate change and solar radiation, and their impacts on solar energy production.

4.5 Climate change impacts on geothermal energy production systems

Shifting air temperatures can affect geothermal energy production in the same manner they affect the efficiency of fossil-fuel turbines. Both energy generation processes are based on the use of steam cycles, where the difference between ambient and combustion temperature have an impact on the overall efficiency of the boiler or turbine.

Hydrologic changes driven by climate change undoubtedly impact geothermal energy production. In most cases either groundwater or surface water is extracted for its use in a variety of geothermal power generation activities. These uses include well drilling, subsurface formations injectivity testing, and cooling among others. Surface and ground water used for non-contact single pass cooling is typically returned to the source with some increased heat content. Although no change in water quality occurs, the process generates the heating of the water source.

4.6 Climate change impact on other alternative energy production systems

The Caribbean region does not make significant use of wave, tidal, or ocean thermal energy. These can all be affected by climate change due to changes in average water temperature, temperature gradients, salinity, sea level and wind patterns affecting wave production, and intensity and frequency of extreme weather events. It will be essential to include climate change modeling tools in the research to develop these new RE technologies.

5. CONCLUSIONS AND RECOMMENDATIONS

Climate change is increasingly being recognized by society as an ongoing phenomenon that whether human induced or not, has an impact on people’s livelihoods. Changes in climate can significantly sharpen energy investment risks, with a potential cost that can reach up to hundreds of billions of dollars per year. Damages caused by hurricane Katrina and Ike to the oil industry are recent examples of this fact (Munich Re, “Insuring against Catastrophe,” January 2002).

In addition to the well known temperature projections, climate models suggest changes in a wide range of climate variables including precipitation, humidity, wind speed and cloudiness (IPCC, 2007). With conventional and renewable technologies inherently reliant on climate, changes will result among other things in:

- Altering availability of natural energy resources;
- Changes in the quantity and timing of renewable resource extraction potential;
- Changes in operational performance of energy production systems.

Renewable energy facilities are generally designed and emplaced based on historical climate data or to suit prevailing climate conditions, without the consideration of future climate change in feasibility studies. If key energy stakeholders are not aware of climate change implications to the productivity, or even the viability, of energy production systems, the ability of the Caribbean region to supply reliable and affordable energy to meet demand may be at serious risk. Impacts on key energy resources, substantially impact the cost competitiveness of these technologies due to changes in resource availability or variability, and may even impede the planning and financing of new RE projects.

Based on these premises, the impact of climate change on the energy sector is may be deemded serious. In this paper issues are raised to prioritize the development of robust evaluation methods that include climate change prediction models in the project decision-making process. The scientific community should be encouraged to promote new studies in this area.

The OAS Energy Team's experience has lead to the recognition for the need of sensitivity studies that show the importance of including the effects of climate change in the evaluation of future energy projects (Contreras-Lisperguer, R, 2008).[17] Hereby the uncertainties in future climate change impacts may be assessed and adequately taken into account to increase the viability of energy projects. In addition, a case is made that the long term sustainability of renewable energy and energy efficiency strategies in the region are highly dependant upon the consistent and integral assessment of future climate change impacts to the energy sector to prevent economic losses and serious damages to a nation's ability to supply reliable and affordable energy.

[17] In draft to be published: Contreras-Lisperguer, Ruben. 2008. Impact of Climate Change in the Hydroenergy, a case of study " Hydro-Plant Chacabuquito", Chile.

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