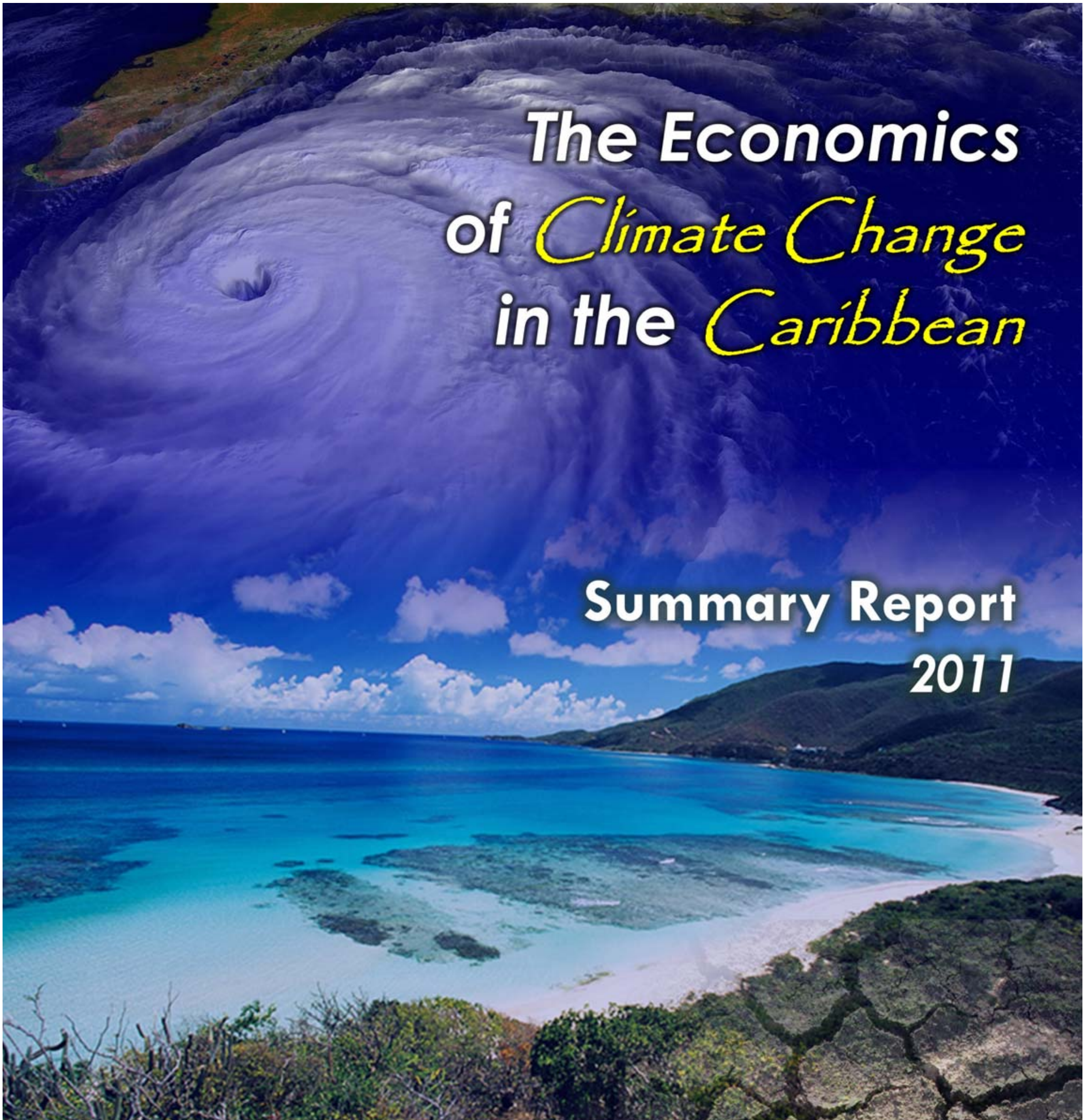
The Economics of Climate Change in the Caribbean

Summary Report 2011



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THE ECONOMICS OF CLIMATE CHANGE IN THE CARIBBEAN

UNITED NATIONS ECONOMIC COMMISSION FOR LATIN AMERICA AND THE CARIBBEAN
Subregional Headquarters for the Caribbean, Port-of-Spain, Trinidad and Tobago

Notes and explanations of symbols:

The following symbols have been used in this study:
A full stop (.) is used to indicate decimals
n.a. is used to indicated that data are not available
The use of a hyphen (-) between years, for example, 2010-2019, signifies an annual average for the calendar years involved, including the beginning and ending years, unless otherwise specified.
The word "dollar" refers to United States dollars, unless otherwise specified.
The term "billion" is taken to refer to a thousand million.
The boundaries and names shown and the designations used on maps do not imply official endorsement or acceptance by the United Nations.

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CHAPTER I.
INTRODUCTION

There is now widespread agreement among climate scientists that the earth is warming as a result of increased concentrations of carbon dioxide (CO_2) and other greenhouse gases emitted by the burning of fossil fuels, primarily as a result of human activity (Doran and Zimmerman, 2009; Anderegg and others, 2010). This situation may be exacerbated by current trends in energy consumption and population expansion and will continue well beyond the twenty-first century (World Health Organization (WHO), 2009).[1]

Climate change poses a serious threat to sustainable human development, impacting negatively on livelihoods, ecosystems, infrastructure, health and the productive sectors. For the small island developing States (SIDS) of the Caribbean subregion, the threat is even more severe due to the biophysical and socio-economic characteristics of these countries which make them especially vulnerable to these impacts. This is a result of the geographic location of many of these States in the hurricane belt, and the concentrations of their populations and economic infrastructure in coastal zones. Additionally, the subregion is dependent on a narrow range of economic activities, including agriculture and tourism, which are intimately linked to the environment, making them highly susceptible to external shocks (ECLAC, 2010a). Thus, climate change is of direct relevance to economic development planning in these countries.

From an economic perspective, sustainable growth in the Caribbean is hampered by persistently large external current account deficits, as well as high public debt that climbed rapidly from an average of 65% of GDP in 1998 to a peak of nearly 99% of GDP in 2002, before falling to a still elevated 70.6% of GDP in 2009. Indeed, in 2002, when regional public debt was at its highest, 7 Caribbean countries were ranked among the top 10 most indebted emerging market economies in the world (Sahay, 2005).

Caribbean economies were dealt a hard blow by the recent global economic crisis, particularly through spillovers from the United States of America, the subregion's most important trading and investment partner. By far the most direct impacts were through declines in tourism receipts, with trade in goods playing a lesser role. Many Caribbean countries are also heavily dependent on foreign direct investment (FDI), particularly from the United States of America, and remittances from the large base of Caribbean migrants living abroad, and these financial flows declined drastically. These characteristics and current development trends suggest that the subregion will be confronting the impact of climate change with a serious disadvantage, thereby emphasizing the urgent need to adopt an integrated approach to addressing climate change.

The 13th meeting of the United Nations Framework Convention on Climate Change (UNFCCC) recognized the need to assess the economic impact of climate change on development in Latin America and the Caribbean. In response, the United Nations Economic Commission for Latin America and the Caribbean (ECLAC) Subregional Headquarters for the Caribbean in Port of Spain, in collaboration with

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[1] World Health Organization. (2009).*Protecting health from climate change: Connecting science, policy and people*. Available online at: http://whqlibdoc.who.int/publications/2009/9789241598880_eng.pdf.

the United Kingdom Department for International Development (DFID) and the Caribbean Community Climate Change Centre (CCCCC), embarked on a project to estimate these impacts. The Review of the Economics of Climate Change in the Caribbean (RECCC) project (Phase 1) in 2008, sought to determine the scope and feasibility of an economic assessment of the costs and benefits of climate change actions in the Caribbean (ECLAC 2010b). Phase 2 (the current phase) began in 2010 and has facilitated the conduct of 26 national studies geared towards quantifying the economic impacts of climate change on various vulnerable sectors.

Estimates of the economic cost of climate change to Caribbean economies are useful in developing adaptation and mitigation strategies within the context of national and subregional development policies and plans. Apart from obvious costs, such as those related to the replacement value of infrastructure due to increased intensity of tropical cyclones, there are real costs, such as productivity loss, potential relocation of persons living near coastlines, and increased resources for dealing with frequent flooding. Indeed, the range of anticipated impacts on key economic sectors in the Caribbean will have implications for overall quality of life in the subregion, and more so among poor and vulnerable groups. It is noteworthy that the uncertainty margins are large because of the long time frames involved in dealing with complex natural phenomena, feedback processes, non-linear impacts and asymmetric consequences.

In determining the action to be taken by Caribbean countries in addressing the impact of climate change, it should be noted that, although the subregion contributes less than 1% of global greenhouse gas emissions, it is likely to suffer disproportional impacts. As such, the focus for the Caribbean is on adaptation to climate change, with mitigation as a supporting mechanism. These strategies need to be mainstreamed into national development policies and plans if they are to support national visions.

The present volume captures the results of the studies conducted during Phase 2 of the RECCC project to date. Chapter 1 provides the contextual framework within which the assessments were conducted and Chapter 2 focuses on the emissions scenarios as set out by the Special Report on Emissions Scenarios by the Intergovernmental Panel on Climate Change (IPCC). The results of the economic assessments of the impacts of climate change on the agricultural, coastal and marine, energy and transportation, health, freshwater resources and tourism sectors in the Caribbean subregion are presented in Chapters 3 to 9, respectively. The report concludes with an examination of adaptation strategies and key policy recommendations for policymakers, in Chapter 10.

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CHAPTER II.
CLIMATE CHANGE SCENARIOS: IMPLICATIONS FOR THE CARIBBEAN

INTRODUCTION

Historical records confirm an anomalous warming of global atmospheric temperatures, alongside growth in anthropogenic greenhouse gas (GHG) emissions over the last century. This has resulted in variations in the distribution of weather patterns and a number of related environmental phenomena.

The concept of "climate" is distinct from the notion of "weather conditions". This distinction is largely based on the time (and space) ranges considered, but also relates to the statistical means by which each can be characterized. Weather is related to empirical observations of variables such as atmospheric temperature, rainfall, and sea level, monitored on a daily, monthly or quarterly basis, but with the main purpose of detecting high resolution (i.e. very localized) short-term trends in surface and atmospheric conditions. Climate refers to statistical parameters of observed long-term trends of variables, usually pertinent to larger regions and time spans, such as decades or, as in paleoclimatology, with ranges in the millennia. Climate change refers to modifications in the state of the climate that can be identified by changes in the mean and/or variability of its properties that persist for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity.[2]

In 1988, in response to growing concerns about global environmental issues, particularly global warming and its effects, the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) established the Intergovernmental Panel on Climate Change (IPCC) which was mandated to assess the state of existing knowledge about the climate system and climate change, to evaluate the environmental, economic, and social impacts of climate change, and to advise on possible response strategies. IPCC has produced a strong, credible body of evidence that attributes observed climate changes, in large part, to human activities.[3]

A. IPCC SCENARIOS

The IPCC has developed a number of scenarios which are useful to policymakers and experts for planning, given the long time frame and uncertainty involved in analysing climate change issues, including its driving forces. These scenarios are reported in the IPCC Special Report on Emissions Scenarios (SRES) (IPCC, 2000).[4] These SRES scenarios extend to the end of the twenty-first century and

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[2] Climate change in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change, where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

[3] IPCC is the authority on climate change research and frequently publishes research in the area. Landmark publications include the Intergovernmental Panel for Climate Change (IPCC) First (1990), Second (1995), Third (2001) and Fourth (2007) Assessment Reports on Climate Change.

[4] Included are anthropogenic emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), hydrochlorofluorocarbons (HCFCs), chlorofluorocarbons (CFCs), the aerosol precursor and the chemically active gases sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NOs), and non-methane volatile organic compounds (NMVOCs). Emissions are provided aggregated into four world regions and global totals.

are recommended by IPCC for use in conducting assessments of climate change impact and in developing adaptation and mitigation options.

Four families of development scenarios (A1, A2, B1 and B2) were assumed by IPCC and narrative ‘storylines’ were developed to describe the relationships between emissions levels, driving forces and their evolution, and to give context and other relevant details to the quantification of each scenario. Each scenario represents a possible future expressed as a combination of specific characteristics, or driving forces, including demographic, social and economic and technological developments. Relevant global and regional developments, ozone precursors, and sulphur emissions are also considered.

1. The A-family: A group of high-emissions scenarios

The A1 storyline describes a future world of very rapid economic growth, and a global population that peaks in mid-century and declines thereafter with the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity-building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario is further subdivided into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

The A2 storyline describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, and result in a continuously-increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.

2. The B- family: Relatively low emissions scenarios

The B1 storyline describes a convergent world with the same global population as in the A1 storyline, which peaks in mid-twenty-first century and declines thereafter, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

The B2 storyline describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with a continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

The A2 and B2 scenarios were deemed to be the most relevant for projecting the economic impact of climate change in developing countries such as the Caribbean, given their patterns of economic growth and slower adoption of technology.

B. The Caribbean context

The Caribbean has experienced some warming over past decades, as evidenced by increasing average annual maximum and minimum temperatures. Peterson and others (2002) examined changes in temperature and rainfall extremes in the Caribbean over the period 1950 to 2000 and found that the diurnal range (the difference between the minimum and maximum temperature for the year) is decreasing. They also found that the numbers of “very hot” days (temperatures at or above the 90th percentile) are increasing, while the number of "really cool" days and nights (temperatures at or below the 10th percentile) are decreasing. Peterson and others (2002) also found that there was an increase in the average 5-day rainfall total over the period, while the number of consecutive dry days decreased. Meanwhile, Neelin and others (2006), using several sets of observed data, noted a modest but statistically significant drying trend for the Caribbean summer (June to August) period in recent decades.

1. Prospective changes in climatology for the Caribbean

This section presents projections of temperature and precipitation for the Caribbean under two IPCC scenarios – A2 and B2. Predictions are from the Regional Climate Modelling system (RCM) for providing regional climates for impact studies (PRECIS), driven by two models - ECHAM4 and HadCM3.[5] The RCM is maintained by the Institute of Meteorology (INSMET) of Cuba. Baseline references for temperature and rainfall are the 1960-1990 period averages. Sea-level rise and acidification projections are generally taken from proposals in the literature that are based on possible futures determined by mitigation and adaptation on a global scale.

(1) Mean Temperature

Projections for mean annual temperature change show that under the A2 scenario, by 2050, mean temperatures are expected to rise between 1.52° C and 2.64° C above the base period average, with a mean increase of 1.78° C for the subregion (see table 2.1).[6] By 2070, temperatures would have risen by 2.36° C in Turks and Caicos Islands; by 3.85° C in Guyana; and by an average of 2.78° C across the subregion.

In comparison, the B2 scenario projections for mean annual temperature change (also calculated on the basis of the mean of the ECHAM4 and HadCM3 model projections) show that, by 2050, mean temperatures are expected to rise by 1.61° C to 2.83° C above the base period average (1961-1990) depending on the country, with an average increase of 1.84° C for the subregion. By 2070, temperatures are projected to rise by 1.97° C to 3.17° C depending on the country, with a regional average of 2.28° C.

By 2090, the subregional mean annual temperature is expected to increase by an average of approximately 3.55° C under the A2 scenario, and approximately 2.40° C under the B2 scenario (see figure 2.1). This corresponds to the treatment, in the studies, of A2 as a high emissions scenario and of B2 as a low emissions scenario.

(2) Maximum Temperatures

The A2 scenario generated the following potential changes in the maximum temperature change: by 2030, the maximum temperature is forecast to increase by between 0.95° C and 1.85° C depending on the country, with a regional average increase of 1.20° C; and by 2070, maximum temperatures are

[5] Modelling future climate change begins with the inputting of SRES emission scenario information into Global Circulation Models (GCMs), which simulate climate on a global scale with a relatively low spatial resolution. For modelling within a region (such as Latin America and the Caribbean) the outputs from the GCMs are fed into higher spatial resolutions models, called Regional Climate Models (RCM), or into statistical models, called statistical downscaling models. All climate models have varying degrees of uncertainty. The fourth-generation atmospheric general circulation model (ECHAM-4) was developed at the Max Planck Institute for Meteorology (MPI) and is one of a series of models evolving from the spectral weather prediction model of the European Centre for Medium Range Weather Forecasts (ECMWF). The Hadley Centre Coupled Model, version 3 (HadCM3) is a coupled atmosphere-ocean general circulation model (AOGCM) developed at the Hadley Centre in the United Kingdom.

[6] These calculations are on the basis of the mean of the ECHAM4 and HadCM3 model projections. The base period refers to the period 1961-1990. Temperature and precipitation changes all reflect change relative to the average of the baseline period (1961-1990).

expected to increase by 2.86° C on average, with a range of 2.33° C (Turks and Caicos Islands) to 4.47° C (Guyana). By 2090, the maximum temperature is forecast to increase by 3.72° C on average across the subregion (see table 2.2).

Table 2.1: Caribbean mean annual temperature change under the A2 and B2 scenarios (2030 to 2090)

Country	2030		2050		2070		2090	
	A2	B2	A2	B2	A2	B2	A2	B2
Anguilla	1.04	1.17	1.61	1.71	2.57	2.16	3.24	2.25
Antigua and Barbuda	1.04	1.13	1.60	1.64	2.54	2.09	3.21	2.11
Bahamas (the)	1.13	1.23	1.55	1.74	2.38	2.05	3.17	2.38
Barbados	1.11	1.15	1.76	1.78	2.87	2.25	3.67	2.28
Belize	1.30	1.36	1.99	2.02	3.21	2.60	4.17	2.82
British Virgin Islands	1.03	1.15	1.60	1.68	2.55	2.14	3.23	2.23
Cayman Islands	0.97	1.03	1.55	1.58	2.44	1.97	3.15	2.28
Cuba	1.51	1.55	2.08	2.16	3.35	2.74	4.29	3.05
Dominica	1.03	1.10	1.60	1.60	2.55	2.05	3.20	2.03
Dominican Republic	1.52	1.50	1.97	2.25	3.10	2.52	3.89	2.73
Grenada	1.11	1.15	1.76	1.72	2.78	2.21	3.48	2.08
Guyana	1.73	1.94	2.64	2.83	3.85	3.17	5.04	3.55
Haiti	1.44	1.51	2.13	2.21	3.55	2.86	4.56	3.42
Jamaica	1.04	1.13	1.66	1.73	2.61	2.17	3.34	2.44
Martinique	1.07	1.12	1.67	1.64	2.64	2.11	3.33	2.11
Montserrat	1.03	1.12	1.60	1.62	2.54	2.07	3.20	2.06
Saint Kitts and Nevis	1.04	1.14	1.60	1.66	2.54	2.12	3.21	2.16
Saint Lucia	1.04	1.08	1.61	1.58	2.55	2.04	3.19	2.04
Saint Vincent and the Grenadines	1.03	1.07	1.61	1.58	2.54	2.05	3.18	2.04
Trinidad and Tobago	1.50	1.59	2.22	2.32	2.90	2.34	3.63	2.17
Turks and Caicos Islands	0.96	1.15	1.52	1.61	2.36	2.07	3.12	2.21
Caribbean	**1.18**	**1.26**	**1.78**	**1.84**	**2.78**	**2.28**	**3.55**	**2.40**

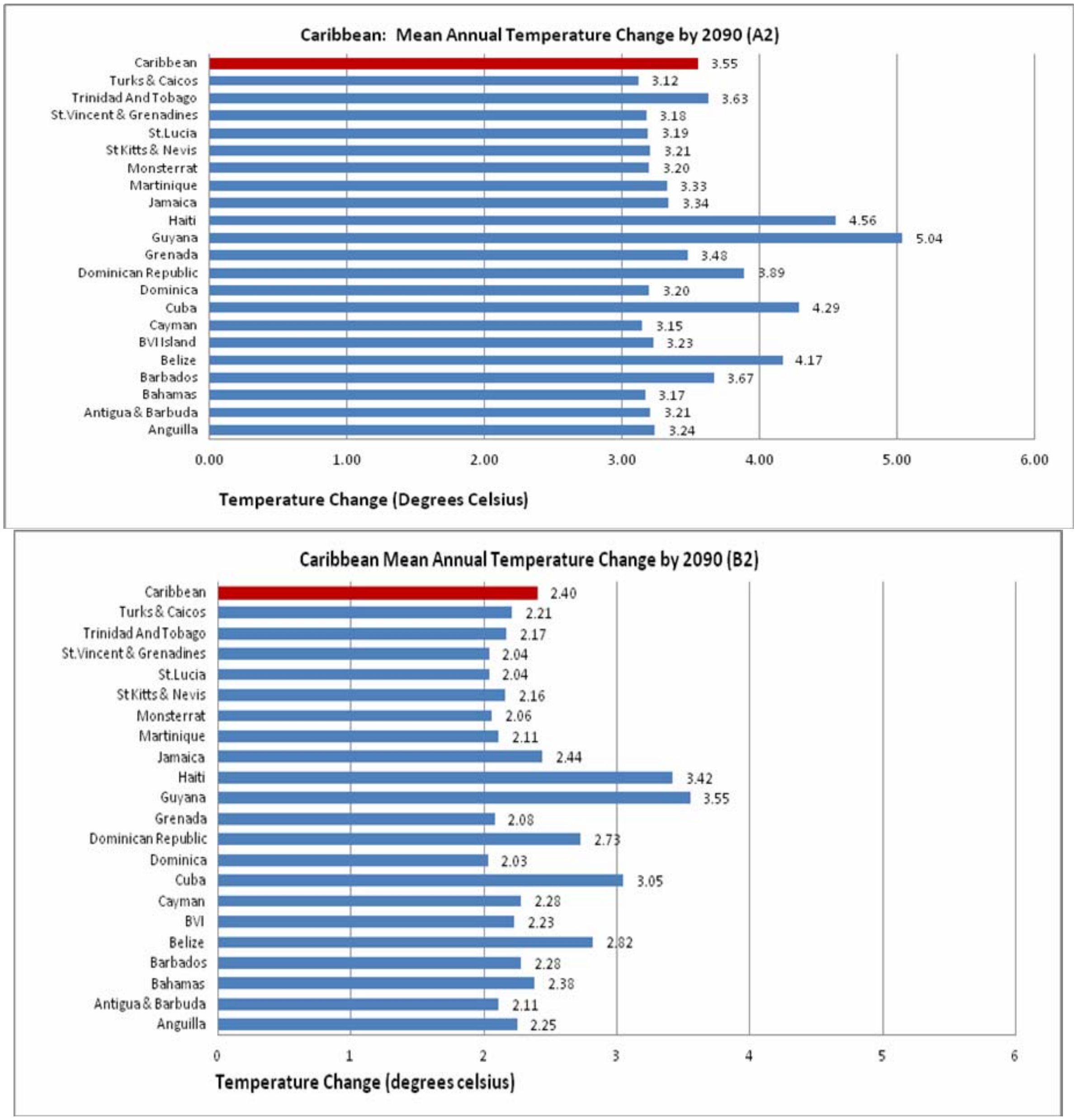
Note: Selected Caribbean countries: ECLAC Member States monitored by the Subregional Headquarters in Port of Spain
Source: INSMET, Cuba

Under the B2 scenario, maximum annual temperatures are forecast to increase by an average of 1.27° C across the subregion by 2030, with a range of 1.04° C in Cayman Islands and 2.16° C in Guyana. By 2070, maximum temperatures would rise by 2.34° C on average; and by 2090, the maximum temperature change may rise by an average of as much as 4.76° C (Guyana), or 2.77° C across the subregion.

Figure 2.2 shows the relative changes in maximum temperature by 2090 under the A2 and B2 scenarios. Compared to the base period (1961-1990), the average maximum annual temperature for the subregion is projected to be at least one degree higher for the A2 scenario compared to the B2 scenario by 2090.

Visual plots of the variation over time of average annual temperatures using the average of the two models (ECHAM4 and HadCM3) show that there is little variation between the forecasts for A2 and B2 in the first half of the twenty-first century, but in the second half of the century temperatures under the A2 scenario increase at a faster rate than under the B2 scenario (see figure 2.3). By 2050, mean and maximum temperatures are forecast to increase by about 1.8° C on average, compared to the base period averages, irrespective of the scenario; but by 2090 mean annual temperature change can be as much as 3.55° C under the A2 scenario or 2.40° C under the B2 scenario. Maximum temperature change will range somewhere between 2.77° C and 3.72° C depending on the scenario, by 2090.

Figure 2.1: Caribbean mean temperature change by 2090 under the A2 and B2 scenarios compared to the base period average (1961-1990)



Source: INSMET, Cuba

Figure 2.4 shows the pattern of change of the annual temperature for the period 2071-2099, according to emissions scenarios A2 and B2. In this figure, a substantial heating on the whole Caribbean subregion can be appreciated, with major temperature increases in terrestrial areas.

Table 2.2-Caribbean maximum temperature change under the A2 and B2 Scenarios (2030-2090)

Country	2030		2050		2070		2090	
	A2	B2	A2	B2	A2	B2	A2	B2
Anguilla	1.03	1.07	1.59	1.57	2.53	2.31	3.20	2.92
Antigua and Barbuda	1.03	1.13	1.59	1.65	2.51	2.09	3.21	2.44
Bahamas (the)	1.12	1.23	1.53	1.75	2.35	2.02	3.12	2.38
Barbados	1.17	1.21	1.86	1.93	3.05	2.35	4.01	2.84
Belize	1.60	1.67	2.38	2.39	3.7	3.08	5.01	3.58
British Virgin Islands	1.02	1.15	1.57	1.66	2.51	2.12	3.19	2.48
Cayman Islands	0.98	1.04	1.56	1.60	2.45	1.99	3.18	2.39
Cuba	1.48	1.51	2.02	2.10	3.36	2.62	4.23	2.93
Dominica	1.05	1.12	1.64	1.65	2.6	2.11	3.32	2.46
Dominican Republic	1.52	1.34	1.81	2.13	3.45	2.67	4.51	3.07
Grenada	1.15	1.21	1.83	1.83	2.89	2.3	3.71	2.65
Guyana	1.85	2.16	2.73	3.16	4.47	3.74	6.34	4.76
Haiti	1.37	1.35	2.01	2.05	3.35	2.72	4.38	3.18
Jamaica	1.03	1.13	1.66	1.75	2.57	2.15	3.30	2.56
Martinique	1.09	1.15	1.72	1.84	2.72	2.16	3.51	2.56
Montserrat	1.04	1.12	1.60	1.65	2.56	2.10	3.26	2.45
Saint Kitts and Nevis	1.02	1.13	1.58	1.65	2.5	2.09	3.18	2.44
Saint Lucia	1.05	1.09	1.63	1.62	2.59	2.06	3.27	2.43
Saint Vincent and the Grenadines	1.04	1.07	1.63	1.61	2.57	2.05	3.24	2.41
Trinidad and Tobago	1.57	1.73	2.27	2.53	3.01	2.43	3.85	2.81
Turks and Caicos Islands	0.95	1.09	1.49	1.61	2.33	2.04	3.09	2.38
Caribbean	**1.20**	**1.27**	**1.80**	**1.89**	**2.86**	**2.34**	**3.72**	**2.77**

Source: INSMET, Cuba

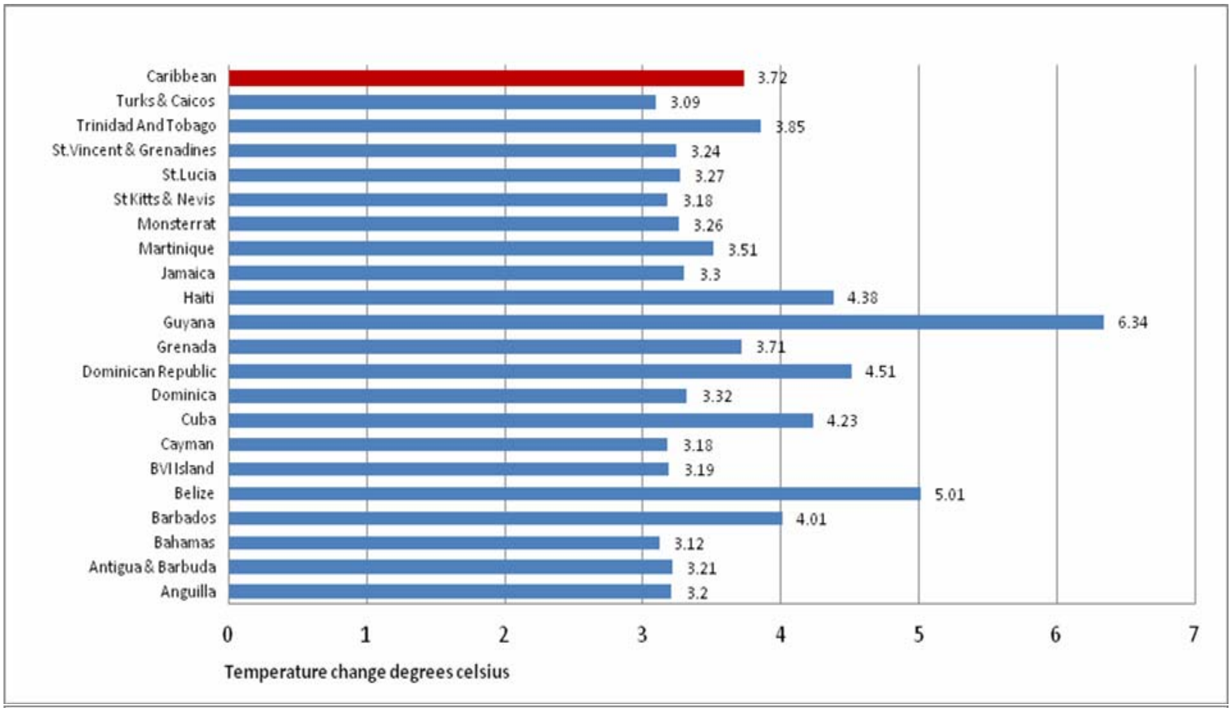
(3) Precipitation

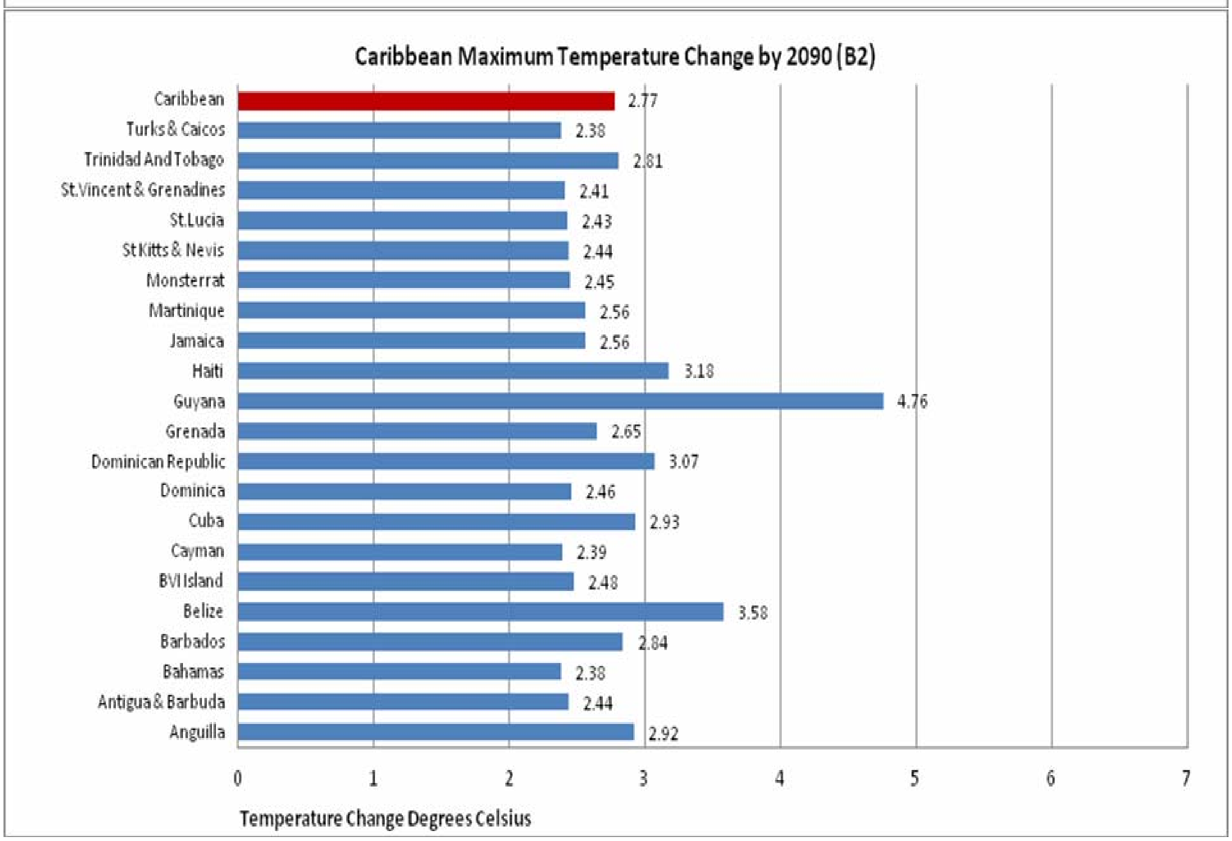
The projections for mean annual precipitation change are calculated on the basis of the mean of the ECHAM4 and HadCM3 model projections (see table 2.3). Under the A2 scenario, by 2030, increases in some countries of 7.76% (Haiti) and declines of as much as 12.59% in others are predicted, with a mean precipitation decline of 3.05% across the subregion; and by 2090, the mean precipitation change is forecast to decline in most countries, with the subregion projected to experience an overall drastic decline in rainfall of about 25.33% on average by 2090.

Meanwhile, under the B2 scenario, the following potential changes in the mean annual precipitation are expected relative to the base period averages: by 2030, mean precipitation changes of between -22.93% and 18.60% depending on the country, with a 3.69% decrease on average for the subregion; and by 2090, the mean precipitation change would be between -71.57% and 85.47%, with an average decline of 14.05% for the subregion.

A visual plot of the subregional average trend in precipitation patterns shows that the Caribbean is projected to experience progressive declines in the total annual rainfall under both scenarios, with the A2 scenario predicting a more precipitous decline than the B2 scenario after 2060. Under the A2 scenario, by 2090 the subregion will experience an average of approximately 25% less rainfall for the year, while under the B2 scenario the subregion can expect a 14 % average reduction in total annual rainfall (see figure 2.5).

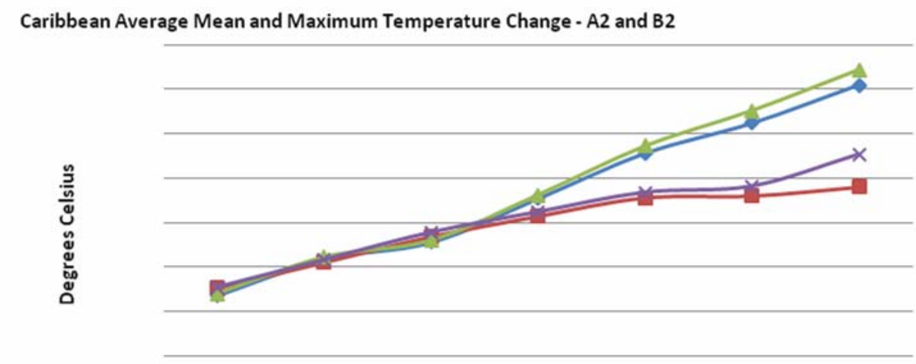
Figure 2.2: Caribbean maximum temperature change by 2090, A2 and B2 compared





Source: INSMET, Cuba

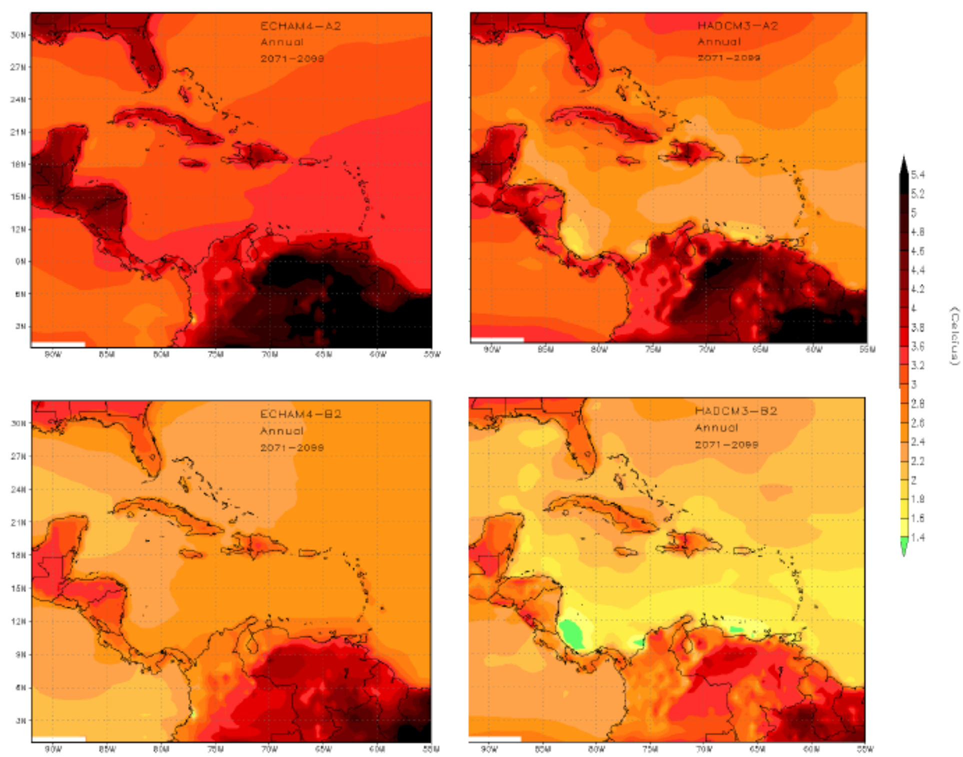
Figure 2.3: Caribbean: Mean and maximum annual temperature under the A2 and B2 scenarios (2030-2090)



	2030	2040	2050	2060	2070	2080	2090
Mean Annual Temperature Change A2	1.18	1.59	1.78	2.27	2.78	3.12	3.55
Mean Annual Temperature Change B2	1.26	1.55	1.84	2.07	2.28	2.30	2.40
Max Annual Temperature Change A2	1.20	1.61	1.80	2.31	2.86	3.26	3.72
Max Annual Temperature Change B2	1.27	1.58	1.89	2.12	2.34	2.41	2.77

Source: INSMET, Cuba

Figure 2.4 Patterns of change of the annual average of temperature for the period 2071-2099 relative to 1961-1989



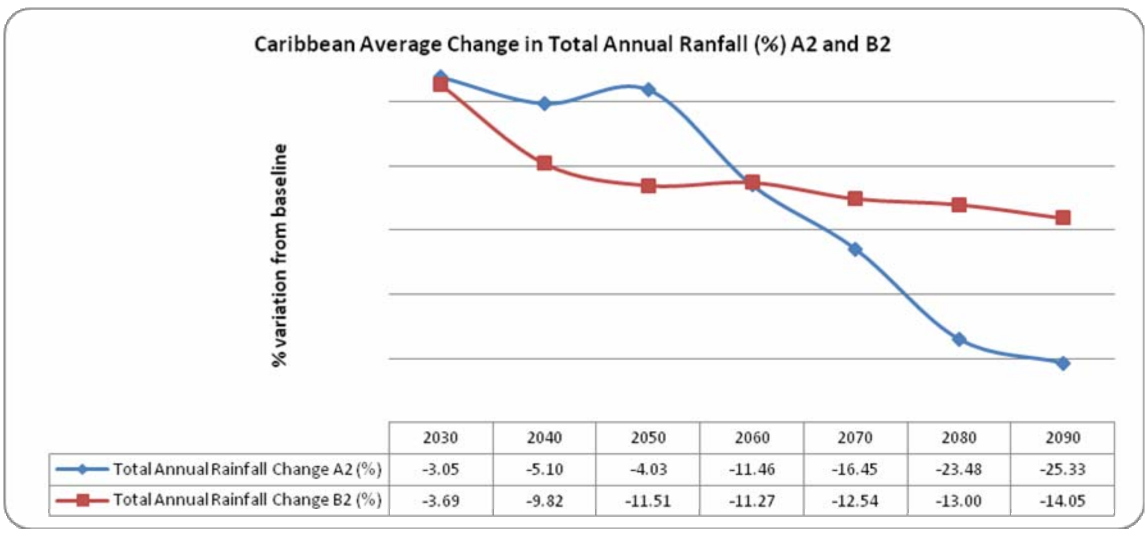
Source: Centella, 2010

Table 2.3: Caribbean annual mean precipitation change under the A2 and B2 scenarios (2030 to 2090)

Country	2030		2050		2070		2090	
	A2	B2	A2	B2	A2	B2	A2	B2
Anguilla	4.31	8.23	-0.18	3.97	-3.73	7.6	-2.16	4.82
Antigua and Barbuda	0.41	-5.56	-3.47	-16.29	-15.31	-16.96	-17.39	-22.97
Bahamas (the)	-10.07	-8.63	-9.8	-12.41	-12.47	-7.79	-15.19	-0.65
Barbados	-4.03	-7.33	-4.15	-24.07	-19.86	-19.64	-36.03	-28.05
Belize	-12.59	-10.46	-13.36	-5.5	-18.9	-18.03	-35.79	-14.27
British Virgin Islands	2.75	7.85	1.74	1.16	-5.91	3.63	-5.08	1.5
Cayman Islands	-11.14	-8.88	-18.1	-14.62	-29.06	-25.15	-38.3	-24.63
Cuba	-8.28	-0.59	-3.18	-4.25	-7.43	-6.26	-4.72	6.67
Dominica	-1.4	-15.92	-15.59	-42.92	-29.01	-65.3	-51.8	-71.57
Dominican Republic	-3.83	12.56	10.18	5.74	-19.19	-13.38	-19.19	-4.74
Grenada	-5.14	-10.77	-3.77	-23.71	-17.97	-22.36	-36.35	-28.07
Guyana	3.14	-1.11	11.59	-7.3	-11.74	9.89	-27.51	-6.31
Haiti	7.67	18.6	23.34	24.38	13.87	64.46	3.77	85.47
Jamaica	-6.01	-10.32	-16.99	-20.85	-26.46	-32.21	-30.77	-26.56
Martinique	1.7	-4.86	0.55	-14.14	-11.24	-16.41	-23.77	-24.05
Montserrat	-5.85	-15.28	-12.8	-32.07	-27.22	-38.91	-35.6	-47.32
Saint Kitts and Nevis	0.61	1.22	-4.28	-6.52	-10.88	-5.84	-13.83	-10.73
Saint Lucia	-9.85	-22.93	-19.04	-38.83	-32.48	-58.42	-52.72	-66.97
Saint Vincent and the Grenadines	-2.98	12.82	-5.26	13.17	-24.52	25.35	-34.17	18.73
Trinidad and Tobago	4.64	-15.03	12.24	-16.49	-16.7	-23.59	-38.3	-31.2
Turks and Caicos Islands	-8.06	-1.12	-14.3	-10.26	-19.14	-4.1	-17.08	-4.05
Caribbean	**-3.05**	**-3.69**	**-4.03**	**-11.51**	**-16.45**	**-12.54**	**-25.33**	**-14.05**

Source: INSMET, Cuba

Figure 2.5: Caribbean: Total annual rainfall variation SRES A2 and B2, 1960-2100 (%)



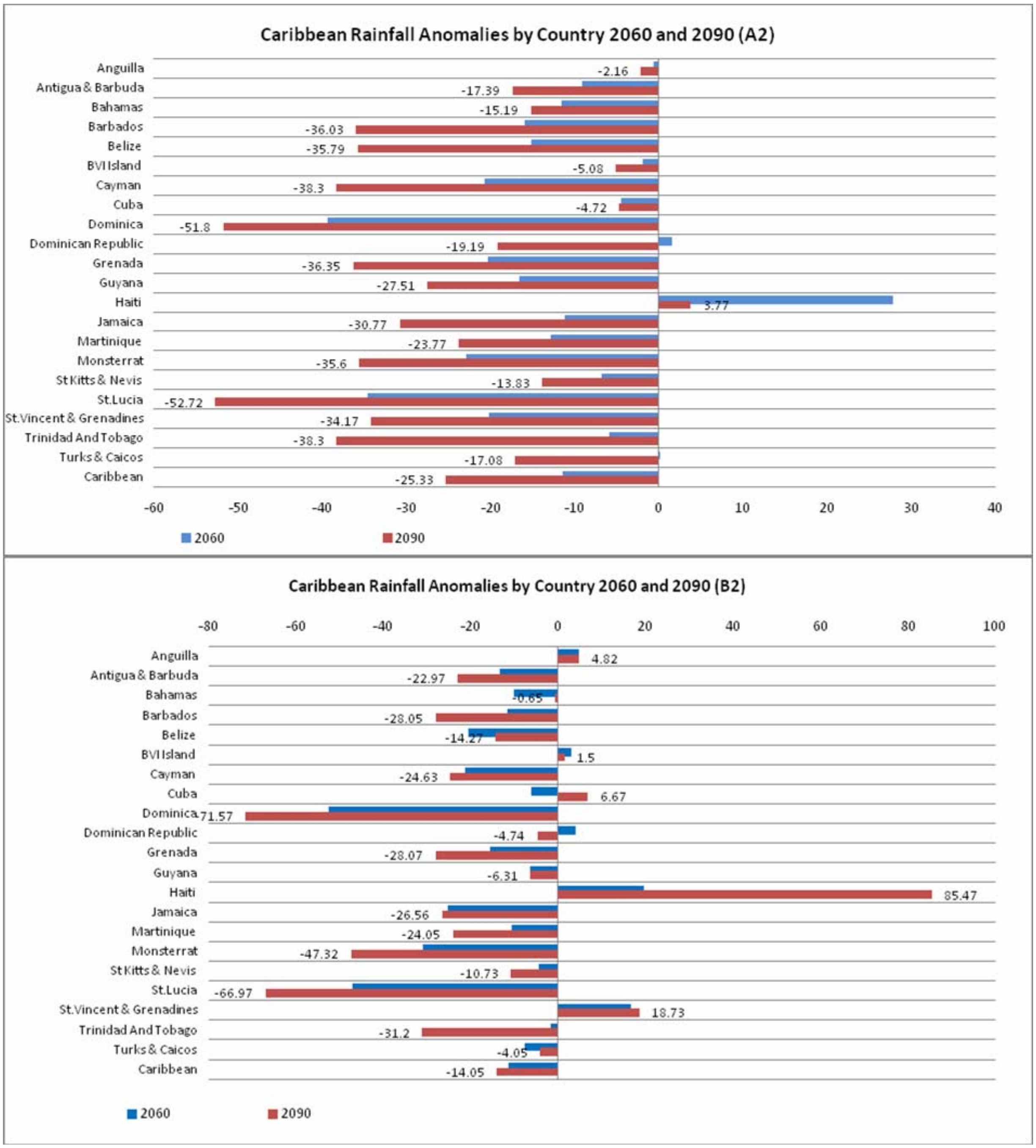
Source: INSMET, Cuba

It should be noted that the predictions for mean monthly and annual precipitation for the Caribbean vary widely depending on which model is used (ECHAM4 or HadCM3), with the result that the forecasts for the next ninety years display a large variability that makes it difficult to identify long-term trends properly. Data for individual countries based on the respective models are presented in tables A2.2 and A2.3 in appendix A2. Figure 2.6 compares the percentage variation in mean annual rainfall, under the A2 and B2 scenarios, using the average of the predictions from the two models.

(4) SEA-LEVEL RISE

Continued growth of GHG emissions and associated global warming could well promote sea-level rise (SLR) of 1m-3m in the twenty-first century, with the possibility of a 5m increase if there is an unexpectedly rapid breakup of the Greenland and West Antarctic ice sheets (Dasgupta and others, 2007). In the RECCC studies, an estimated SLR of 2m corresponds to the A2 scenario and a SLR of 1m corresponds to the B2 scenario.

Figure 2.6: Caribbean: Rainfall anomalies 2060 and 2090: A2 and B2 compared (%)



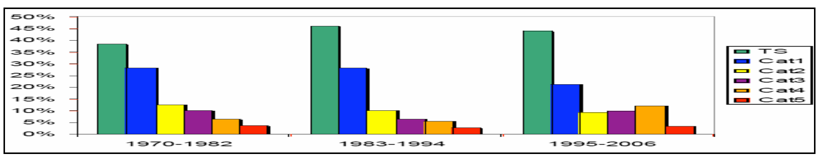
Source: INSMET, Cuba

(5) EXTREME WEATHER EVENTS

Climate change related disasters such as storms, hurricanes, floods, and droughts have devastating effects on Caribbean SIDS, impacting negatively on the ecological, economic and social infrastructure, sparing no sector from their direct or indirect impact. Historical data indicate that, since 1995, there has been an increase in the intensity and distribution of hurricanes in the Caribbean (see figure 2.7). The number of Category 4 and 5 hurricanes in the North Atlantic have also increased from 16 in the period of 1975-1989 or 1.1 per year, to 25 in the period of 1990-2004 or 1.6 per year, a rise of 56% (Webster and others, 2005). There was only one outlier year in the early twentieth century when the average speed for storms was 130 mph due to a storm with winds of more than 150 mph passing through the subregion. It is likely that some increase in tropical cyclone intensity will occur if the climate continues to warm.

Another phenomenon that may be linked to changes in climate is the El Nino Southern Oscillation (ENSO) which has been responsible for inter-annual variability in the climate of the southern Caribbean. ENSO influences sea surface temperatures in the Atlantic and the Caribbean, with El Niño episodes bringing warmer and drier than average conditions during the late wet season, and La Niña episodes bringing colder and wetter conditions at this time.

Figure 2.7: Intensity distribution of North Atlantic tropical cyclones 1970 – 2006



Source: Dellarue, Howard, 2009. Climate Change and Disaster Risk Reduction in Caribbean Small Island Developing States 45 ISOCARP Congress 2009[7]

Based on a range of models, IPCC suggests that future hurricanes of the north tropical Atlantic are likely to become more intense, with larger peak wind speeds and heavier near storm precipitation. It is projected that there will be an increase in the frequency of hurricanes in Categories 3 to 5, and also it is most likely that a tropical storm will develop into a Category 5 hurricane within a very short time span, such as within 24 hours.

(6) GREENHOUSE GAS EMISSIONS

Data for carbon dioxide (CO_2) emissions for selected Caribbean countries (see tables 2.4 and 2.5) show that Trinidad and Tobago is the largest per capita contributor irrespective of the indicator used (tonnes of CO_2 per person or total CO_2 emissions per year).

In terms of the relative contribution to global GHG emissions, the average per capita emissions for the Caribbean in 2001 exceeded that of both South and Central America, but a look at the emissions for individual countries suggests that emissions are much lower than either world or Organization for Economic Cooperation and Development (OECD) averages. With emissions levels as high as some of the most developed economies, Trinidad and Tobago stands out as an anomaly among its Caribbean counterparts (see figure 2.8).

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[7] Dellarue, Howard, 2009. "Climate Change and Disaster Risk Reduction in Caribbean Small Island Developing States." ISOCARP Congress 2009, in ECLAC (2010). *Caribbean Regional Report for the five-year Review of the Mauritius Strategy for the further implementation of the Barbados Programme of Action for the sustainable development of small island developing States* (msi+5). Online at: http://www.sidsnet.org/msi_5/docs/regional/caribbean/Caribbean_Regional_ Synthesis-MSI5-Final.pdf.

Table 2.4: Caribbean: Total carbon dioxide (CO_2) emissions (Thousands of tonnes of CO_2)

Country	1990	1995	2000	2005	2007
Antigua and Barbuda	301.0	323.0	345.0	411.0	436.0
Bahamas	1 951.0	1 731.0	1 797.0	2 109.0	2 149.0
Barbados	1 074.0	829.0	1 188.0	1 316.0	1 346.0
Belize	312.0	378.0	689.0	396.0	425.0
Dominica	59.0	81.0	103.0	114.0	121.0
Grenada	121.0	172.0	205.0	235.0	242.0
Guyana	1 140.0	1 481.0	1 580.0	1 492.0	1 507.0
Haiti	994.0	942.0	1 368.0	2 076.0	2 398.0
Jamaica	7 965.0	9 703.0	10 319.0	10 165.0	13 964.0
Dominican Republic	9 571.0	16 105.0	20 117.0	19 893.0	20 759.0
Saint Kitts and Nevis	66.0	95.0	103.0	235.0	249.0
Saint Vincent and the Grenadines	81.0	132.0	158.0	198.0	202.0
Saint Lucia	165.0	312.0	330.0	367.0	381.0
Suriname	1 811.0	2 182.0	2 127.0	2 380.0	2 439.0
Trinidad and Tobago	16 960.0	20 968.0	24 514.0	30 949.0	37 037.0

Source: ECLAC – CEPALSTAT, ENVIRONMENTAL STATISTICS AND INDICATORS, GHG, Carbon dioxide (CO_2) emissions (Total)

Table 2.5: Caribbean: Per capita carbon dioxide (CO2) emissions (Tonnes per person)

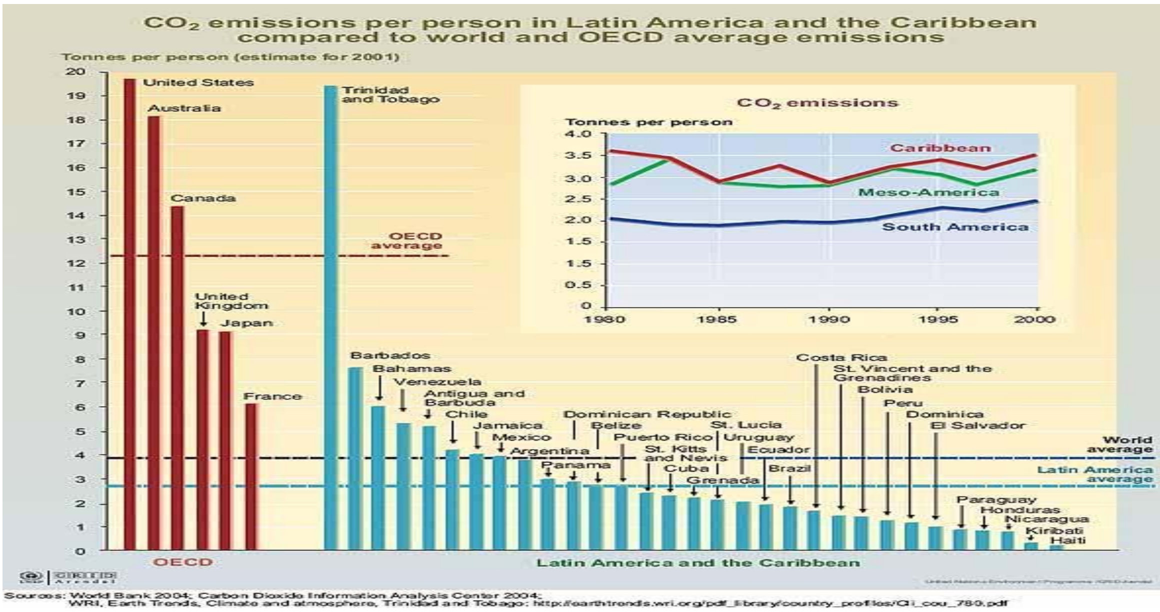
Country	1990	1995	2000	2005	2007
Antigua and Barbuda	4.9	4.8	4.5	4.9	5.1
Bahamas (the)	7.6	6.2	5.9	6.5	6.4
Barbados	4.1	3.2	4.7	5.2	5.3
Belize	1.6	1.7	2.7	1.4	1.4
Dominica	0.9	1.2	1.5	1.7	1.8
Grenada	1.3	1.7	2.0	2.3	2.3
Guyana	1.5	2.0	2.1	2.0	2.0
Haiti	0.1	0.1	0.2	0.2	0.2
Jamaica	3.4	3.9	4.0	3.8	5.2
Dominican Republic	1.3	2.0	2.4	2.2	2.2
Saint Kitts and Nevis	1.6	2.2	2.2	4.8	5.0
Saint Vincent and the Grenadines	0.8	1.2	1.5	1.8	1.9
Saint Lucia	1.2	2.1	2.1	2.2	2.3
Suriname	4.4	5.0	4.6	4.8	4.8
Trinidad and Tobago	13.9	16.6	18.9	23.5	27.9

Source: ECLAC – CEPALSTAT, ENVIRONMENTAL STATISTICS AND INDICATORS, GHG, Carbon dioxide (CO_2) emissions (per capita)

Mitigation strategies aim to reduce the rate and magnitude of climate change, by reducing the human contribution to GHG emission. Conversely, adaptation refers to actions taken to adjust natural or human systems in response to actual or expected effects of climate change, which moderate, harm or exploit beneficial opportunities.

GHG emissions may be significantly decreased through the use of renewable energy (RE) technologies. Many Caribbean countries are indeed seeking to increase the sources of renewable energy in the overall energy mix thereby making a contribution to the reduction of GHG levels, which can significantly contribute to reducing the overall vulnerability of its international transport infrastructure to climate change. In Barbados, for example, the Government has committed to having renewable energy account for 30% of the island's primary electricity by 2012. Bagasse and solar water heaters contribute 15% of the island's primary energy supply. The proposed new sources of renewable energy include the following: wind energy and fuel cane, compressed natural gas (CNG), energy efficiency and renewable energy standards, introduction of gasohol based on a 10% ethanol-to-gasoline mix, further investment in ethanol production, increasing to 10% the biodiesel content for all diesel-fuelled vehicles by 2025 and providing incentives to the private sector for the development of the biodiesel industry.

Figure 2.8: CO_2 emissions per person in Latin America and the Caribbean compared to the world and OECD average emissions. (2005).



Source: UNEP/GRID-Arendal Maps and Graphics Library. Retrieved 03:36, July 19, 2011 from http://maps.grida.no/go/graphic/co2-emissions-per-person-in-latin-america-and-the-caribbean-compared-to-the-world-and-oecd-average-emissions.

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CHAPTER III.
THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE AGRICULTURAL SECTOR

A. AGRICULTURE AND CLIMATE CHANGE

With nearly half (2.5 billion) of the economically active population in developing countries relying on agriculture for their livelihoods, the effects of climate change are likely to threaten both the welfare of populations and the economic advancement of these economies (Nelson and others, 2009).

The impact of climate change on agriculture is deemed to be particularly serious, compared to other threats posed by variations in climate, due to the number of people that are likely to be affected and the severity of impacts on those least able to cope (OECD, 2010). The main drivers of agricultural responses to climate change are biophysical effects and socio-economic factors. Crop production is affected biophysically by meteorological variables, including rising temperatures, changing precipitation patterns, and increased atmospheric carbon dioxide (CO_2) levels, the availability of water resources and the anomalous presence of extreme events. Current research anticipates that biophysical effects of climate change on agricultural production will be positive in some agricultural systems and regions, and negative in others, and these effects will vary temporally. Socio-economic factors influence responses to changes in crop productivity, with price changes and shifts in comparative advantage.

Elevated levels of CO_2 are expected to have a positive impact on plant growth and yields, but these effects are likely to be eroded by other effects of climatic change, including increasing temperatures. These interactions are not very well understood in the literature, although it is known that the impacts are likely to vary by geographic region and crop type. Rising temperatures, for example, are expected to result in reduced yield and proliferation of weeds, pests and diseases; and changes in precipitation patterns are likely to increase the likelihood of short-run crop failures and long-run production declines (Nelson and others, 2009). Although there will be gains in some commodities in some regions of the world, the overall impact is expected to be negative (Mendelssohn and Dinar, 1999).[8]

Additionally, the increased intensity of extreme events such as floods, droughts, heat waves and windstorms are likely to lead to even greater production losses than those due to increased temperatures, with consequent implications for GDP. Thermal stress due to sudden changes in temperature extremes and the occurrence of droughts may also result in large scale losses of cattle and other livestock due to increased mortality and decreased reproduction rates. Wet vegetation promotes the proliferation of bacteria, while prolonged dry spells in other geographic regions encourage insect- borne diseases (OECD, 2010). Consequently, climate change is regarded as a major threat to food security (Mendelssohn and Dinar, 1999). Table 3.1 provides a summary of key potential climate change impacts on the agricultural sector.

Agriculture is also a significant source of anthropogenic greenhouse gas (GHG) emissions, accounting for 14 % of global emissions, but the sector also has the potential for mitigation (FAO, 2009).[9]

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[8] Agronomic simulation models predict that higher temperatures will reduce grain yield as the cool wheat-growing areas get warmer (Mendelssohn and Dinar, 1999).

[9] Methane, mainly from rice cultivation and manure handling, and nitrous oxide from a range of soil- and land-management practices, account for the largest proportion of anthropogenic greenhouse gases from agriculture.

Land use planning and management practices, reforestation, irrigation, N-fertilization all have the potential to reduce carbon stocks (OECD, 2010)

Table 3.1: Climate change and related factors relevant to global agricultural production

Climate and related physical factors	Expected direction of change	Potential impact on agricultural production
Atmospheric CO_2	Increase	Increased biomass potential and increased potential efficiency of physiological water use in crops and weeds Modified hydrological balance in the soils due to C/N ratio modification Changed weed ecology with potential for increased weed competition with crops
		Agro-ecosystems modifications
		N-cycle modification with greater elevations resulting from livestock farming
		Lower than expected yield in some plant species and more vigorous growth in others
Atmospheric O_3	Increase	Crop yield decrease; less than robustness in livestock development
Sea level	Increase	Sea level intrusion in coastal agricultural areas and salinization of water supply
Extreme events	Poorly known but significant increased temporal and spatial variability expected increased frequency of floods and droughts	Crop failure and increase mortality rate in livestock Yield decrease in both crop and livestock Competition for water Destruction of livestock dwellings predispose animals to harsh conditions Greater incidences of forest fires due to drought conditions
Precipitation intensity	Intensified hydrological cycle, but with regional variations	Changed patterns of erosion and accretion Changed storm impacts Changed occurrence of storm flooding and storm damage Increased water logging Increased pest damage
Temperature	Increase	Modification in crop suitability and productivity; stunted growth in animals Changes in weeds, pests and diseases that affect plants and livestock Changes in water requirements Changes in crop quality crop quality and animal health
	Differences in day-night temperatures	Modification in productivity and quality of agricultural products Modified ecosystems, flora and fauna
Heat stress	Increase in heat waves	Damage to grain formulation, increase in some pests, droopiness in animals

Source: Adaptation from Iglesias and others (2009) Impacts of climate change in agriculture in Europe. PESETA-Agriculture study. European Commission, Joint Research Centre. http://ftp.jrc.es/EURdoc/JRC55386.pdf

It is widely argued that competition between crops for food and fuel could exacerbate the socio-economic challenges posed by climate change to agricultural production (as evidenced, for example, by current rising food prices), but renewable energy sources (including biofuels) could help mitigate climate change and offer new markets for agricultural producers, thus offering both food and fuel security (OECD, 2010).

These effects are, however, characterized by various uncertainties, including the rate and magnitude of climate change itself, the biological response of agricultural output, and the economic and social response to projected or realized impacts. The use of the IPCC scenarios for decision-making is particularly useful in attending to these uncertainties.

B. Implications for the Caribbean

The contribution of primary agriculture to Caribbean GDP is 10 % on average, but the importance of the sector varies widely across the subregion, from 32 % in Guyana to as low as 2 % in Trinidad and Tobago (FAO, 2007). The sector is a significant export earner and means of livelihood in several countries, accounting for 30 % of employment, particularly in rural areas (see table 3.2). Farmers now make up the traditional small subsistence farming population which typifies Caribbean agriculture, and which uses traditional farming methods, typically labour intensive, rain-fed systems.

Table 3.2: Share of agricultural employment in total employment (2000)

Country	Agricultural employment ('000)	Share in total employment (%)
Antigua and Barbuda	8	25
Bahamas (the)	6	3.8
Barbados	6	4.1
Belize	25	30.1
Dominica	8	22.9
Dominican Republic	603	16.7
Grenada	9	24.3
Guyana	56	17.6
Haiti	2 156	62.3
Jamaica	264	20.6
Saint Kitts and Nevis	4	21.1
Saint Lucia	15	23.4
St. Vincent and the Grenadines	12	24
Suriname	30	18.9
Trinidad and Tobago	50	8.7

Source: FAO 2007, Table 1.6

Caribbean agriculture may be broadly described under two categories: domestic and export agriculture, although, in recent times, there has been a trend towards domestic agricultural produce finding a place in niche export markets.

1. Domestic agriculture

Domestic agriculture consists primarily of livestock, vegetables, spices and non-traditional export crops. This type of agriculture is the characteristic occupation of the subregion's small subsistence farmers who occupy less than two hectares of land on average, scattered on hilly terrains with little or no access to proper roads, irrigation systems and other basic amenities for farming.

The livestock subsector is usually classified under domestic agriculture due to its significant role in the subregion's food security requirements. It consists mainly of small livestock (sheep and goats), piggery, poultry (layers and broilers) and cattle (beef and dairy).[10] The current mode of operation for livestock production in the Caribbean is generally not amenable to coping with extreme weather conditions. Major retrofitting and upgraded technologies will be needed as part of any adaptation strategy used to mitigate climate change effects of the entire livestock subsector of the Caribbean.

The major crops grown for domestic consumption include fruits and vegetables, root crops/tubers (potatoes, cassava, yam, taro, and sweet potatoes), cereals (corn, sorghum and millet), groundnuts and pulses and condiments (nutmeg, cinnamon, escallion). Many of the short-term crops (corn, pigeon peas, sweet potatoes and vegetables) are seasonal, and any significant shifts in climatic conditions such as increased temperatures, more frequent or more intense droughts, and any changes in mean rainfall, could have adverse effects on food production and supply. This type of farming is particularly vulnerable to drought, pests and diseases.

[10] The livestock sector is essential in the Caribbean agricultural mix, but is not addressed in the present paper due mainly to data limitations.

2. Export agriculture

Export agriculture in the Caribbean consists of traditional crops including bananas, sugarcane, coffee, citrus, cocoa[11] and rice. Historically, banana and sugarcane have been the major agricultural exports and have benefitted from specialized market conditions, which have generally been removed within the last decade. Many of these economies are monocrop exporters, serving one major market, which results in a high degree of vulnerability. The European Union and the United States of America markets alone account for more than two-thirds of Caribbean agricultural exports, with less than 15 % of exports going to 'other' destinations (see table 3.3). Within the Caribbean subregion, the Organisation of Eastern Caribbean States (OECS) is probably more vulnerable to climate change than other CARICOM Member States, due primarily to their disproportional dependence on agriculture.[12] Table 3.3 provides a summary of major agricultural exports from the Caribbean subregion and the key markets that they supply.

Table 3.3: Summary of Caribbean agricultural exports by country

Country	Top agricultural export	Share in total agricultural exports (average 2001-2003)	Percentage of production exported (average 2001-2003)	Percentage shipped to main market (2002)	Main market
Antigua and Barbuda	Beverages (dist alcoholic)	31.3	-	76	CARICOM
Bahamas (the)	Beverages (dist alcoholic)	55.4	-	89	EU
Barbados	Sugar (centrifugal, raw)	31.7	92.5	99	EU
Belize	Orange juice (concentrate)	28.3	75.5	99	CARICOM
Dominica	Banana and plantains	63.1	75.9	82	EU
Dominican Republic	Cigars (cheroots)	40.6	-	66	USA
Grenada	Nutmeg, Mace, other spices	57.4	89.4	75	EU
Guyana	Sugar (centrifugal, raw)	41.3	94.2	62	EU
Haiti	Mangoes	25.7	3.2	96	USA
Jamaica	Sugar (centrifugal, raw)	26.6	80.5	10	EU
Saint Kitts and Nevis	Sugar	83.8	39.6	99	EU
Saint Lucia	Bananas	68.2	38.5	97	EU
St. Vincent/Grenadines	Bananas	49.8	71.2	85	EU
Suriname	Rice, Husked	31.2	99.1	76	EU
Trinidad and Tobago	Beverages (Non-alcohol)	30.9	-	81	CARICOM

Source: FAO 2007, Table 1.4

In 2007, Caribbean agricultural exports exceeded US$ 3 billion, but since July 2008, the major commodity exporters of some CARICOM countries, namely, Belize, Guyana, Jamaica, Suriname and Trinidad and Tobago, have been subjected to the global deterioration in commodity prices. World commodity prices, driven by high energy prices, soared to unprecedented levels in July 2008 and then fell dramatically. Other commodity prices exhibited a similar pattern (CARICOM Secretariat, 2010).

Kendal and Petracco (2006) described export agriculture in recent years, even with preferential market access, as "a sputtering engine of economic growth", a sentiment which is echoed in the Jagdeo

[11] Due to data limitations, the impact of climate change on cocoa production for the subregion was not evaluated. However, it is important to note that, historically, cocoa was at the forefront of the agricultural sector. The sector probably realized its greatest setback when it was exposed to the ravages of several pests and diseases for decades, with little or no effective method of control. To date, the demise of the crop has been blamed primarily on the lack of effective labour force and other disincentives that render it unattractive to farmers. Despite such negative scenarios, the Caribbean continues to fetch premium prices for its cocoa on the world market.

[12] Organization of Economic States (OECS): Seven CARICOM States (Antigua and Barbuda, Dominica, Grenada, Montserrat, Saint Kitts and Nevis, Saint. Lucia and Saint Vincent and the Grenadines) constitute the OECS, while Anguilla and British Virgin Islands are associate members. These islands are organized on the basis of economic harmonization and integration, as well as promotion of legal rights and good governance.

Initiative (The Private Sector Commission of Guyana Ltd, 2007). The initiative has described the subregion's agricultural operations as being characterized by progressive decline over the years, a situation which has been exacerbated with the removal of specialized market access, especially of traditional agricultural exports. While there has been some variation in the performance of individual countries, in the Caribbean subregion in general, the ratio of agriculture export earnings to GDP fell from 9 % in 1980 to 3.5 % in 2004, reflecting the substantial contraction in export volume and prices.

3. Food security

Other major challenges affecting Caribbean agriculture include the increasing food import bill and the fact that the agricultural sector is neither providing for food security nor earning the foreign exchange to cover the Caribbean's growing food import bill. In a recent study, the Caribbean Food and Nutrition Institute (CFNI) indicated that food security in the subregion is compromised, not so much by lack of food availability as by inadequate access to foods and dietary patterns that have good nutritional content (CFNI, 2007). This situation is further compounded by rising food prices, especially since more nutritious food tends to be relatively expensive. During the period 2007 to 2009, rising food prices, compounded by the global economic crisis affected all countries (manifested in increasing unemployment, reduced income due to lower tourist arrivals and a falloff in remittances) and further increased the threats on food security, especially among the poor. According to the Regional Food and Nutrition Security Policy (CARICOM, 2010), the external economic challenges derived from increasing prices of imports and loss of export demand due to global recession have particularly exposed the Caribbean to the ravages of natural disasters. Such vulnerability is compounded by a number of structural constraints related simultaneously to size and distance that affect the economic performance of Caribbean agricultural sectors.

Taking rice as an example, the subregion's main producer is Guyana. However, in recent years, the scare on the world market, where major wheat and grain-producing countries cut back on their exports of those commodities, has challenged the Caribbean to take a new look at its ability to address its own food security. Included in their 'new agriculture' initiative, islands such as Jamaica and Trinidad and Tobago have now engaged in rice production on a larger scale.

However, transformation and development of the agricultural sector in the Caribbean needs to be addressed and, in this regard, a supportive regional policy framework is indeed important.[13] This transformation and development will need to be grounded in innovation, science and management that would enhance competitiveness in all segments of the value chain. Growth through market expansion, including domestic, regional and extra-regional will form the basis of a resilient sector that meets the development needs of the rural sector by improving livelihoods and renewing the economic vibrancy of communities.

C. Historical impact of extreme events on Caribbean agriculture

A key factor influencing the subregion's vulnerability to the impact of extreme weather events is the fragility of agriculture-based economies which are heavily dependent on their natural environment to sustain livelihoods. Large-scale losses are not unusual, as more than half of the countries in the subregion depend on one or two commodities for export revenues. In 2007, Hurricane Dean destroyed all of Jamaica's major export crops, and the food-growing areas of the southern part of the island suffered

[13] According to Kendall and Petracco (2006), the Caribbean clearly needs a transformation of the agricultural sector that must include the following: (1) Technological enhancements, both human and material; (2) Diversification into dynamic, high value and processed export products which account globally for more than 50% of agricultural exports; (3) The creation of a product mix that enhances the incomes and life chances of the rural poor; and (4) An export regime that continues to earn foreign exchange but pays much greater attention to issues of food security, production and the environment.

major dislocation; Haiti lost large portions of its banana, bean, and yam crops to high winds and salt water intrusion on its southern coast, and there was extensive damage to the agricultural sectors in Dominica and Saint Lucia.

Many countries have discontinued the production of bananas for export, partly due to frequent crop devastation from intense hurricanes (and partly due to loss of preferential access to European markets). Some countries ceased other agricultural operations due to diseconomies caused by severe weather conditions including extreme droughts, floods and storms as well as variations in temperature. In Guyana and Suriname, where most of the arable land is at sea level, sea walls are built for protection against flooding.

D. APPROACH TO ESTIMATING THE ECONOMIC IMPACT OF CLIMATE CHANGE

Assessments were conducted in Guyana, Jamaica, Trinidad and Tobago and Saint Lucia. Table 3.4 shows the countries studied, with the respective range of commodities investigated. The commodities included were selected primarily on the basis of their importance to the subregion's agricultural contribution to GDP. Collectively, these Caribbean States provide a fair representation of the Caribbean agricultural sector due to their socio-economic roles, vulnerabilities to climate change and general nature of operations.

Table 3.4: Countries studied and crops investigated

Countries	Commodities
Guyana	Sugarcane
	Rice
	Fish
Jamaica	Sugarcane
	Yam
	Escallion
St. Lucia	Banana
	Fish
	Other Crops
Trinidad and Tobago*	Root Crops
	Green Vegetables
	Fish

*The Trinidad and Tobago data reflect harvested produce in Trinidad only.
Source: ECLAC (2011): ECLAC (2011a): ECLAC (2011b): ECLAC (2011c)

The total impact of climate change on the agricultural sector was taken as the sum of impacts on major export and domestic crops, fisheries and forestry.[14] A production function approach was applied to

[14] The approach to estimating the potential impact of climate change on agriculture adopted by the RECCC studies was to focus on the impact of temperature and rainfall changes on dominant exports and domestic crops, because of their relative weight in terms of contribution to agricultural GDP. However, in addition to these impacts, other climate-related changes are likely to impact on agricultural activities. These other impacts, which are not considered, include: sea-level rise, which will affect the salinity of the underground water sources and increase the risk of extreme wave actions; rising sea surface temperatures, that will increase the risk of coral bleaching with attendant negative impacts on reef life with consequent impacts on fisheries; periods of intense rainfall and flooding, alternating with periods of severe drought, which may potentially destroy crops at various stages in the growth cycle. In addition, flooding increases the rate of soil erosion on the steep slopes cultivated by small farming communities. Drought increases the potential for losses due to fires and increases the rate of evaporation of soil moisture, decreases stream-flows, and causes increases in the breeding rate of pests, bacteria and viruses that are harmful to plants and animals.

model the impact of climate change on various types of crops, each in turn, over the baseline period under the assumption that production (yield) is a function of land, capital, and price of the output, as well as climate variables (specifically, temperature change and rainfall).

The historical relationships were then used to forecast production up to 2050 under the A2 and B2 scenarios, and the results were compared to a Business as Usual (BAU) case, which assumed no climate change. This approach was adopted for root crops, vegetables and export crops. A real price corresponding to the 2008 value was assumed for these commodities. The effects of tropical cyclones and hurricanes were considered separately and the impacts calculated in relation to the sector as a whole.

To achieve an estimate of the total impact of climate change on the agricultural sector, the impact on fish production, relative to 2005 catch, was added to the estimated impact for crops. The impact on fish production was estimated using data for temperature preference and population dynamics for commercial fish species, following Pauly (2010).[15] The potential catch in a given year (to 2050) was predicted on the basis of projected sea temperature from the Ocean-Atmosphere Coupled General Circulation Model (OACGCM), and global maps. It was assumed that losses to fisheries revenue would be 20% and 10% under the high (A2) and low (B2) emissions scenarios, respectively. Given recent trends in the real price of fish, it is assumed that the real price of fish will remain constant at the mean 2008 prices through to 2050.

E. RESULTS

1. Export agriculture

(a) Sugarcane

Projected temperature changes showed no significant impact on sugarcane yield in Guyana when annual data were used, but in the Jamaica case study, where monthly data were used, the research found that any deviation from the optimal temperature of 29° C had a negative impact on sugarcane yield. The results further suggested that sugarcane yield is more sensitive to changes in rainfall than temperature in this geographic region. For instance, in Guyana, a 5% increase in rainfall above the optimum level causes sugarcane production to decline by 8%. In Jamaica, sugarcane production is maximized during the growing season (April to July), when rainfall does not fall below the optimal level of about 190 mm per month, and when it is less than, or equal to, 196 mm per month during the ripening season (August to November). During the reaping season (December to March), the optimal rainfall requirement is least (102 mm per month on average). Yields under both emission scenarios are lower than those under the BAU from 2020 to 2050.

In Guyana, the sugarcane subsector is expected to realize early gains of US$ 48 million by 2020 under B2 at a 1% discount rate, but by 2050, the subsector is expected to experience cumulative losses of US$ 300 million (1% discount rate) under A2, which is around twice the amount of losses under B2. In Jamaica, forecasts show that sugarcane yield under both the A2 and B2 scenarios decline at first (during the decade of the 2020s) then increase steadily through to 2050. The difference in the direction of yield projections for the two countries can be explained in part by the use of slightly different methodological approaches (modelling techniques), but more so by the difference in rainfall and temperature predicted under the two scenarios for the two countries, based on their geospatial differences (see also Chapter II – Climate scenarios).

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[15] Pauly, Daniel (2010), "If you don't like overfishing, you sure won't like global warming" In Proceedings of the 62nd Gulf and Caribbean Fisheries Institute (GCFI). Volume 62. Conference on November 2-6, 2009, Cumana, Venezuela. GCFI, Fort Pierce, Fl. The baseline used was the 2005 commercial fish landings for Trinidad and Tobago, which was 15,899 tonnes. Real prices were fixed at the mean price in 2008, for both scenarios.

(b) Bananas

Banana production is more susceptible to the effects of tropical cyclones and high intensity hurricane events, than to absolute changes in temperature or rainfall. The results for Saint Lucia showed that a 1 % decrease in rainfall is expected to cause an approximate 0.27 % decrease in the growth of banana exports; while a 1 % increase in temperature is expected to result in a 5.1 % decrease in the growth of banana exports. Banana production is therefore doubly affected by projected declines in rainfall over time alongside projected increases in temperatures in the next four decades. By 2050, the value of cumulative yield losses (2008 dollars) for bananas is expected to be about US$ 61 million, regardless of the scenario.

(c) Rice

The results showed that there is an optimal temperature of 27.4° C for rice production in Guyana and that every 1.0° C increase above this optimum level reduces rice production by 6.7 %. In Guyana, mean temperatures are projected to rise by about 5 degrees above the baseline average under A2 (see also Chapter II on climate scenarios), and these high temperatures may be detrimental to rice production, with significant implications for rice exports and foreign exchange earnings. The research also revealed that the optimal rainfall for rice averages 1,700 mm per year and that a 6 % increase in rainfall above this level may reduce rice production by 4.8 %. Generally, the results showed that rainfall and air temperature uniquely explain about 9 % of the variations in rice production for Guyana.

By 2050, Guyana is expected to experience cumulative losses of US$ 1,577 million under the A2 scenario (1% discount rate), whereas gains are projected under the B2 scenario, where projected temperatures are not as high as under the A2 scenario, and drought conditions not as extreme.

2. Domestic agriculture

(a) Root crops[16]

The assessments showed that, on average, root crops are likely to be worse off overall from the expected fall-off in rainfall and the rising temperature. For Saint Lucia, where the average rainfall in the last decade was already below the optimal amount for root crops such as sweet potatoes and yams, it is expected that any further decrease in rainfall should have a negative effect on root crop production. By 2050, root crops are expected to lose between US$ 22.73 million and US$ 21.50 million under the A2 and B2 scenarios, respectively (in 2008 dollars).

In Jamaica, yellow yam is typically grown under conditions where farmers rely solely on rainfall as a source of water, and as such the precipitation impact was considered separately for planting (wet) and reaping (dry) seasons.[17] The model predicted moderate impacts and yield is expected to increase over the forecast horizon under both scenarios, but yield will grow at a lower rate than BAU. Overall, root crop production is expected to be better under the B2 scenario, relative to the A2 scenario, cumulatively for all decades up to 2050.

For Trinidad and Tobago, the mean monthly rainfall for the base period is estimated to be 166.5 mm (1995 to 2008) and mean annual rainfall is 1998 mm. This value exceeds the optimal rainfall range for

[16] Root crops remain the most formidable domestic crops of the Caribbean, comprising about 70 % of the subregion's domestic agriculture. The category root crops comprised yams, dasheen, cassava, tannia, sweet potato, eddoes and ginger. The study attempted to address the impact of climate change on this subsector collectively, using yellow yams as the focus of study.

[17] The results suggest that the optimal precipitation requirement for planting and reaping seasons are 192 mm and 101 mm per month respectively; and the optimum temperature is about 30° C.

cassava, yam and sweet potatoes, and is virtually at the upper end of the optimal range for dasheen, tannia and eddoes, thus any further increase in rainfall is expected to have a deleterious effect on root crop production as a whole. By 2050, the value of yield cumulative losses (2008$) for root crops is expected to be approximately US$ 248.8 million under the A2 scenario and approximately US$ 239.4 million under the B2 scenario.

(b) Vegetables[18]

In Saint Lucia, further decreases in rainfall are expected to have an adverse impact on vegetable crop yield. Additionally, the mean temperature for the base period (27° C) was found to be in excess of the optimal temperature range for tomatoes, though it was well within the ideal range for several other vegetable crops. For vegetable crops, for all decades, the yield values are lowest under the baseline, with A2 having the highest values of all decades, so that by 2050, expected gains of US$ 123.45 million under the A2 scenario and US$ 116.23 million under the B2 scenario, respectively, (2008$) are projected.

In Trinidad and Tobago, the average rainfall for the base period exceeded the optimal rainfall range for sweet pepper, hot pepper and melongene, while other crops such as tomatoes have a much higher tolerance for rainfall. Therefore, it was expected that any further decrease in rainfall should have a mixed effect on individual vegetable production. By 2050, the value of yield cumulative gains (2008$) for vegetables is expected to be approximately US$ 54.9 million under the A2 scenario and approximately US$ 49.1 million under the B2 scenario, at a 1 % discount rate.

For Jamaica, despite projected changes in temperature and precipitation, the model forecast increases in the yields of escallion up to 2050 at virtually the same rate for the A2 and B2 scenarios.

3. Fisheries

Due to the geographic location of the Caribbean, with its occupied space consisting predominantly of oceans, the fisheries sector is a key source of economic activity. As such, any change in climate that affects sea-level rise or sea temperatures could have far reaching implications for the subsector. In addressing the impact of climate change on the fisheries subsector, it was estimated that there would be a decrease in catch potential of 20% under A2 and 10% under B2 by 2050 relative to 2005 catch potentials, other things remaining constant. Such negative impacts are expected to result from increased intensity of rainfall and rising temperatures. It is forecast that, by 2050, the corresponding losses in fisheries revenue for Trinidad and Tobago under the A2 and B2 scenarios could be US$ 160.2 million and US$ 80.1 million, respectively, at a 1% discount rate. Similarly, for Saint Lucia, by 2050 under the A2 and B2 scenarios, losses in real terms were estimated to be US$ 23.18 million and US$ 11.81 million, respectively, at a 1% discount rate.

4. Impact of extreme events

Extreme events may lead to large scale losses across the agricultural sector. There is ongoing debate as to whether changes in the pattern of tropical cyclones are due to climate change or not. Nevertheless, there

[18] The category of vegetables was made up of 17 items: tomato, cabbage, cucumber, melongene, bodi, okra, lettuce, pumpkin, pak choi, water melon, sweet pepper, celery, cauliflower, chive (scallion), hot pepper, dasheen bush and sorrel. These data were all converted to thousands of kilograms, using conversion factors provided by the National Marketing and Development Company (NAMDEVCO) for cases where quantities were presented as bundles, singles or heads, as in the case of commodities such as lettuce.

is general consensus that the pattern of these events is changing over time, and while it is uncertain if there will be an increase in frequency over time, it is widely expected that there will be an increase in the intensity of these events (which has direct impacts associated with wind speed, rainfall intensity, rainfall duration, and the likelihood of flooding and the creation of waterlogged conditions).

Flooding: "A 100 year review (1887-1987) of destructive events from natural hazards in Jamaica reveals one disastrous flood event every four years." (WMORAIV Hurricane Committee, 1987). At this rate, Jamaica can expect 10 more 'disastrous floods' between now and 2050. The flood of 2001 was classified by the Agriculture Disaster Risk Management Plan (ADRM) as a major flood and the damage it caused was estimated to cost J$ 541 million (Spence, 2009), or 2% of agricultural GDP in that year. In the following year, 2002, heavy rains in the last week of May and the first week of June caused an estimated J$ 781 million, or 3% of agricultural GDP in that year.[19]

Hurricanes: While the scientific evidence for the link between climate change and the frequency of hurricanes is mixed, there is a growing consensus that the intensity of hurricanes will increase. According to the ADRM, since the 1850s some 43 major storms have affected Jamaica of which over 16 % were category 3 and stronger. Of the category 3 and stronger storms impacting Jamaica since 1851, 57 % occurred after the year 2000. Similarly, between 1955 and 2009, Saint Lucia was hit by eleven tropical cyclones, which resulted in significant losses in terms of deaths, injuries to persons, property damage and loss of crops, livestock and infrastructure. In general most of the losses in the agricultural sector tend to be due to damage of banana and tree crops.

5. Summary impacts

In general, the crops selected for study for each of the country case studies represent those crops that account for the greatest share of agricultural contribution to GDP. Table 3.5 shows the cumulative estimated losses (benefits). The general findings of the RECCC studies suggest that changing climatic conditions associated with temperature, precipitation and extreme events may be of major importance to the survival of Caribbean agriculture. Except for Guyana and Suriname, most Caribbean agriculture is carried out away from coastal plains, usually on hilly terrains and, as such, are not prone to salt water intrusion from sea-level rise. Flooding, hurricane, droughts and erosion are thus the major concerns.

Based on the analysis conducted, the impact on agricultural output for export crops and fisheries is significant; while the result for root crops and vegetables is mixed.

Saint Lucia: Relative to the baseline case, the key subsectors in agriculture are expected to have mixed impacts under the A2 and B2 scenarios. In aggregate, in every decade up to 2050, these subsectors combined are expected to experience a gain under climate change, all scenarios, with the highest gains under A2. By 2050, the cumulative gain under A2 is calculated as approximately US$ 144.20 million and approximately US$ 115.03 million under B2, which represent 17.9 % and 14.3 % of 2008 GDP, respectively.

Trinidad and Tobago: For root crops, fisheries and vegetables combined, the cumulative loss under A2 is calculated as approximately US$ 352.8 million and approximately US$ 270.8 million under B2 by 2050. This is equivalent to 1.37 % and 1.05 % of 2008 GDP under the A2 and B2 scenarios, respectively.

[19] See IDB-ECLAC, 2007, p.17, table 4.2

Guyana: The total cost due to climate change accrued over the next four decades is anticipated to cost the country about 1 to 2 times the value of 2008 GDP under A2, whereas under B2, the total cost should range between 1% (4% discount rate) and 53% of 2008 GDP (1% discount rate).

Table 3.5 summarizes the direct estimated impact on the agricultural sector for the countries and crops studied.

Table 3.5: Agricultural sector cumulative losses to 2050 (all commodities), 1% discount rate

	Trinidad and Tobago		Jamaica		Saint Lucia		Guyana	
	A2	B2	A2	B2	A2	B2	A2	B2
US$ million	352.8	270.8	n.a.	n.a.	-144.2	-115.0	1911.0	n.a.
% GDP	1.37	1.05	n.a.	n.a.	-17.9	-14.3	2.04	n.a.

Note: Negative values indicate gains under the relevant scenario for the country based on the crops studied and range of impacts studied. Source: ECLAC (2011): ECLAC (2011a): ECLAC (2011b): ECLAC (2011c)

In general, these percentages should be considered in the context that the true reflections (in terms of both direction and difference) of climate change under A2 and B2 are more obvious beyond the year 2050. Lower yields will have a direct negative effect on employment in the agricultural sector, as persons may be laid off as farmers' profits decline. This will have a negative multiplier on indirect employment in the sector, as well as supporting services such as marketing and distribution of produce. Overall, the livelihoods of farmers and their families will be affected, especially in the rural areas.

The implication of these results is primarily in terms of food security. Firstly, food must be available from either local or imported sources, in a form that is needed. Climate change threatens the availability of food from global sources, as the increased incidence of drought in key production areas may result in reductions in produce from export sources, since those countries may switch to focusing on meeting their own local demand, with exports given a lower priority.

F. Climate change adaptation strategies

According to IPCC, adaptation involves "initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects" (IPCC, 2007). Adaptation may be preventive or reactive; private or public; autonomous or planned. Autonomous adaptation represents the response of a farmer, for example, to changing precipitation patterns, through crop changes or using different harvest and planting/sowing dates.[20] Planned adaptation measures indicate conscious policy options or response strategies targeted towards altering the adaptive capacity of the agricultural sector. Farm level analyses have shown that large reductions in adverse impacts from climate change are possible when adaptation is fully implemented (Mendelsohn and Dinar, 1999).

The following ten major potential adaptation options were identified for the agricultural sector:

[20] The Agriculture Disaster Risk Management Plan (ADRM) for Jamaica noted that since the devastation caused by Hurricane Gilbert in 1988, there is evidence of enhanced resilience arising from greater awareness and preparedness especially at the community level. An indication of this is the practice adopted by fishermen of storing their boats and gear away from the beaches.

1. Use of water-saving irrigation systems and water management systems e.g. drip irrigation.
2. Mainstreaming climate change issues into agricultural management.
3. Repairing/maintaining existing dams.
4. Altering crop calendar for short-term crops.
5. Adopting improved technologies for soil conservation.
6. Establishing systems of food storage.
7. Promoting water conservation – install on-farm water harvesting off roof tops.
8. Designing and implementing holistic water management plans for all competing uses.
9. Building on-farm water storage (ponds, tanks etc)
10. Improving agricultural drainage.

Of these, the following are shortlisted as relevant to the entire subregion:

1. WATER MANAGEMENT

In many instances the studies identified water as being of paramount importance to the survival of agriculture, since farmers still depend largely on rain-fed systems. Several adaptation measures were examined which include the use of water-saving irrigation and water management systems e.g. drip irrigation; the building of on-farm water storage facilities to include new dams; promotion of water harvesting and conservation strategies; design and implementation of holistic water management plans for all competing uses; repair and maintenance of existing dams to minimize water loss and provide fiscal incentives for water conservation; effecting changes in water policies to reflect changing situations; and, building of new desalination plants to meet water demand deficits, and utilization of more ground water sources.

2. PROTECTED AGRICULTURE

Protected agriculture was highlighted as an approach to mitigate the incidence of adverse weather conditions, the eventual advancement of pest of diseases due the creation of favourable condition for their multiplication, and to increase productivity. Protective strategies should include installation of greenhouse facilities; amending cultural practices to reflect awareness of changing climatic conditions, e.g. increase use of mulches for crop production; introduction of wind breaks on farms; establishment of crop and livestock insurance schemes to reduce the risk-aversion of the farmer to the adoption of new technologies and new agricultural enterprises.

3. LAND DISTRIBUTION AND MANAGEMENT

Well-planned and implemented land distribution systems will ensure the allocation and preservation of the most suitable lands for agricultural production. Likewise, sustainable land management practices are critical to avoid soil erosion and loss of fertility. The main adaptation strategies recommended include allocating farms to lands with good agricultural capability; the adoption of improved technologies for soil conservation; implementation of land policy to preserve high quality agricultural lands; and the promotion of integrated watershed management.

4. Research and development

Research and development systems remain deficient in most Caribbean countries but must be improved considerably and should be accompanied by extension systems that are more responsive will allow for the flow of information to and from researchers to farmers and other agricultural producers. Sugar research in Jamaica provides a template which can be adopted for other commodities. Several measures have been examined, including: the establishment of germplasm banks of indigenous, drought-tolerant varieties, and the provision and distribution of planting material on a timely basis; investigations into altering the crop calendar for short-term crops; the development of ways of reducing non-indigenous species competition by controlling invasive species; and the establishment of research and development for adoption of cultural/ biological control measures.

5. Climate change issues streamlined into planning

It is recognized that climate change is a crosscutting issue and, as such, there are implications for existing and future agricultural programmes, the development of partnerships, and coordination of intersectoral efforts. Such measures include: mainstreaming climate change issues into agricultural management; agricultural diversification; introduction of more drought-resistant, tolerant species; establishment of wildfire eradication schemes at national/farm levels; and the preparation and adoption of disaster management plans for farmers and farming communities.

6. Climate sensitive farming systems

Changing the farming systems in the Caribbean would require investment in financial and human resources. Crucial interventions include the building of sea walls and other sea defence mechanisms; relocation of agricultural production to less sensitive locations; adjusting planting calendars and cycles to changing rainfall patterns; the development/introduction of salt tolerant/ resistant crop varieties, the adoption of more integrated and intensive livestock farming; the establishment of systems of food storage; improvement of irrigation and agricultural drainage systems; better design of livestock pens and facilities to allow for greater airflow and temperature management; and the establishment of early warning systems.

7. Increased awareness and communication

Increased awareness and communication will encourage producers to enhance the abilities of people to interpret changes in the local climate and enable them to build on their traditional knowledge, and to become more conscious of the traditional adaptation measures that had helped them formerly to cope with changes. Groups likely to be most severely impacted by climate change are the poor and vulnerable, particularly those in rural coastal and remote areas. Any threats that are identified must be communicated widely, along with opportunities, adaptive techniques and research findings.

The broader policy implications for agriculture include:

1. Diversification of agricultural exports, especially through the creation of niches, by redirecting the remaining traditional export agricultural firms towards organic production so as to take advantage of premier prices. Such a practice will synergise environmental preservation strategies and could attract the Carbon credit market, an additional potential source of income for the sector.

2. Expansion of non-traditional agricultural produce for export, especially of crops that are already being exported without preferential arrangements. Policy decisions should focus on eliminating various impediments such as inadequacies in extension services, human capital constraints, ineffective marketing, transportation difficulties, inadequate irrigation, skewed distribution of land resources, and the presence of trade barriers. Many non-traditional exports already have competitive advantages on international markets, the potentials of which should be explored further.

3. Incentives for environmentally friendly practices, through the institutionalization of national and subregional environmental programs for their promotion. Commitments from markets and other stakeholders to "buy in" to these initiatives would complement this strategy.

4. Increased focus on the use of indigenous material for the agricultural sector, to mitigate challenges with imported raw materials that are often impacted by climate change and environmental factors and pressure for competing uses.

5. Deliberate ongoing assessment of farming practices as a strategy to minimize vulnerability to climate change as well as research to identify varieties that are adaptable to changing environmental conditions.

6. Establish standards to formalize an insurance programme for agriculture, including the development and implementation of revised land reform programmes and distribution policies for agriculture; and manipulating production schedules and increasing warehousing to minimize the effects of adverse climatic conditions on food security.

G. CONCLUSION

Notwithstanding the seemingly small contribution of agriculture to GDP, the importance of the sector to the Caribbean cannot be underscored. Agriculture is the single mainstay of a considerable segment of the population of the subregion, proving employment for more than 30 % of the population. Not only is it a major pillar on which any attempt to address the subregion's food security issues may be grounded, but agriculture is also an essential spring board from which to launch any meaningful initiative to mitigate against climate change eventualities.

The extent to which climate change will impact agriculture, particularly within the Caribbean, remains arguable. Generally, the undertone provided by the reports suggests that only marginal changes are anticipated with respect to temperature and precipitation due to climate change, and that such change will have mixed impacts on agriculture by 2050. Among the commodities investigated, only fisheries and rice production appear to be very sensitive to even low changes in temperature and rainfall, and in the case of fisheries could realize up 20 % decline in yield.

The discussions advanced in the present report so far have focused almost entirely on temperature and precipitation as the important climate change eventualities of the Caribbean. However, it must be noted that there are other aspects of climate that are changing which are likely to impact agriculture in the subregion. Flooding that alternates with periodic drought as precipitation patterns change has far-reaching implications especially on small farm enterprises. Drought will increase the incidence of fires due to frequent slash and burn. Higher temperature will result in proliferation of pest and diseases, and sea-level rise may affect salinity of underground water sources.

Furthermore, the livestock sector, which consists mainly of small livestock (sheep and goat), piggery, poultry (layers and broilers) and cattle (beef and dairy), is highly essential in the subregion's agricultural mix, and further research is needed the better to prepare the subsector for climate change The current mode of operation for livestock production in the Caribbean is generally not equipped to handle extreme weather conditions. Major retrofitting and upgraded technologies will hallmark any adaptation strategy used to mitigate climate change effects of the entire livestock subsector of the Caribbean.

For many years, farmers have been adapting, by way of adjusting planting cycles and regulating cultural practices, to suit changing weather conditions, but at this point formal adaptation strategies may need to be taken on board in order for the subregion to cope with the potentially disastrous impact of climate change on agriculture.

It is quite clear that for this subregion, which is beset by various environmental, market and other potentially destabilizing variables, nothing can be allowed to be left to chance. Strategic approaches must be employed by policymakers, agricultural practitioners, and technocrats from various other sectors, to encourage collective awareness of the interrelationship of sectors, in a holistic thrust to thwart under-production and low productivity attributable to climate change and related variables. The wakeup call has been made: governments must rally resources towards greater levels of targeted production, with a sustainable focus. Efforts towards food security must be kept on the front burner. In the final analysis, policymakers should consider a holistic approach to the development of agriculture, including a policy framework for agriculture at the subregional level, which would promote an integrated and proactive approach to the future of agriculture while addressing various, environmental and climate-related concerns.

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CHAPTER IV.
THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE COASTAL AND MARINE ENVIRONMENT

INTRODUCTION

The coastal and marine environment in the Caribbean represents an important area of wealth and diversity that supports and contributes to the socio-economic wellbeing of its people. This environment sustains the livelihoods of millions in the subregion by providing many ecosystem services that are vital to life, producing considerable amounts of food, providing opportunities for recreation and leisure, and playing a key role in the global water cycle. The coastal and marine environment is also a major driving force of weather and climate.

The definition of "coastal zone" may vary, depending on the specific focus of interest and data that are available (Small and Nichols, 2003; McGranahan and others, 2007), but it is typically represented by some combination of distance-to-coast and elevation. The United Nations Environment Programme (UNEP) defines the coastal zone as the area of land subject to marine influences and the area of the sea subject to land influences.[21] More specifically, UNEP divides the coastal zone into three main components: the sea, the beach, and the land behind the beach.[22] The UNEP definition was used in the studies for British Virgin Islands and Saint Kitts and Nevis, while the studies for Barbados and Guyana focus on the low elevation coastal zone (LECZ).

Small and Nichols (2003) define the coastal zone as that area 100 kilometres from the coast (the distance threshold) and 50 metres above sea level (the elevation threshold), whichever is closer to the sea. Defining the coastal zone in this way from the standpoint of Caribbean SIDS is, however, problematic, due to two main features of these islands. Firstly, because of their smallness, 100 kilometres can quickly encompass an entire country; and secondly, inland activities can quickly impact the coast.[23]

Coastal zones are complex, highly productive environments, which comprise many ecosystems, whose health is intimately linked to each other and to that of neighbouring ecosystems and also to some which may be some distance away (UNEP).[24] At the same time, coastal zones are ecologically fragile and vulnerable, and the large scale climatic changes that have been predicted may well become a major threat to this valuable natural resource.

The effects of climate change on coastal and marine environments include:

- **Sea-level rise.** This is projected to accelerate during the twenty-first century due to melting of polar ice caps and thermal expansion of water with implications for low lying areas, especially

[21] http://www.cep.unep.org/issues/czm.html#what

[22] From a management perspective, the coastal zone refers to the use to which the resources on the coast are being put, and it is from this perspective that Fabbri (1998) suggests that the 'the boundaries of the coastal zone should extend as far inland and as far seaward as necessary to achieve the objectives of the management programme. The 'Ridge to Reef' concept describes this second feature of small islands and best captures the symbiotic relationship between watersheds and the coral reefs into which they ultimately empty and impact upon.

[23] McGranahan and others (2007) define the low elevation coastal zone (LECZ) as "the contiguous area along the coast that is less than 10 metres above sea level." However, no distance threshold is specified.

[24] http://www.cep.unep.org/issues/czm.html.

where subsidence and erosion already exist (National Oceanic and Atmospheric Administration (NOAA), 2000). Sea-level rise is also expected to exacerbate coastal erosion, resulting in damage or increased loss of coastal ecosystems, threatening property and infrastructure located in coastal areas and resulting in salt-water intrusion of underground coastal aquifers.

- **Increased sea surface temperatures.** Such increases are expected to result in loss of habitat, coral bleaching and increased incidence and intensity of weather-related extreme events.

- **Ocean acidification.** This is expected to occur as a result of increased carbon dioxide levels in seawater. Recent research shows that the oceans have become more acidic over the last 30 years, and that by 2060 they could be 120 % more acidic compared to today (Turley, 2010). According to Turley (2010), the implication of this is a reduction of calcareous rates affecting growth, development and recovery of coral reefs. This is particularly challenging given the increased frequency of coral bleaching predicted.

- **Increases in the intensity of tropical cyclones and storm surges.** These will also exacerbate erosion events and increase the vulnerability of coastal areas.

A. CHANGING CLIMATE: IMPLICATIONS FOR THE CARIBBEAN

Climate change poses a challenge to the Caribbean subregion that is already challenged in striking a balance between socio-economic development and environmental conservation. This situation is exacerbated by the existing pressures inherent to SIDS.[25] One of the main challenges is that a large proportion of the population lives within one kilometre of the coast. In several territories, population density exceeds 200 persons per square kilometre; the density is as high as 580 persons per square kilometre in Barbados (CARICOM Secretariat, 2003). In addition to concentrations of population along the coastal zone, most of the physical infrastructure, commerce and industry (particularly tourism), shipment and trans-shipment facilities and mineral production are also located there. Such urbanization of the coastal zone results in air, water and land-based marine pollution, deterioration of coastal ecosystems, and depletion of living fresh water and marine resources. For these populations, coastal and marine resources are a critical factor in their economy, society, culture and politics (Pantin and Attzs, 2010).

The Caribbean contains the greatest concentration of marine species in the Atlantic Ocean and is a global hotspot of marine biodiversity (Roberts and others, 2002). Table 4.1 provides a sample of the marine biodiversity of select insular Caribbean countries. While the Eastern Caribbean has the smallest absolute number of species in comparison to the other eco-regions, it has the highest number of species per coastal length (109 species/100 km of coast).

The most characteristic ecosystems in the subregion comprise coral reefs covering about 20,000 to 26,000 square kilometres (Burke and Maidens, 2004; Burke and others, 2008), seagrass beds with an area of about 66,000 square kilometres (Jackson, 1997), and mangroves at nearly 11,560 square kilometres (Food and Agriculture Organization of the United Nations, 2003). These resources provide shoreline protection services by buffering the coastline from the impact of wave action and extreme weather events, while at the same time serving as nurseries and habitat for reptiles, mammals, fish, crab, birds, and many commercial fish species (CCA, 2006).

[25] Pressures include limited human resources, often limited water supplies, limited fertile land for agricultural production, limited land available for industrial or commercial development, and limited means of generating foreign exchange (Beller, 1990; Griffith and Ashe, 1993; Lockhart and others, 1993; Kakazu, 1994; Ramjeawon, 1994; Persaud and Douglas, 1996).

Table 4.1: Number of Caribbean marine species per kilometre of coast per country within select eco-regions, 2010

Eco-region/country	Sponges	Corals	Molluscs	Amphipods	Echinoderms	Coastline length (km)	Species/ 100km
Southern Caribbean	**225**	**87**	**944**	**208**	**151**	**3 444**	**47**
Venezuela	144	79	664	195	124	2 722	37
Aruba, Bonaire, and Curacao	113	68	239	20	-	360	117
Trinidad and Tobago	-	41	-	-	55	362	27
Greater Antilles	**335**	**91**	**1 943**	**164**	**248**	**8 477**	**33**
Jamaica	169	72	824	-	86	1 151	113
Cayman Islands	82	62	477	-	-	160	388
Puerto Rico	40	72	1 078	25	121	501	262
Cuba	255	72	1 300	131	145	3 735	47
Hispaniola	71	72	572	16	117	3 059	27
Eastern Caribbean	**126**	**71**	**1 119**	**46**	**79**	**1 322**	**109**

Source: Miloslavich, P., J.M. Díaz, E. Klein, J.J. Alvarado, C. Díaz, J. Gobin, E. Escobar-Briones, J.J. Cruz-Motta, E. Weil, J. Cortés, A.C. Bastida, R. Robertson, F. Zapata, A. Martín, J. Castillo, A. Kazandjian, and M. Ortiz.(2010), "Marine biodiversity in the Caribbean: Regional estimates and distribution patterns." *PLoS One*. Public Library of Science, 5(8): 1-25.

The World Resources Institute (2004) reports that, to date, coastal ecosystems are already under severe threat from the impact of human activities and this has resulted in pollution, alien species invasion, overexploitation of resources and urbanisation. The report estimated that just under two thirds of Caribbean coral reefs are threatened by coastal development from various human activities such as overfishing (the major threat), sewage discharge, urban runoff, construction, and tourism development. This represents the most visible impact of climate change in the subregion (Petit and Prudent, 2008),[26] and is set to become one of the most serious and widespread threats.

In 2005 (the hottest year in the Northern Hemisphere on average since the advent of reliable temperature records in 1880), a heatwave caused bleaching of more than 95% of reefs around some of the islands. This resulted in a high rate of mortality among corals already weakened by other human impacts (Wilkinson and Souter, 2007). An update of the Reef at Risk assessment[27] (based on overfishing and destructive fishing, coastal development, watershed-based pollution and marine-based pollution and damage) has revealed an increase in the proportion of Caribbean reefs threatened by human activities to more than 75%, with more than 30% in the high and very high threat categories (Burke and others, 2011).

According to a recent survey by the World Resources Institute, the net economic value accruing from coral reefs through tourism, fishing and the protection of the shores amounts to some US$ 350 million to US$ 870 million per year (World Resources Institute, 2009).

The coastal region is the main asset upon which the regional tourism product is based, but in recent years, beaches and coastlines in Caribbean countries have experienced accelerated erosion (UNEP/GPA, 2003; Cambers, 1999). The tourism industry contributes significantly to the economies of the countries in this subregion, particularly in terms of its impacts on employment and foreign exchange earnings. However, the potential to facilitate sustainable economic livelihoods, through establishing linkages between the industry and other sectors, such as agriculture, manufacturing and cultural services, is yet to be fully realized. The World Travel and Tourism Council describes the Caribbean as "the most

[26] Corals bleach when the coral animal host is stressed and expels the symbiotic zooxanthellae (algae) that provide much of the energy for coral growth, and coral reef growth. Although several different stresses cause bleaching, by far the most significant cause of coral bleaching in the past 25 years has been sea surface temperatures (SSTs) that exceed the normal summer maxima by 1^{o} C or 2^{o} C for at least 4 weeks (Heileman, 2011).

[27] http://www.wri.org/project/reefs-at-risk?utm_source=americanwaymag.com&utm_medium=reefsatrisk&utm_campaign=americanairlines

tourism-intensive region of the world."[28] The industry is even more important for some Caribbean countries where it is the single most important sector in the economy.

An increase in sea surface temperature is already evident in the Caribbean Sea and, in broad terms, this occurrence was evident from the 1970s. In some sites, some cooling occurred before the sustained rise commenced (Sheppard and Rioja-Nieto, 2005). However, for most areas of the subregion, the rise generally became marked from about 1980, and continued to increase. The scientific evidence indicates that increased surface temperature will intensify tropical cyclone activity and heighten storm surges.[29] These surges[30]will, in turn, create more damaging flood conditions in coastal zones and adjoining low-lying areas. The destructive impact will generally be greater when storm surges are accompanied by strong winds and large onshore waves. The historical evidence highlights the dangers associated with storm surges.

These changes may well be associated with climate change, thereby impacting goods and services produced within the coastal zone as follows:

- The proportion of reefs at risk in the Caribbean is expected to reach 90% by the year 2030, and up to 100%, with about 85% at high, very high, or critical levels, by 2050. The reefs considered to be under low threat are almost entirely in areas remote from large land areas, such as the Bahamas (Heileman, 2011). Given the abnormally warm water in 2010, Heileman (2011) predicts that to date, this may have been the worst year ever for coral death in the subregion, where bleaching and high temperatures devastated reefs in the Dutch Antilles and negatively impacted corals along the western and southern areas of the Caribbean Sea, including reefs off Panama. The extent of the devastation across the rest of the Caribbean is still to be seen (Heileman, 2011).

- There is also likely to be detectable influences on marine and terrestrial pathogens, such as coral diseases linked to El Niño Southern Oscillation (ENSO) events (Harvell and others, 2002). These changes will occur in addition to coral bleaching, which could become an annual or biannual event in the next 30 to 50 years, or sooner in the absence of increased thermal tolerance of 0.2° C -1.0° C (Donner and others, 2007; Sheppard, 2003). Declines in the abundance of seagrass beds are likely to accelerate if climate change alters environmental conditions in coastal waters, since changes in salinity and temperature, and increased sea level, atmospheric CO_2, storm activity and ultraviolet irradiance can affect their distribution, productivity and community composition (Short and Neckles, 1999).

- Fish species are expected to migrate to colder waters (Parmesan and Yohe, 2003) potentially resulting in widespread extinction where dispersal capabilities are limited or suitable habitat is unavailable (Thomas and others, 2004). Climate change may alter the abundance and range of distribution of fish species (Wood and McDonald, 1997) through changes in growth,

[28] The WTTC estimates that direct contribution of the tourism sector to Caribbean GDP is US$ 15.8 billion (4.6% of total GDP) in 2011, rising by 3.7 % per annum to US$ 22.9 billion (4.7%) in 2021 (in constant 2011 prices). The 2011 figure is almost 50% above the world average. Its total contribution to employment is expected to be 2,167,000 jobs in 2011 (12.6 % of total employment) rising to 2,764,000 jobs (13.7% of total employment) by 2021, representing an increase of 2.5 % per annum over the period. The similar pattern emerges in respect of capital investment in tourism as a share of total capital investment, which is estimated at US$ 5.7 billion or 11.6 % of total investment in 2011 and predicted to increase by 3.9 % per annum reaching US$ 8.4 billion (or 12.5 %) of total investment in 2021.

[29]A sea-surface temperature of 28° C is considered an important threshold for the development of major hurricanes of Categories 3, 4 and 5 (Michaels, Knappenberger, and Davis 2005; Knutson and Tuleya 2004).

[30]Storm surge refers to the temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions: low atmospheric pressure and/or strong winds (IPCC AR4, 2007).

survival, reproduction, or responses to changes at other trophic levels. Furthermore, coral reefs and other coastal ecosystems severely affected by climate change will also have an impact on fisheries (Graham and others, 2006).

- With a wide range of fishery resources exploited by traditional fishers who mainly operate just off the coast and by commercial fishing fleets from many countries of the world, fisheries is also dependent on ecosystem services and products of the coastal and marine environment. The fishing industry is estimated to employ some 200,000 people on a full-time or part-time basis. Another 100,000 persons are estimated to be employed in processing and marketing, net-making, boat-building and other support industries. The Caribbean fishing industry is reportedly responsible for some US$ 1.2 billion in annual export earnings. Thus, changes in fish abundance and distribution will undoubtedly negatively impact the livelihoods of fishers and consumers as well as the value of commercial fisheries.

- Reduction in biological diversity and possible wildlife extinctions is likely to occur. For example, sea-level rise is projected to cause a decrease in turtle nesting habitats by up to 35 % if sea level rises by 0.5 metres (Fish and others, 2005). It is also possible that mangrove vegetation will migrate landward in response to changing ecological conditions brought on by inland movement of the sea and salt water intrusion into coastal waterways.

- Other impacts include human illness and death from ingesting contaminated fish, mass mortalities of wild and farmed fish, and alterations of marine food chains through adverse effects on eggs, marine invertebrates (for example, corals, sponges), sea turtles, seabirds, and mammals. Coastal waterfowl and seabirds will also be affected through a shifting of bird seasonal responses; changes in egg laying dates; changes in migratory timing; mortality from wind, rain and flooding; geographic displacement by winds; mismatches between behaviour and environment; loss of habitat, particularly wetlands; and vulnerability of long distance migrants. Already the increased intensity of storms in the Caribbean appears to be reducing the number of some migratory bird species reaching their breeding grounds (Department of Environment, Food and Rural Affairs, 2005).

- One of the greatest threats to marine mammals perhaps comes from changes in their food resources, as a result of climate change. Many prey species such as fish and plankton appear to rely on, and are influenced by, particular sets of environmental conditions (Harwood, 2001). Any changes in the geographic distribution of these oceanographic conditions as a result of climate change will affect the abundance and distribution of prey species (Department of Environment, Food and Rural Affairs, 2005). Apart from species residing within the subregion, it appears that other long-ranging migratory species may need to access for food supplies from these niches, thereby increasing competition.

- Sea-level rise represents one of the most significant impacts of climate change for Caribbean countries because of the high concentration of human settlements located in the coastal zone, particularly in countries such as Antigua and Barbuda, Barbados, Guyana, Cayman Islands where an appreciable proportion of the land near the coastline is low lying.[31] For Guyana, for example, the threat of sea-level rise can be dire because 90 % of the population live in the

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[31] Various studies predict sea-level rise in the subregion of 1 to 2 millimetres per year (Church and others, 2001; Miller and Douglas, 2004). Other estimates have put sea-level rise at 4 millimetres per year (Cazenave and Nerem, 2004; Leuliette and others, 2004). At the upper end of the spectrum is Rahmstorf (2007) who projects that seas in the subregion will rise by 0.5 to 1.4 metres by 2100 (5 to 14 millimetres per year).

coastal zone, and a substantial proportion of its coast, some of which is already below sea level, is protected from tidal and wave action by a series of sea walls. A similar situation can develop in Barbados, where most of its tourism plant which are the engines of the economy, are located along the southwest and western coasts and are already being subjected to the impact of coastal erosion. Key impacts include accelerated coastal erosion resulting in loss of beaches and habitat, destruction of arable land due to loss of landmass, saline intrusion into freshwater lenses, increased flooding from the sea, and loss of natural and built coastal structures.

B. APPROACH TO ESTIMATING THE ECONOMIC IMPACT

Coastal and marine areas have high ecological and economic value and quantitative estimates of the potential impact of climate change on these areas will be useful to national planning processes or in situations where policymakers are faced with decisions concerning balancing future development with investing in efforts to protect a threatened resource. The economic impact of climate change on the coastal and marine environment was estimated by combining a number of frameworks and economic valuations from the literature.[32] Two approaches were used: the first is a "value of ecosystems" approach (British Virgin Islands and Saint Kitts and Nevis); the second is a "value of exposed assets" approach (applied in the case of Barbados and Guyana).

The "value of ecosystems approach" used a layered approach that amalgamates the loss of services provided by marine and coastal waters (fisheries and tourism), loss of services provided by coral reefs and mangroves (research, pharmaceutical and biodiversity services), and loss of coastal lands.[33] The "value of exposed assets" approach is more narrow in focus and estimates the impact of sea-level rise on coastal human settlements (population and economic assets at risk in the LECZ) following the work of McGranahan and others, (2007) and Nicholls and others, (2007), using an elevation based Geographic Information Systems (GIS) analysis.

In both approaches, the current value of coastal resources was used as a baseline, and losses (or increases in asset exposure) to 2100 were estimated based on the IPCC's A2 and B2 scenarios. Initially, the current value of coastal resources was established using one of two approaches and then the impact of climate change on the future value of services or assets provided by the coast was estimated. These estimates were then discounted to present value terms.[34] The impact of climate change is the loss of service value or increased vulnerability of coastal assets.

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[32]This approach is not without a degree of uncertainty since the coastal and marine environments are highly complex ecosystems, making it difficult to assess risks and quantify in monetary terms the changes expected as a result of projected changes in climate. Additionally, the lack of available data also added to the problems of the researchers and is reflected by the use of proxy data from studies conducted in other countries that may be based on different physical and socio-economic conditions.

[33] The basic approach of examining the amount of economic activity an ecosystem service generated in the local economy involves looking at the revenues, taxes, and jobs generated by an activity (Pendleton, 2008). For the purposes of this project and ease of data availability, the World Resources Institute framework was employed for valuing tourism and fisheries (World Resources Institute, 2009).

[34] In the Stern Review report, discount rate for climate change damages is approximately 1.4 % (Dietz, 2008).[34] This relatively low rate is consistent with the view that the welfare of future generations is as important as that of the current generation. Critics of the Stern Review, for example, Nordhaus (2007), suggest that a discount rate of 4 % or higher should be employed, to be consistent with the observed real rate of return in the stock market.

C. RESULTS

1. Current valuation of coral reef and mangrove ecosystems

The value of services provided by the coastal and marine waters was estimated as the sum of the value of services provided to tourism and recreation, fisheries, research, pharmaceuticals and biodiversity.[35] One important example of the potential medicinal value of coastal and marine resources is the drug azidothymidine (AZT) which is based on the chemicals found in sponges in the Caribbean. Similarly, the medicinal properties of the bark of red mangrove trees have been used in folk remedies for a wide array of diseases (Duke and Wain, 1981). Valuing marine biodiversity is complicated because the marine environment is difficult to sample and monitor (Ray and Grassle, 1991). The value of the services provided by coastal and marine ecosystems or biodiversity (considered as an indirect use value) is determined in terms of the ecological functions they provide, such as the control of coastal erosion, following Costanza and others (1997).[36]

The results for a current valuation of the services provided by the coastal and marine sector for Saint Kitts and Nevis and British Virgin Islands are presented in table 4.2. The largest contributor to the overall valuations by far is the pharmaceutical component, making up almost 93% and 85% of the total, respectively. In comparison to 2008 GDP of approximately US$ 570.1 million for Saint Kitts and Nevis and approximately US$ 1.1 billion for British Virgin Islands, all component values were very large, with the exception of research, which was negligible. In particular, the pharmaceutical value of the coral reefs is almost 700 times larger than 2008 GDP for Saint Kitts and Nevis and almost 900 times larger than 2008 GDP for British Virgin Islands.

Table 4.2: Current value of coastal and marine sector, 2008 (Baseline)

	British Virgin Islands			Saint Kitts and Nevis		
	Value (US$ billion)	Share of Total Value (%)	Share of 2008 GDP (%)	Value (US$ million)	Share of Total Value (%)	Share of 2008 GDP (%)
Tourism and recreation	.4	4	40	74.6	1.7	13
Fisheries	0.5	4	44	2.3	0.1	0.4
Research	0.0004	0	0	0.2	0.0	0.0
Pharmaceutical	9.5	85	871	3 971	92.8	697
Biodiversity	0.7	7	67	231.2	5.4	41
Total	$11.2	100	1 021	$4 279.2	100	751

Source: ECLAC (2011): ECLAC (2011a)

2. Economic valuation of losses from coastal lands and waters due to climate change

The estimation of coastal zone losses from coastal lands and coastal waters[37] due to sea-level rise considered the potential losses of beaches, the land behind the beach, coral reefs, sea grass beds and the coastal shelf to a 30 metre depth. Estimation of losses of coastal lands took into account losses in beach width, which was proven from previous studies to be of economic importance as a characteristic of coastal properties and measure of beach quality (Whitehead and others, 2008).

[35] These valuations do not take into account whether these resources are being used at a sustainable level, and do not address the damage that overcrowding, inadequate waste treatment, and fishing at current levels, among other things, may be doing to the beaches, rocky shores, mangroves and reefs.

[36] Briefly, the global valuation study estimated the value per unit area of 17 ecosystem services: gas regulation; climate regulation; disturbance regulation; water regulation; water supply erosion control and sediment retention; soil formation; nutrient cycling; waste treatment; pollination; biological control; refugia; food production; raw materials; genetic resources; recreation; and cultural values. Each ecosystem considered in Costanza and others' study in 1997 provides some, but not all, of the aforementioned services. The annual global values were estimated in 1994 US$ on a per hectare basis.

[37] Coastal land refers to the "beach" and "land behind the beach", while "coastal waters" refers to coral reefs, sea grass beds and the coastal shelf.

The economic assessment of the impact of climate change on the coastal and marine sector in Saint Kitts and Nevis and British Virgin Islands studies continued the work conducted by Sheppard and Rioja-Nieto (2005) in the Dominican Republic, where it was estimated that erosion rates would increase by 73% to 113% relative to current rates as a result of sea-level rise and a decline of live corals (WRI, 2010).[38] Using erosion rates determined for the respective country and applying rate increases calculated for the Dominican Republic study, estimation of land losses due to erosion were determined. For British Virgin Islands, the rise in sea level is expected to cause erosion of 26 metres of land by 2050 under the B2 scenario, and 32 metres under the A2 scenario. Similarly, sea-level rise in Saint Kitts and Nevis is predicted to cause 65 metres of erosion by 2050 under the B2 scenario, and 80 metres under the A2 scenario (see table 4.3).[39]

The results for losses due to sea-level rise and coral reef decline for British Virgin Islands and Saint Kitts and Nevis (see table 4.6) and the value of the losses from 2009 to 2050 for the two countries (see figure 4.1) confirm that under each scenario, cumulative coastal losses increase exponentially with time.

- By 2050, losses for British Virgin Islands are projected to be at least US$ 0.63 billion. In present value terms, if A2 occurs, losses range from US$ 0.15 billion to US$ 0.51 billion; if B2 occurs, losses will be lower, ranging from US$ 0.12 billion to US$ 0.41 billion; and if BAU occurs, losses range from US$ 0.14 billion to US$ 0.46 billion, depending on the discount rate. These estimates imply that the cost to coastal lands due to sea-level rise and coral reef decline may have a lower value as high as 11 % of 2008 GDP.

- For Saint Kitts and Nevis, coastal losses are estimated at US$ 1,026.4 million, US$ 832 million and US$ 929 million under the A2, B2 and BAU scenarios, respectively. At the calculated discount rates, losses under the A2 scenario could range from US$ 1,977 million to US$ 6,578 million. If B2 occurs, losses could range from US$ 160.2 million to US$ 547.8 million, and if BAU occurs, losses range from US$ 178.9 billion to US$ 611.8 billion. The economic evaluation of losses to coastal lands as a result of sea-level rise and coral reef decline may reach as high as 28 % of 2008 GDP.

Table 4.3: Value of losses to coastal lands due to sea-level rise and coral reef decline

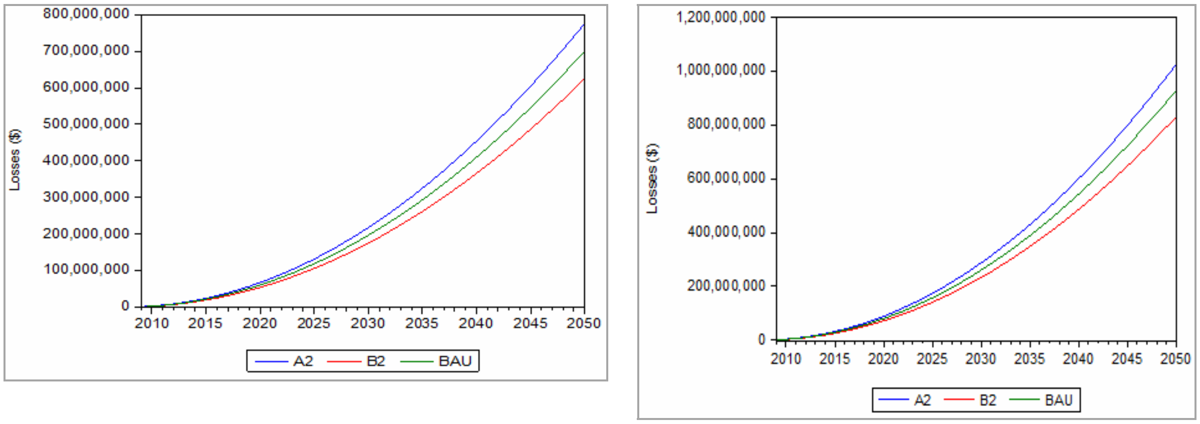
Losses to coastal lands due to sea-level rise and coral reef decline	British Virgin Islands (billions)			Saint Kitts and Nevis (millions)		
	A2	B2	BAU	A2	B2	BAU
Nominal losses by 2050 (US$)	0.77	0.63	0.70	1 026.4	832.0	929.2
Present value (US$ bn.) (d = 1%)	0.51	0.41	0.46	675.8	547.8	611.8
Share of 2008 GDP (%)	47	38	42	119	96	107
Present value (US$ bn.) (d = 2%)	0.43	0.34	0.35	446.8	362.2	404.5
Share of 2008 GDP (%)	31	25	28	78	64	71
Present value (US$ bn.) (d = 4%)	0.15	0.12	0.14	197.7	160.2	178.9
Share of 2008 GDP (%)	14	11	12	35	28	31

Sources: ECLAC (2011): ECLAC (2011a)

[38] Similar erosion rates have been measured at other sites (Scoffin and others (1980); Eakin (1992)), but have been shown to vary greatly between reefs (Hutchings (1996)) and within different sites of reefs (Eakin (1996)).

[39] Recognising that the coastal and marine geomorphology in the Dominican Republic differ from these countries, the predicted erosion rates from the Dominican Republic study formed the basis for predicting erosion losses. The Saint Kitts and Nevis and British Virgin Islands studies assume that the lower rate (73%) represented the approximate rate of erosion under the B2 scenario and the upper bound was used for the A2 scenario.

Figure 4.1: Cumulative losses to coastal lands due to sea-level rise and coral reef decline



British Virgin Islands **Saint Kitts and Nevis**

Sources: ECLAC (2011): ECLAC (2011a)

The coastal waters of both British Virgin Islands and Saint Kitts and Nevis are estimated to have a higher value compared to the coastal lands, due primarily to the high value of the many ecosystem services they provide. Increasing sea surface temperatures are expected to have adverse effects on marine biodiversity, thus impacting coral reefs, sea grass beds and the coastal shelf. Climate change impacts would translate into loss of productivity from these important ecosystems in the future**.**

The value of coral reefs, seagrass beds and the coastal shelf in 2050 are estimated using the direct and indirect use values for economic valuation, projected to 2050, utilizing an average United States consumer price inflation (from 2004-2008) of 3.2 %. Vergara and others (2009) estimated anticipated coral loss to be almost 100 % by 2050 as a result of increases in sea surface temperature under the A1F1emissions scenario. Adjusting this estimate for the current studies, losses from coastal waters by 2050 are assumed to be about 80 % under the A2 scenario and 50 % under the B2 scenario.

(a) Estimation of valuation of losses from coastal waters

By 2050, nominal losses due to increases in sea surface temperature in British Virgin Islands are valued between US$ 19.4 billion and US$ 30.9 billion. For Saint Kitts and Nevis, these losses are estimated between US$ 8.069 billion and US$ 12.910 million. As a result of the scenarios modelled and the discount rate applied, the costs range from 341% to 1,863 % of the 2008 GDP of British Virgin Islands; and from 273% to 1,491% of the 2008 GDP of Saint Kitts and Nevis (see table 4.4 and figure 4.1).

Table 4.4: Value of losses to coastal waters due to sea surface temperature rise

Losses due to Sea Surface Temperature Rise	British Virgin Islands (billions)			Saint Kitts and Nevis (millions)		
	A2	B2	BAU	A2	B2	BAU
Nominal Losses by 2050 ($)	30.9	19.4	25.2	12 910.0	8 068.8	10 489.4
Present Value ($bn.) (d = 1%)	20.4	12.8	16.6	8 500.2	5 312.6	6 906.4
Share of 2008 GDP (%)	1 863	1 165	1 514	1 491	932	1 211
Present Value ($bn.) (d = 2%)	13.5	8.4	10.9	5 619.8	3 512.4	4 566.1
Share of 2008 GDP (%)	1 232	1 165	1 514	986	616	801
Present Value ($bn.) (d = 4%)	6.0	3.7	4.8	2 846.1	1 553.8	2 020.0
Share of 2008 GDP (%)	545	341	443	436	273	354

Sources: ECLAC (2011): ECLAC (2011a)

(b) Summary of losses due to the impact on coastal lands and waters

If the values of losses from coastal lands and waters are combined, the analysis shows that for British Virgin Islands and Saint Kitts and Nevis, the costs of climate change could be astronomical. In the case of British Virgin Islands, values ranged from 557% to 1,905 % of 2008 GDP for the A2 scenario; from 352% to 1,204% of 2008 GDP under the B2 scenario; and from 456% to 1,557 % of 2008 GDP under the BAU (see table 4.5). For Saint Kitts and Nevis, the estimated costs ranged from 471% to 1,609 % of 2008 GDP under A2; 301% to 1,028 % of 2008 GDP under the B2 scenario; and 386% to 1,319 % of 2008 GDP under the BAU scenario.

Table 4.5: Total cost of climate change for the coastal and marine sector

Total cost of climate change	British Virgin Islands (billions)			Saint Kitts and Nevis (millions)		
	A2	B2	BAU	A2	B2	BAU
Nominal Losses by 2050 (US$)	31.7	20.0	25.9	13 936.4	8 900.8	11 418.6
Present Value (US$ bn.) (d = 1%)	20.9	13.2	17.1	9 176.0	5 860.5	7 518.2
Share of 2008 GDP (%)	1 905	1 204	1 557	1 609	1 028	1 319
Present Value (US$ bn.) (d = 2%)	13.8	8.7	11.3	6 066.6	3 874.6	4 970.6
Share of 2008 GDP (%)	1 259	796	1 030	1 064	680	872
Present Value (US$ bn.) (d = 4%)	6.1	3.9	5.0	2 683.8	1 714.1	2 198.9
Share of 2008 GDP (%)	557	352	456	471	301	386

Sources: ECLAC (2011): ECLAC (2011a)

3. Impact of sea-level rise and extreme events on human settlements

In considering the impact of climate change on human coastal settlements, an alternative approach which considers the value of exposed assets in the LECZ, was applied for an assessment of impacts in Barbados and Guyana. This approach estimated the vulnerability of human settlements (populations and infrastructure) in the LECZ to sea-level rise.[40]

BARBADOS CASE STUDY

In Barbados, about 70 % of the population lives on the coast, where the population density is projected to increase by 2100 to 314, 275 persons and 378,418 persons, under the B2 and A2 scenarios, respectively. Additionally, projections indicate that, under both the A2 and B2 scenarios, population density will increase within the LECZ by 80% and 20%, respectively. The tourism industry in Barbados is typical of that of other islands in the Caribbean, whereby most of the industry's assets are located on the coast. Over 90% of all hotels in Barbados are within the coastal zone. Most hotels, especially the larger ones, are generally located within the LECZ, placing them at risk of major structural damage associated with sea-level rise and storm surges. The vulnerability to erosion would be aggravated by the expected increase in high-intensity extreme weather events such as hurricanes and floods.

[40] Low elevation coastal populations are at risk from sea-level rise, stronger storms and other seaward hazards induced by climate change. McGranahan and others (2007) showed that a large share of the population and economic assets of small island countries are found in the LECZ. The Barbados and Guyana studies show that this is true for these Caribbean countries, with Guyana having the largest share of its total population in the LECZ.

The coastline of Barbados is currently subjected to high rates of erosion, particularly along the west coast. Christ Church and Saint James were the two most vulnerable parishes, accounting for 89% of the reported land loss to date. Using a benefit transfer methodology, loss of beach width was estimated at US$ 106.8 million per metre, and the projected loss of beach width due to coastal erosion is estimated at 135.91 metres (corresponding to 1- metre rise in sea level), with a value of losses estimated at US$ 14.5 billion. In addition, 49,000 to 51,000 residents, mainly in Saint Michael and Christ Church, would be seriously affected by the loss of these coastal lands. Overall, the A2 exposed asset value reached an estimated US$ 4.7 billion in 2020, and reached in excess of US$ 44 billion in 2100, compared to a value of US$ 39.4 billion for the B2 scenario.

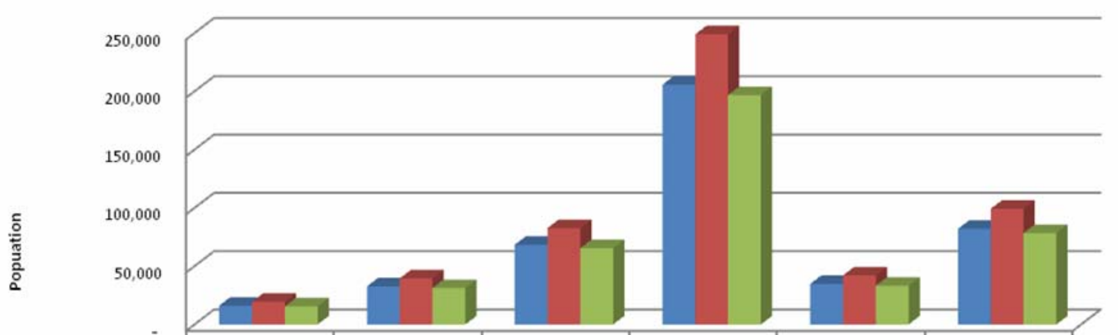
GUYANA CASE STUDY

The Guyana study is more typical of Caribbean continental landmasses rather than islands such as Barbados. The analysis shows that, based upon the exposed assets and population located within the LECZ, sea-level rise will potentially have catastrophic impacts for Guyana, owing to the concentration of socio-economic infrastructure along the coastline in vulnerable areas.

Climate change threatens serious losses to coastal housing and other infrastructure in coastal areas of Guyana. A total of 90 % of the population of Guyana lives within 100 kilometres of the coastline, occupying about 5% of the country's total landmass (figure 4.2). About 55% (415,456 persons) of the total population lives within the LECZ (Center for International Earth Science Information Network, 2007) and of this number, 58% live within the capital city of Georgetown (Government of Guyana, 2002). In monetary terms, the impact of climate change on economic assets could also be significant, with the estimated value of exposed assets standing at approximately US$ 3.2 billion in the year 2010. The value of mangroves in Guyana (which takes into account the sea wall which acts as a buffer protecting the land from the action of the sea) was estimated to be worth US$ 4.624 billion per annum.

The population is forecast to increase under the A2 and B2 scenarios, while the BAU case projects a decrease in the exposed population over the medium- to long term starting in the decade 2030. Trends in population density and GDP exacerbate the vulnerability to sea-level rise within some regions relative to others.

Figure 4.2: Guyana: Exposed population by Administrative Region

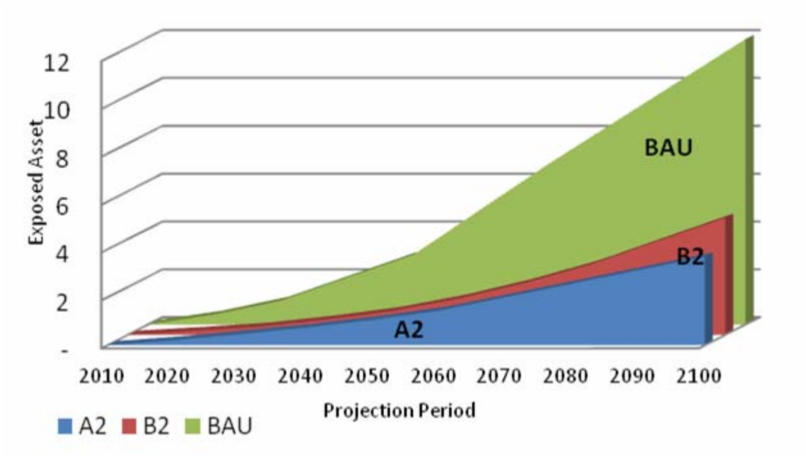


	Barima-Waini	Pomeroon-Supenaam	Essequibo Islands-West Demerara	Demerara-Mahaica	Mahaica-Berbice	East Berbice-Corentyne
A2	16,086	32,639	68,296	205,641	34,743	81,970
B2	19,472	39,508	82,670	248,923	42,055	99,222
BAU	15395	31236	65360	196801	33249	78446

Source: ECLAC (2011c)

The exposed assets across the Administrative Regions of interest ranged from a minimum of US$ 27 million to a high of US$ 5 billion, with the BAU case having the greatest asset exposure. Both the A2 and B2 scenarios show an increase in exposed assets over the period. This is consistent with projected population trends. Exposed assets for the BAU case is on average twice that of the A2 or B2 scenarios over the projection period (figure 4.3).[41]

Figure 4.3: Relative Asset Exposure



D. ADAPTATION STRATEGIES

The critical element that drives adaptation is to ensure that public health and safety, the protection of the natural resource base and the economic and physical infrastructure are maintained. Sustainable development in the context of SIDS not only requires careful planning and protection of the coastal and marine environment but also the promotion of sustainable coastal communities.

There are a number of options available to countries to adapt their coastal and marine zones to climate change, and these fall under three main categories (Nicholls and Klein, 2005; Nicholls and others, 2007). The first is planned retreat from coastline to reduce the risk to human life by pulling back from the coast using land use planning and development control. However, given their limited land size and topography, this is not a feasible option for most Caribbean countries. The second option, referred to as accommodation, focuses on increasing a country's ability to cope with the effects of sea-level rise through the adoption of measures that would lead to changes in human behaviour and use of the coastal zones, and increased resilience and reduced risk (e.g. raising homes on pilings), implementation of warning systems and protection from risk by the use of insurance. The third category, also known as protection, looks at measures that would reduce the risk associated with sea-level rise on the coastal zone by the development of soft or hard engineering works (such as nourished beaches and dunes or sea walls), and the reduction of human impacts likely to make these areas more vulnerable to sea-level rise.

Adaptation of coastal and marine environment to climate change requires Caribbean Governments and people to implement a combination of policy interventions, as well as physical and biological interventions that would reduce the vulnerability of these areas. Many countries in the subregion are taking action against the impact of climate change or are in the process of formulating or implementing adaptation measures. At one end of the spectrum are countries like Guyana and Barbados, that have already begun to implement corrective actions, geared at reversing impacts already manifested

[41] Per capita GDP multiplied by population in the LECZ multiplied by a factor of five. For every person on the LECZ, there is a constant capital per person ratio.

and to reducing the magnitude of anticipated shocks to the economy that may arise. In Guyana, for example, a national climate change adaptation strategy has been developed and measures implemented to reduce vulnerability to sea-level rise and flooding. Measures include reform of the main institutions involved in sea and river defence, the rehabilitation and maintenance of sea defence and river embankments works, and increasing the capacities of both national and conservancy drainage systems. In Barbados, adaptation to climate change within the coastal and marine zone comprises the implementation of engineering works within vulnerable coastal areas, as well as a range of policies and legislature to protect the entire natural resource base, and to regulate and manage human activity and use.

Consequently, given the importance of the coastal and marine environment to the economic development of Barbados and Guyana, the implementation of these adaptation measures is expected to reduce and manage the vulnerability of their economies, especially vulnerability within the LECZ. The country case study for Barbados, for example, estimates that the reduction in average vulnerability in the coastal zone by 2050 will cost approximately US$ 12.7 billion, or about 270% of the estimated GDP for the year 2010. Similarly, in Guyana, this reduction is calculated at approximately US$ 15.54 billion which is about 1.4% of estimated 2010 GDP. However, the residual vulnerability within both economies will remain high. Continued planning for climate change, as well as an effective disaster management system, will be crucial for all Caribbean countries.

Saint Kitts and Nevis and British Virgin Islands have also begun to plan for climate change. A number of measures that would protect coastal lands and marine resources and promote alternative fishery and resource use are already being considered. With an inflation rate of 3% and discount rate of 2%, cost benefit analysis (CBA) over a 20-year horizon on the following adaptation options listed in table 4.6 had ratios of above 1 for British Virgin Islands and Saint Kitts and Nevis.

Table 4.6: Selected adaptation strategies in British Virgin Islands and Saint Kitts and Nevis

Adaptation Strategy
Enhance monitoring of coastal waters to provide early warning alerts of bleaching events
Develop artificial reefs or fish-aggregating devices
Introduce alternative attractions
Increase recommended design wind speeds for new tourism-related structures
Develop national evacuation and rescue plans
Irrigation networks that allow for the recycling of waste water

Sources: ECLAC (2011): ECLAC (2011a)

E. CONCLUSION

Over the next century, climate change is expected to negatively affect coastal resources, including land, ecosystems, biodiversity, infrastructure and human settlements. Some of these impacts are expected to be considerable and would add to existing problems, including pollution, invasive species, habitat destruction and urbanization of highly-exposed areas. One of the more important impacts is rising sea level, which will increase exposure and vulnerability of the population on the coast and affect important economic sectors, including tourism, which is the primary income earner and employer in many Caribbean countries. Another impact, coral bleaching, due principally to increased sea surface temperature and ocean acidification, is already a major concern for policymakers, managers and resource users. The resulting coral reef loss and habitat destruction has the potential to drastically reduce commercial marine species and reduce the capacity of coral reefs to protect the coastline from wave action.

Caribbean countries are at different stages of climate change adaptation. One key intervention implemented is the establishment of coastal protection works to reduce the risk associated with rising sea level. Those countries currently in more advanced stages of adaptation are the ones at greater risk of being impacted by climate change. The preliminary cost-benefit analysis has shown that adaptation may prove to be financially beneficial in the long run, and helps to demonstrate the need for all countries to take the necessary measures to protect their coastal and marine environment.

In respect of policy recommendations, the following are suggested:

- **Improved data collection and management:** The establishment of improved data collection and management systems must be given priority, for reliable data to be available to facilitate valid projections of the impact of climate change on the coastal and marine environment. Information on climate change should also be housed in a centralized location and be easily accessible.

- **Improved management of coastal and marine protected areas**: Many Caribbean nations have established national parks and other protected areas to safeguard coastal and marine ecosystems and biodiversity. An assessment study of marine protected areas showed that, of 285 marine protected areas declared in selected Caribbean countries, almost half of them were inadequately managed (Burke and Maidens, 2004). Allocating resources to the management of these areas has become critical. There is a system in place for monitoring the subregion's coral reefs, particularly with respect of coral bleaching. However, monitoring of human activities within these protected areas should also be improved. There are examples of co-management of marine areas which can be duplicated in areas in need of improved coastal protection. Given that land-based pollution remains a major challenge for all Caribbean States, efforts to better manage coastal and marine protected areas should be complemented by programmes to improve land management, control deforestation and reduce pollution, thus decreasing the threats which make these fragile areas more vulnerable to climate change. Climate change represents an additional pressure on the subregion's fisheries resources and should be taken into account in monitoring and conserving remaining stock.

- **Increase research into the impact of climate change on the coastal and marine environment at the local and subregional levels**: The impact of climate change on the coastal and marine environment, and the impact of adaptation, would vary by country. Research is therefore needed at the local level on the physical and economic impact in order to acquire more accurate knowledge and information that can be used by policymakers and managers. It is also clear that a description of subregional and local climate change scenarios is needed and should be well defined. Additional research should be carried out on specific vulnerability indicators of coastal and marine zones and on the impact of ocean acidification on coastal and marine environment.

- **Improved physical development planning and control**: There should be an integrated approach to coastal planning and management at both national and regional levels, and adaptation to climate change should be incorporated into existing coastal management plans. All new plans must consider climate change adaptation. In many countries of the Caribbean, the national physical planning system remains inadequate and, therefore, strengthening development planning and control is important at the local level to ensure that adequate regulations are in place to manage land use, particularly in highly exposed coastal areas.

- **Optimize the use of insurance and other financial services products**: The use of insurance and re-insurance schemes that would enhance adaptive measures would be cost effective. These would be pertinent to the development of infrastructural works and therefore safeguard against weather-related disaster events.

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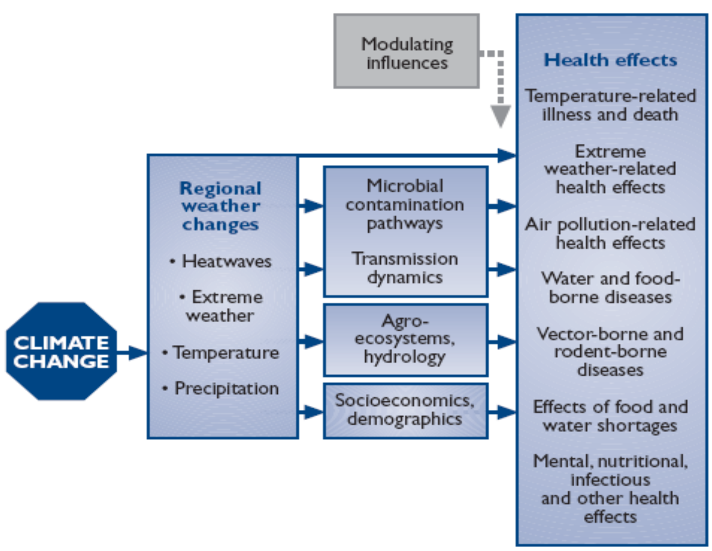
CHAPTER V.
THE ECONOMIC IMPACT OF CLIMATE CHANGE ON HUMAN HEALTH

A. CLIMATE CHANGE AND HUMAN HEALTH

Climate change poses a serious threat to public health and wellbeing worldwide (Maibach and others, 2011)[42]. Disease incidence and mortality can be affected both directly and indirectly by climate change across a wide range of conditions. Direct effects of climate change on human health are due to increased exposure to extreme weather events such as hurricanes and tropical storms, rising temperatures and heat waves, and increased precipitation in some areas, concurrent with drought in others. Indirect effects stem from climate-related alterations to the complex socio-economic-environmental systems that govern disease transmission (McMichael and others, 2004).

As depicted in figure 5.1, a host of factors with complex inter-relationships including exposure, socio-economic status, the built environment and cultural practices result in diverse health consequences, most of which are adverse (Maibach and others, 2011; McMichael and others, 2003; Patz, 2000).[43] Modulating influences which can help to buffer the impact of extreme weather events include access to good health care, proper urban planning and proactive surveillance and monitoring systems.

Figure 5.1: Pathways by which climate change affects population health



Source: McMichael and others (2003). World Health Organization (WHO, 2008).

[42] Public health is "the science and art of preventing disease, prolonging life and promoting health through the organized efforts and informed choices of society, organizations, public and private, communities and individuals".

[43] While there are some beneficial impacts, it is expected that these benefits will be outweighed by the potential negative effects of rising global temperatures.

The World Health Organization (WHO) (2008) has identified five major health consequences of climate change:

1. Climate-related ecosystem changes

Climate-related ecosystem changes can increase the range, seasonality, and infectivity of some vector- and water-borne diseases, such as cholera and diarrhoeal diseases, malaria and dengue fever, many of which are highly climate sensitive to temperature and rainfall. Changing temperatures and patterns of rainfall are expected to alter the geographical distribution of insect vectors that spread infectious diseases, thus bringing new challenges to the control of infectious diseases.

2. Rising temperatures and more frequent droughts and floods

Rising temperatures and more frequent droughts and floods can compromise food security. Increased malnutrition is expected to be especially severe in countries where large numbers of the population depend on rain-fed subsistence farming. Malnutrition, much of which is caused by periodic droughts, is already responsible for an estimated 3.5 million deaths worldwide each year. This has particular implications for child growth and development (Intergovernmental Panel on Climate Change (IPCC), 2007b) and could negatively affect the achievement of the Millennium Development Goals (MDGs).

3. More frequent extreme weather events

More frequent extreme weather events are linked to a potential increase in the number of deaths and injuries caused by storms and floods. In addition, flooding can be followed by outbreaks of diseases, such as cholera, especially when water and sanitation services are poor or where they have been damaged or destroyed. Storms and floods are already among the most frequent and deadly forms of natural disasters (IPCC, 2007a, 2007b; WHO, 2008).

4. Water scarcity and excess water

Water scarcity (due to droughts) and excess water (due to more frequent and torrential rainfall) are both expected to increase the burden of diarrhoeal disease, which is spread through contaminated food and water (IPCC), 2007a; World Health Organization (WHO)/World Meterological Organization (WMO)/ United Nations Environment Programme (UNEP), 2003). Torrential rainfall can trigger sewage overflows, contaminating ground water that is often used for crop irrigation and as a source of drinking water, causing diarrhoeal diseases – which are already the second leading infectious cause of childhood mortality, accounting for a total of around 1.8 million deaths worldwide each year.

5. Heat waves

Heat waves can directly increase morbidity and mortality, mainly in elderly people, with cardiovascular or respiratory disease (IPCC, 2007b). Apart from heat waves, higher temperatures can increase levels of ground-level ozone and hasten the onset of the pollen season, contributing to respiratory problems such as asthma attacks.

The overarching concern is that the changing global climate is affecting the basic requirements for maintaining health (clean air and water, sufficient food, and adequate shelter) and placing pressure on the natural, economic, and social systems that sustain health, with consequences including poverty, population dislocation, and civil conflict, which have the potential to disrupt the lives of millions of people and reverse successes in development (WHO, 2008). Table 5.1 summarizes the potential impacts of climate change on health.

Table 5.1: Potential health effects of climate change

Manifestation of climate change	Health determinant due to climate change	Health outcome
Climate-related ecosystem changes	Temperature, humidity, rainfall effects on vector-borne (and rodent-borne) diseases	Increased vector-borne disease such as West Nile virus, equine encephalitis, Lyme disease, Rocky Mountain spottedfever, hantavirus, malaria, dengue fever, leptospirosis
	Changes in air pollution and aeroallergen levels	Increased allergies caused by pollenIncreased cases of rashes and allergic reactions from toxic plants such as poison ivy, stinging nettle, and other weeds Deaths and disease cases associated with air pollution, allergies
	Emergence or spread of pathogens via climate-change-driven biodiversity loss	New cases of infectious disease
Risingtemperatures and erratic rainfall patterns	Effects of extreme rainfall and sea-level rise on flooding (attributed to coastal floods, inland floods and landslides)	Fatal injuries; Non-fatal injuries and mental health effects Death from drowning Increased waterborne diseases from pathogens and water contamination from sewage overflows Increased food-borne disease
	Temperature effects on food and waterborne disease	Increased food-borne disease, such as Salmonella poisoning, diarrhoea and gastroenteritis
	Temperature and precipitation effects on incidence and intensity of forest fires and dust storms	Death from burns and smoke inhalation Eye and respiratory illness due to fire-related air pollution Fatal and non-fatal injuries
	Increased average temperature	Increased strain on regional drinking water supplies Increased vulnerability to wildfires and associated air pollution
Water scarcity (drought)	Changing patterns of agricultural yield due to water shortages and increasing temperatures	Disruptions in food supply Changing patterns of crops, pests, and weed species Water shortages Malnutrition Food- and waterborne disease Emergence of new vector-borne and zoonotic diseases
	Sea-level rise and reduced snowmelt impacts on freshwater availability	Water-related diseases in resident and displaced populations
Heat waves	Direct impact of heat waves	Premature death due to heat-related illnesses such as heat stroke, heat exhaustion and kidney stones Cardiovascular disease /deaths
Extreme events	Destruction of health infrastructure in floods and storms	Increases in mortality and morbidity in affected areas
	Increased intensity of hurricanes due to higher sea surface temperature	Death from drowning Injuries Mental health impacts such as depression and post-traumatic stress disorder Increased carbon monoxide poisoning Increased gastrointestinal illness Population displacement/homelessness

Source: Adapted from, Campbell-Lendrum, D. H., & Woodward, R. (Eds.). (2007). WHO, 2008.

B. Health implications for the Caribbean

Caribbean countries have the potential to be particularly vulnerable to climate change -related impacts on the health sector because they tend to experience a "dual" disease burden, having many endemic and environmentally-sensitive disease vectors as added to the burden of human populations with high rates of cardio-respiratory diseases (DCPP, 2006). Greater precipitation during storms and other peak periods is expected to be accompanied by more frequent and longer droughts, in parts of the Caribbean. The anticipated negative health impacts include greater heat stress for vulnerable populations (such as the elderly), worse sanitation conditions from limited water supplies or contaminated water from floods, and conditions that can favour the spread of water- and vector-borne diseases.

Although only a limited number of studies on the impacts of climate change on human health within the Caribbean subregion have been conducted to date,[44] those studies that do exist have found significant associations between climate variability and increased prevalence of certain climate-sensitive diseases.

A focus on the Caribbean subregion is especially warranted, given the emerging nature of their economies, the vulnerability of substantial proportions of their populations to disease, and the fact that the public health and care delivery systems, although improving, are generally underfunded. Public health systems may not always be adequate to face greater demands on their services (Bueno and others, 2008) and, as such, increasing rates of disease resulting from climate change have the potential to put considerable strain on the public health care delivery systems in these nations.

1. Climate-sensitive diseases in the Caribbean

(i) Vector-borne diseases

Vector-borne diseases are caused by a pathogen transmitted to humans, primarily via biting arthropods such as mosquitoes, flies, fleas, and ticks (Ebi and others, 2008; Kovats and others, 2003a). At a global scale, prominent vector-borne diseases that are climate-sensitive include: malaria, filariasis, dengue fever, yellow fever, west Nile virus, leishmaniasis, Chagas' disease, Lyme disease, tick-borne encephalitis, plague, varieties of mosquito-borne encephalitis, ehrlichiosis, African trypanosomiasis, and onchocerciasis (Ebi and others, 2008; Githeko and others, 2000; Kovats and others, 2003a; Kuhn and others, 2005). Of these diseases, the two that are most relevant to the Caribbean are malaria and dengue fever.

(a) Malaria

Malaria, currently the most prevalent vector-borne disease in the world and the world's most infectious disease (Baron, 2009; van Lieshout and others, 2004) is considered highly sensitive to climate change.[45] Consideration of malaria in the context of climate change in the Caribbean is particularly interesting because of its near total eradication between 1958 and 1965, and recent resurgence in multiple countries.

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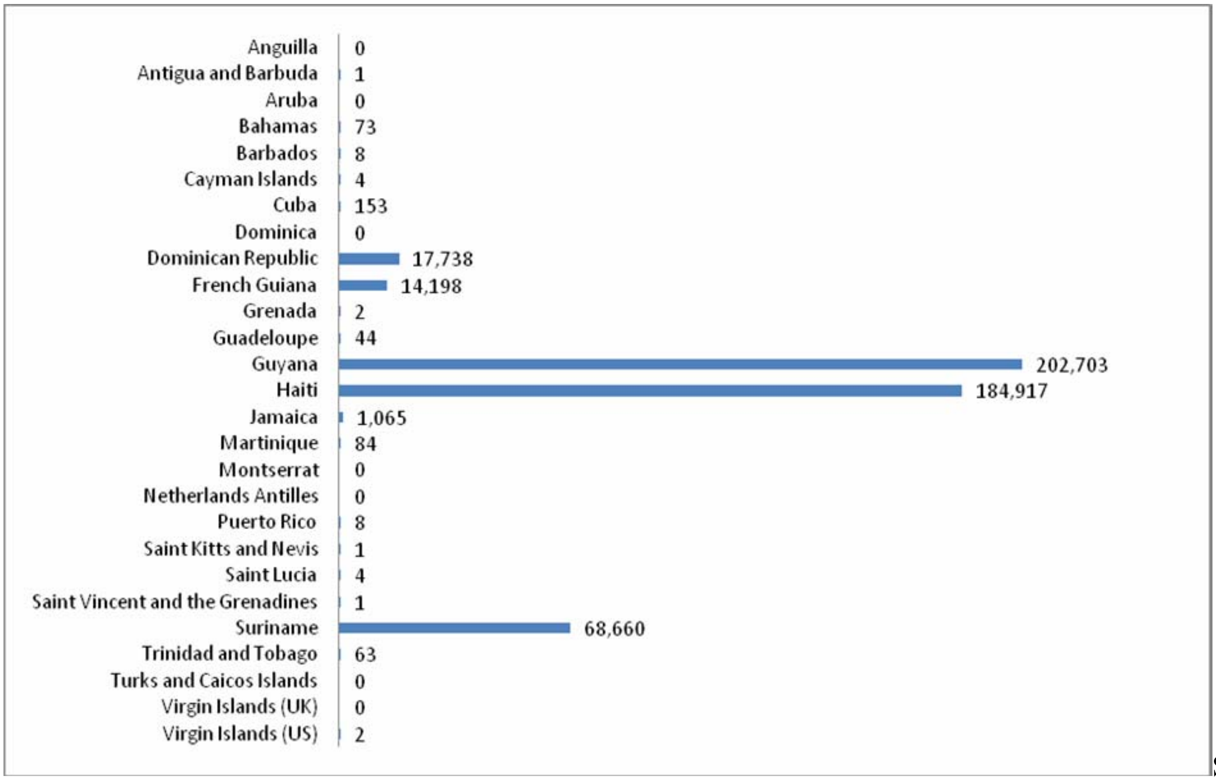
[44] See for example: Amarkoon and others (2005); Bueno and others (2008); Heslop-Thomas and others (2006); Caribbean Environmental Institute (2004).

[45] High temperatures increase the likelihood of malaria transmission, given that they reduce the extrinsic incubation period. Transmission may also increase during high temperatures as activities such as biting and egg laying are also accelerated. It should be pointed out that biting and egg laying are high risk activities for mosquitoes and so these two activities may affect the vector's survival rate (Kovats and others, 2003a; Kuhn and others, 2005; Martens, Jetten, & Focks, 1997; Martens, Jetten, Rotmans, & Niessen, 1995; Martens, Niessen, Rotmans, Jetten, & McMichael, 1995).

During the period 2001 to 2009 there were a total of 489,729 confirmed cases of malaria, with incidence being concentrated in only a few countries – Guyana, Haiti, Suriname, Dominican Republic and French Guiana (see figure 5.2 and appendices). In 2004, 140 non-endemic (imported) cases of malaria were confirmed in Jamaica, with the majority of these being imported due to the displaced Haitian population that began arriving in 2004. Special vector control interventions had to be devised to interrupt transmission (PAHO, 2007).

Figure 5.2: Caribbean: total malaria cases 2001-2009



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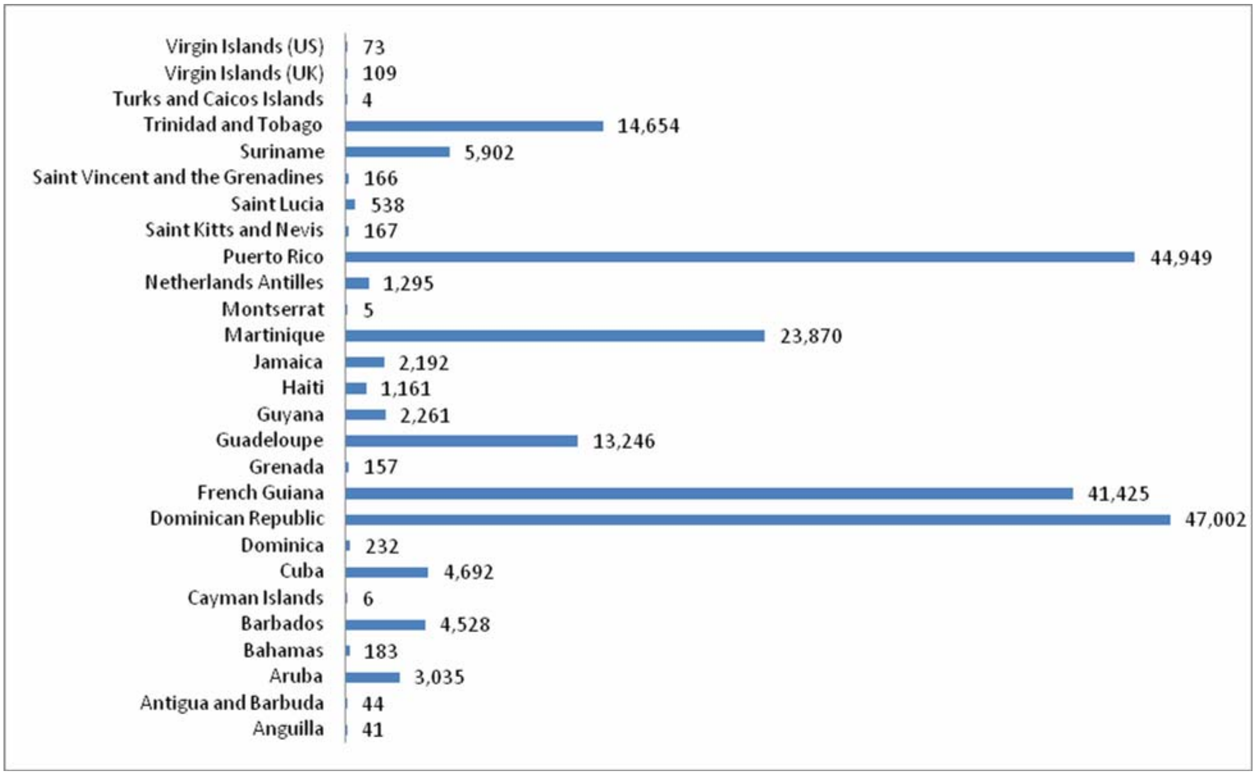
Source: Pan American Health Organization, Health Information and Analysis Project. Regional Core Health Data Initiative. Washington DC, 2010.

(b) Dengue fever

Dengue fever, and the more deadly dengue hemorrhagic fever, is caused by the transmission of a pathogen (one of four types of flavivirus) to humans by mosquitoes (primarily *Aedes aegypti* and *Aedes albopictus*). However, a significant difference between malaria and dengue fever is the extent to which the dengue vectors have become urbanized and indoor-dwelling. The extent of this urbanization is so complete that Aedes mosquitoes tend to breed exclusively in man-made water storage containers, and its lifecycle may be almost completely shielded in certain places from the effects of climate change-induced temperature and precipitation changes (Fuller and others, 2009; Githeko and others, 2000; Jansen and Beebe, 2010; Marten and others, 1997).

Between 50 -100 million cases of dengue fever occur globally every year, making the disease a strong rival to malaria for the title of ‘most important vector-borne disease’ (Fuller and others, 2009; Kovats and others, 2003a). In the Caribbean, between 2001 and 2009, there were 211,937 registered cases of dengue fever (see figure 5.3 and appendices).

Figure 5.3: Caribbean: Total registered dengue fever cases (2001-2009)



Source: Pan American Health Organization, Health Information and Analysis Project. Regional Core Health Data Initiative. Washington DC, 2010.

Considerable research has been undertaken on the potential disease burden of dengue fever due to climate change. Indications are that its transmission in the Caribbean will increase approximately three-fold, as increased temperature reduces the time for the parasite to incubate in mosquitoes, resulting in more rapid transmission of the disease (Chen, 2007). Additionally, greater occurrences of dengue fever in the warmer, drier period of the first and second years of El Niño events have been recorded (Amarkoon and others, 2005). Results obtained from the work of the Climate Studies Group at the University of the West Indies (Mona) suggest that dengue fever outbreaks in Jamaica are associated with warmer conditions, and the seasonality of the epidemics suggests that temperature and precipitation have some explanatory value (Heslop-Thomas, and others, 2006). It has also been suggested that the wet season represents the period of greatest risk for dengue fever transmission in the Caribbean, suggesting that vector mitigation programmes should be targeted at this time of year to reduce mosquito production and dengue fever transmission (Chadee and others, 2006).

(ii) Waterborne and food-borne diseases

Waterborne and food-borne diseases are transmitted to humans through physical contact with, inhalation of aerosolized particles from, or ingestion of, contaminated sources of water and food.[46] Although the specific reactions to changes in environmental conditions vary by pathogen, in general, increasing temperatures can lead to expanded geographic and altered seasonal/temporal ranges of these pathogens, as well as decreased development or replication times and increased pathogen population growth (except in the case of viruses where temperatures higher than particular thresholds result in virus inactivation).

[46] The pathogens that generate these diseases include viruses, bacteria, and parasites. As with vector-borne diseases, the most vulnerable groups are young children, the elderly, and anyone whose immune system is compromised (Ebi and others, 2008).

Extreme variations in precipitation levels may result in higher loading of local water resources with pathogens. This excess of pathogens can then be passed on to humans through contact with, or consumption of, the contaminated water, or through the consumption of food that came into contact with the contaminated water. Importantly, precipitation and temperature changes affecting coastal environments can also drive changes in coastal aquatic bacteria populations as a result of increased or decreased surface water salinity (Ebi and others, 2008; Kovats and others, 1999; Kovats and others, 2003b; McMichael and others, 2004).

The waterborne diseases of most relevance to the Caribbean (and for which data are available) are gastroenteritis and leptospirosis.

(a) Gastroenteritis

The largely non-life-threatening inflammation of the gastrointestinal tract causes bouts of diarrhoea and is triggered by a large number of viruses, bacteria, and parasites which are transmitted to humans via contact with contaminated food and water. Because many of the causative agents of gastroenteritis are sensitive to environmental change, researchers anticipate that the impact of climate change on gastroenteritis will be highly significant (Ebi and others, 2008; Kovats and others, 2003b; McMichael and others, 2004).

Between 1980 and 2005, a total of 739,856 gastroenteritis cases were reported among children less than 5 years of age in Caribbean Epidemiology Centre (CAREC) member countries.[47] Reports for Jamaica, Guyana and Suriname accounted for 55%, 12% and 8% of all cases, respectively, over the review period (CAREC, 2008). Trends indicate that rates of the disease appear to be increasing over time. In Guyana, since 1994 when reporting of gastroenteritis cases in persons 5 years old and over began, there has been an increasing trend, from a low of 7,138 cases in 1994 to highs of 46,403 and 39,294 cases in 2004 and 2005, respectively. During 2010, there were 30,861 cases of gastroenteritis reported for Guyana, with approximately 38% of these cases being among the under-5 years of age population. Similarly, in Trinidad and Tobago, the rates of new cases reported show an increasing linear trend between 1989 and 2005 (see appendices).

(b)Leptospirosis

Leptospirosis is caused by more than 200 serovars of the more than 16 species of bacteria in the genus *Leptospira*, which are common around the world (Levett, 2001). Transmission to humans occurs when contact occurs between the bacteria (which are released into the environment through the bodily fluids of various mammals, including rodents, reptiles, and amphibians) and human mucous membranes, waterlogged skin, or broken skin.

Transmission of leptospirosis to humans is responsive to environmental change in two respects. First, land use patterns can make certain environments more conducive to populations of the bacteria-carrying mammals; and secondly, precipitation events wash the bodily fluids containing the bacteria into local bodies of water, thereby concentrating them and increasing the likelihood of human contact with them (Victoriano and others, 2009). For example, above-average precipitation which results in flooding can displace rodent populations, forcing them to seek shelter and food in higher ground, thereby increasing possible human contact with rodents. Flooding may also increase the risk of food and water contamination with rodent urine and/or rodent feces, thus increasing the risk of transmission.

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[47] Anguilla, Antigua and Barbuda, Aruba, the Bahamas, Barbados, Belize, Bermuda, Cayman Islands, Dominica, British Virgin Islands, Grenada, Guyana, Jamaica, Montserrat, Netherlands Antilles, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Turks and Caicos Islands.

In Trinidad and Tobago, the number of new leptospirosis cases has increased significantly over the period 1981 to 2007, with more than 2,500 cases reported during this period (CAREC, 2008). Over 100 cases were reported each year during the period 1997 to 2006. Leptospirosis incidence (per 100,000 population) in 2007 was 3 times that in 1981. Relatively high incidence rates were recorded over the period 1997 to 2006.

Research confirming the relationship between precipitation and the incidence of leptospirosis is fairly limited. However, a study using data from Guadeloupe (see figure 5.4) shows a clear association between changes in precipitation and reported leptospirosis incidence through time (Storck and Herrmann, 2008).

Figure 5.4: Overlapped time series of reported cases of leptospirosis and rainfall in Guadeloupe

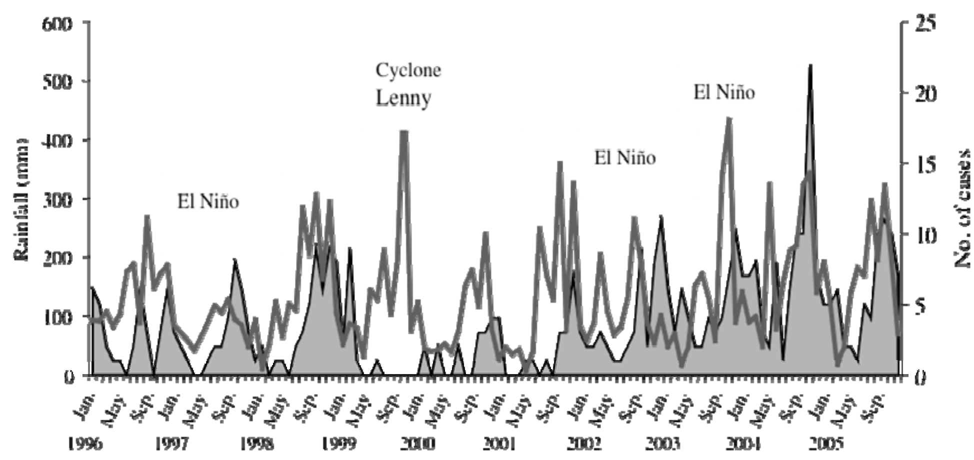

Fig. 2. Monthly rainfall (—) and leptospirosis cases (□) for 1996 2005.

Source: Storck, C. & Hermann, D. (2008)

2. Other conditions that could be impacted by climate change

These include diseases and conditions that may be potentially impacted by changes in the environment including heat-related morbidity and mortality, morbidity and mortality resulting from extreme events such as cyclones, or hurricanes, cardiovascular and respiratory diseases including hypertension and asthma, and malnutrition.

There is strong evidence suggesting that climate change will impact on the disease burden associated with cardiovascular and respiratory conditions because of the sensitivity of human cardiovascular and respiratory systems to temperature change. Increases in temperature increase blood viscosity. In turn, this can trigger heart attacks, strokes, and other vascular events. Temperature changes can also increase the heart rate, cause constriction of the bronchial tubes, and exacerbate both acute and chronic respiratory conditions (Campbell-Lendrum and others, 2003; Ebi and others, 2008; McMichael and others, 2004). Adults, who suffer from preexisting cardiovascular and respiratory diseases, the elderly, children, outdoor labourers, and the mentally ill, are most vulnerable to this category of impact. Additionally, individuals who lack access to air conditioning are more at risk, as are those individuals who reside in cities and are exposed to the 'urban heat island effect,' as both these factors exacerbate the effects of temperature increases (Ebi and others, 2008; Hales and others, 2003; Luber and Prudent, 2009).

The importance of this potential health impact is largely a consequence of the fact that cardiovascular diseases are currently the global leading cause of death (Chiu and others, 2010). This is also true for the Caribbean. In 2000, cardiovascular and respiratory diseases held six of the top ten spots for leading causes of death among CAREC member countries (CAREC, 2005; Freeman and others, 1996; PAHO, 2009). As is the case with most regions currently suffering a significant burden from cardiovascular and respiratory diseases, the Caribbean started to experience increased incidence of these diseases following an epidemiological transition. This transition saw increased caloric availability, decreased vector-borne and water and food-borne illness compared to historic levels, and a significant dietary shift comprising of increased sugary, salty and fatty foods intake (Albert and others, 2007; Cunningham-Myrie and others, 2008).

C. APPROACH TO ESTIMATING CLIMATE CHANGE IMPACT

The relationship between climate change and health is complex, as climate change is not a typical "health exposure" variable since it does not directly display a cause to effect nexus as sometimes seen in other determinants of health. The complexity of the relationship is compounded by the interrelationship between health and factors such as socio-economic status, disease susceptibility, cultural practices and the built environment.[48] These are also influenced by the choices people make at the individual and governmental policy levels.[49]

1. Methods available for estimating the effects of climate change on health

There are several methods available for estimating the effects of climate change on health (McMichael and others, 2001):

1. Partial analogue studies that project future aspects of climate change
2. Observing early evidence of changes in health status linked to changes in climate
3. Using existing empirical knowledge and theory to conduct predictive modelling or other integrated assessment of likely future health outcomes.

See table A1 in the appendix for a detailed explanation of the various methodologies that can be used to estimate the effects of climate change on health.

Climate change impacts on disease incidence were estimated for dengue fever, malaria, gastroenteritis (in total population and separately for children under 5 years old and population over 5 years old), leptospirosis and food borne diseases. In general, multivariate regressions were estimated to establish relationships between disease incidence and key independent variables. This technique was applied in the studies for Guyana, Jamaica, and Trinidad and Tobago. In the case of Saint Lucia and Montserrat, a dose response function was applied (see box 5.1).

These models were then used to predict disease incidence for the next four decades (2011 through 2050) based on forecast climate variables for the IPCC A2 (high emission) and B2 (a low emission) scenarios. Projected disease estimates under A2 and B2 were then compared to estimates made under business as usual (BAU), a baseline representing a scenario without climate change impacts. The economic value of the potential disease burden due to climate change was estimated from the projected

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[48] Three primary reasons for this complexity are: the large spatial scale (i.e. national, regional or global); the long temporal scale (20-100 years); and the level of complexities in the biological systems and their relationship with the other determinants of health (disease susceptibility, the built environment, socio-economic status and cultural practices) (McMichael, Haines, & Kovats, 2001).

[49] A simplistic example is our natural response to heat. If climate change causes extreme heat, people may choose to stay in a cool place (e.g. an air conditioned room), thereby reducing their exposure to heat stress. The ability of human beings to adapt to their environment adds to the uncertainty of future health impacts on climate change. Thus, making an assessment of the health impact of climate change in the future is complex.

disease incidence on the basis of current per capita treatment costs and other related costs associated with each disease.

2. Dose-response approach to projecting climate change impacts

A linear dose-response approach may be used to project and value the excess disease burden caused by climate change in cases where data is scarce. This approach assumes that for every unit change in a climate change variable, there will be specific unit change in the incidence of disease. The relationships are assumed to be linear since the rate of change in disease incidence will not vary across different climate change values. The published literature provides established dose-response relationships under the various climate scenarios. Unlike regression models, other factors such as socio-economic variables and environmental and technological variables are not included (and therefore implicitly remain constant). For Montserrat and Saint Lucia, established dose-response relationships for malaria, gastroenteritis and cardiovascular and respiratory disease (mortality) were obtained and used to predict future disease incidence, based on projected changes in temperature and rainfall for the Caribbean under the IPCC SRES A2 and B2 scenarios. For example, the literature suggests that for every 1 degree Celsius increase in temperature, the incidence of gastroenteritis in the entire population, as well as in the population over the age of 5, is projected to increase by 3% (see table 5.2).

Table 5.2: Dose-response relationships used to project disease incidence in Montserrat and Saint Lucia

Diseases		Morbidity dose-response relationship		Mortality dose-response relationship	
		Relationship	Source	Relationship	Source
Malaria		0.475 days illness/↑1˚C	(Tol, 2008)	1.045 deaths/↑1˚C	(Tol, 2008)
Gastro enteritis	<5 years of age	↑4%/↓10 mm rain	(Lloyd, 2007)	n.a.	n.a.
	>5 years of age and Total Pop	↑3%/↑1˚C	(Singh and others, 2001)	n.a.	n.a.
Cardiovascular and Respiratory Diseases		n.a.	n.a.	↑3.2%/↑1˚C	(Hashizume, and others, 2009)

D. RESULTS

1. Dengue fever

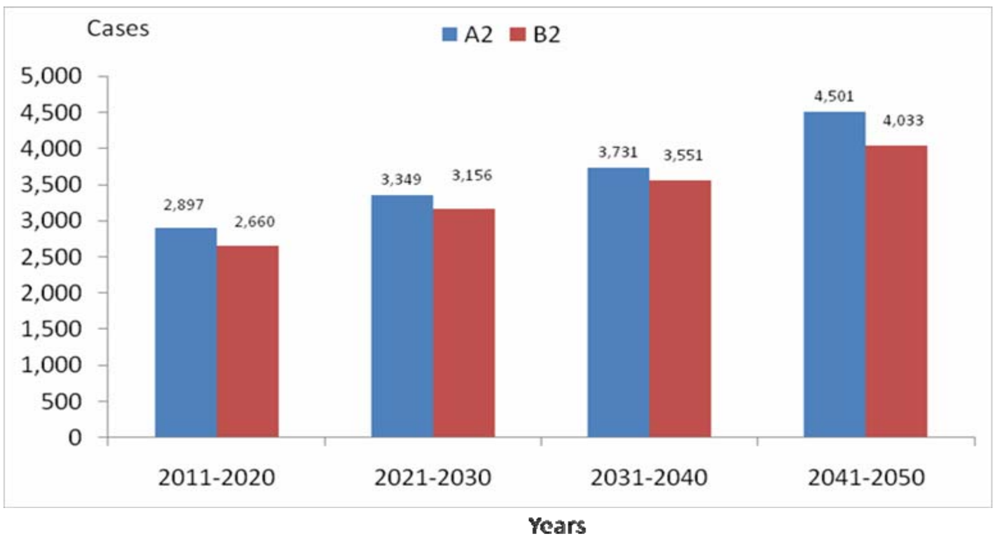
Projections of the incidence of dengue fever in Jamaica, Guyana, and Trinidad and Tobago show different trajectories across the three countries over a four-decade period. In Jamaica, the disease incidence under both the A2 and B2 scenarios increased steadily across the four decades, as shown in table 5.3 and figure 5.5 (ECLAC, 2011a). In the case of Guyana, the number of cases projected under both the A2 and B2 emissions scenarios remained relatively static over time (see figure 5.6) (ECLAC, 2011). However, in Trinidad and Tobago, incidence levels under the A2 and B2 scenarios appeared to follow a similar increasing trend until 2037 (ECLAC, 2011b) when the number of cases decreased in the B2 scenario and increased under the A2 scenario (see figure 5.7). Total numbers of cases for the period 2008 through 2050 were estimated at 153,752 and 131,890 for the A2 and B2 scenarios, respectively. Increased rainfall was found to be associated with increases in the number of dengue fever cases in all three countries, but the degree of sensitivity largely depended on the specification of the models.

Table 5.3: Projected dengue fever cases by scenario and decade

Country	2011-2020		2021-2030		2031-2040		2041-2050	
	A2	B2	A2	B2	A2	B2	A2	B2
Jamaica	2,897	2,660	3,349	3,156	3,731	3,551	4,501	4,033
Guyana	4,200	4,200	4,215	4,189	4,210	4,210	4,295	4,272
Trinidad and Tobago	27,814	24,847	36,880	35,207	40,169	35,714	40,645	27,885

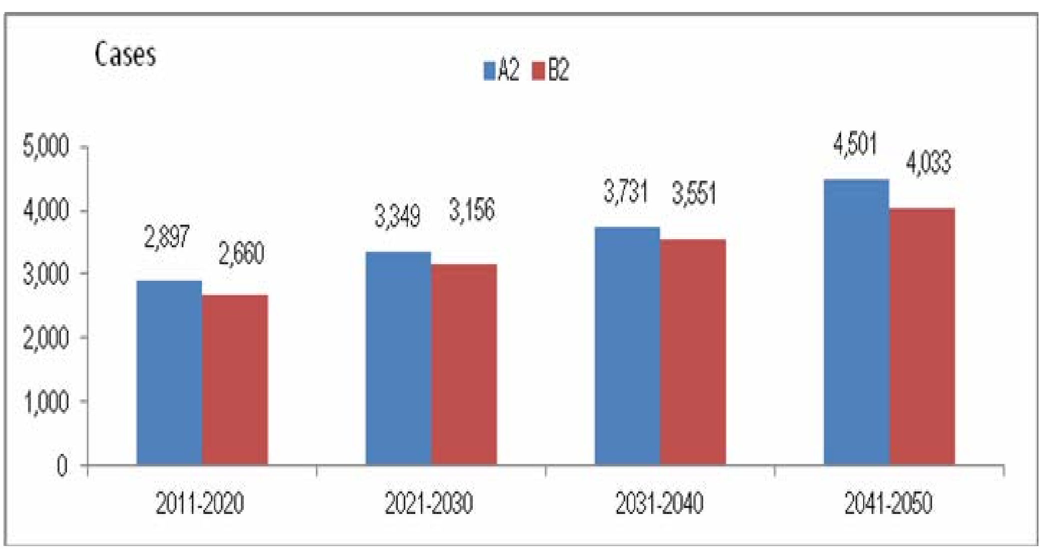
Sources: ECLAC (2011): ECLAC (2011a): ECLAC (2011b)

Figure 5.5: Projected dengue fever cases by scenario and decade, Jamaica



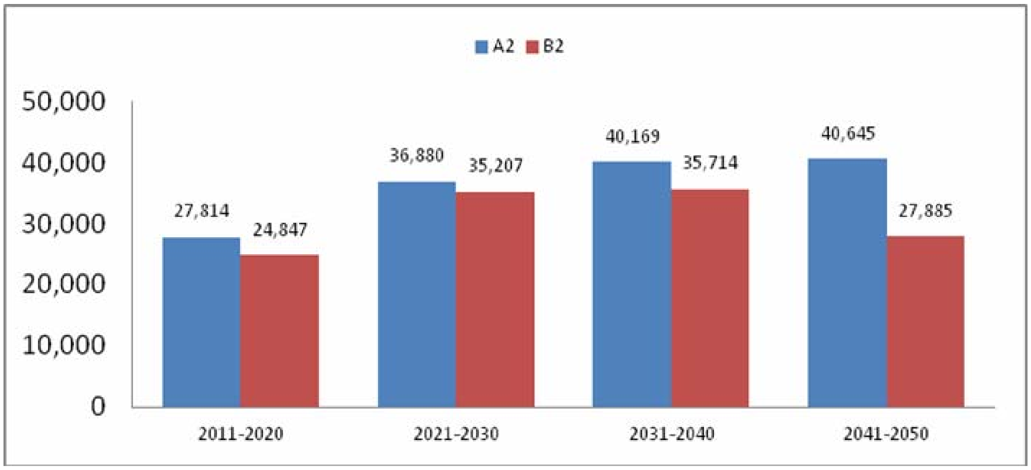
Source: ECLAC (2011a)

Figure 5.6: Projected dengue fever cases by scenario and decade, Guyana



Source: ECLAC (2011).

Figure 5.7: Projected dengue fever cases by scenario and year, Trinidad and Tobago



Source: ECLAC (2011b).

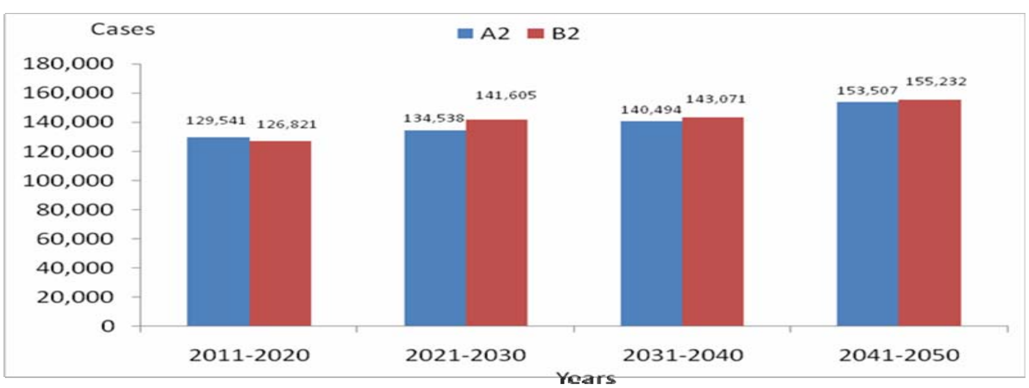
2. Gastroenteritis

Guyana and Jamaica present two conflicting trends associated with the incidence of gastroenteritis in their total populations through to 2050. In Guyana, under both the A2 and B2 scenarios, the number of cases are expected to increase over time (as shown in figures 5.8 and 5.9) (ECLAC, 2011).

In comparison, the incidence of gastroenteritis among the under-5 population in Jamaica declines across the decades for both scenarios (see figure 5.10) (ECLAC, 2011a). However, both in Guyana and Jamaica, the number of A2 cases are generally fewer than the number of cases under the B2 scenario (ECLAC, 2011a).

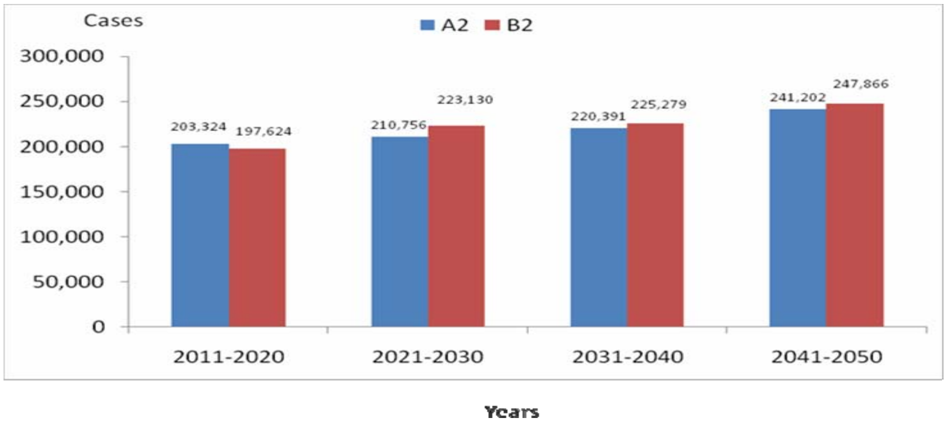
One explanation for the differences in projections has to do with the impact of temperature on the prevalence of the disease. In Jamaica, both increases in rainfall and temperature result in a decrease in the number of cases, with changes in temperature having more influence than rainfall (ECLAC, 2011a). However, in Guyana, although increase in rainfall had a negative effect on the number of cases, unlike Jamaica, temperature increases had a positive effect on the prevalence. As in Jamaica, in Guyana temperature had a much greater effect on the number of cases compared to rainfall and therefore drove the change in the number of cases over time (ECLAC, 2011).

Figure 5.8: Projected gastroenteritis (under age 5) cases by scenario and decade, Guyana



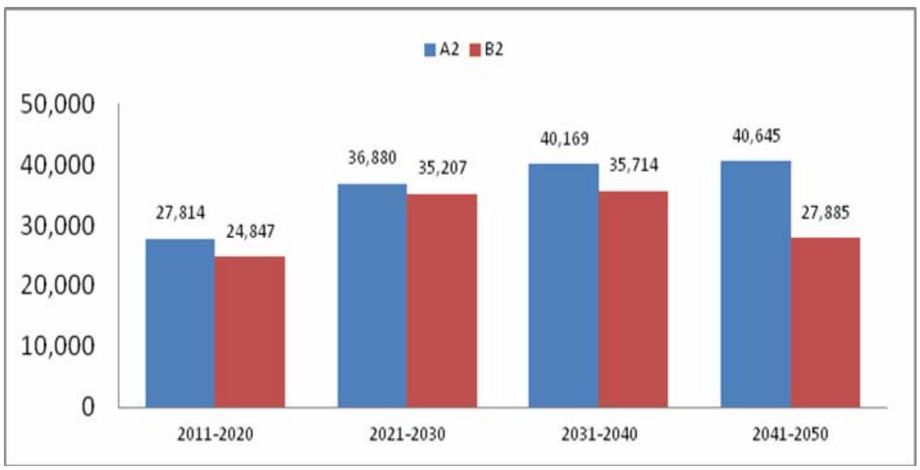
Source: ECLAC (2011).

Figure 5.9: Projected gastroenteritis (over age 5) cases by scenario and decade, Guyana



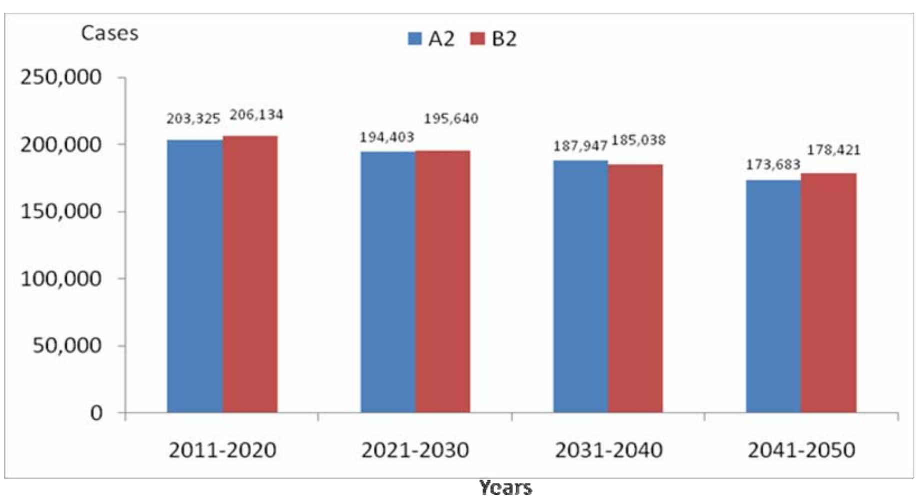
Source: ECLAC (2011).

Figure 5.10: Projected Dengue Fever Cases by Scenario and Decade, Trinidad and Tobago



Source: ECLAC (2011b)

Figure 5.11: Projected gastroenteritis cases (under age 5) by scenario and decade, Jamaica

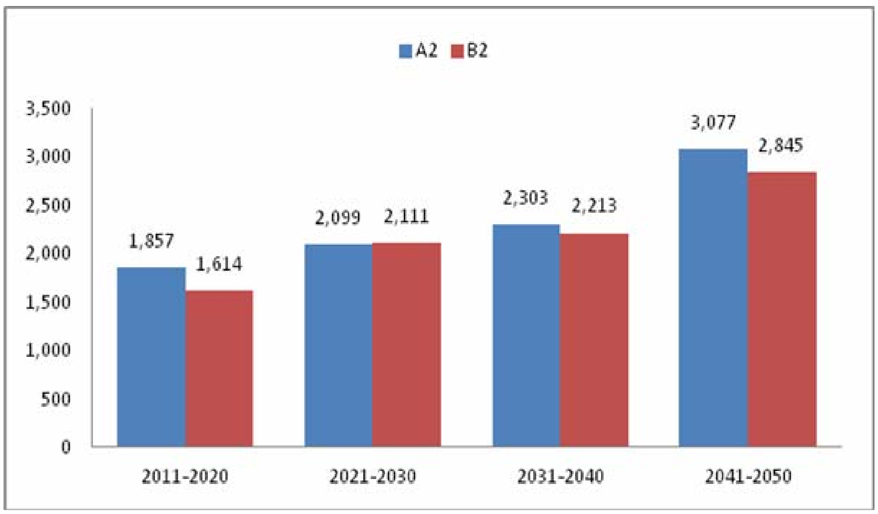


Source: ECLAC (2011a).

3. Leptospirosis

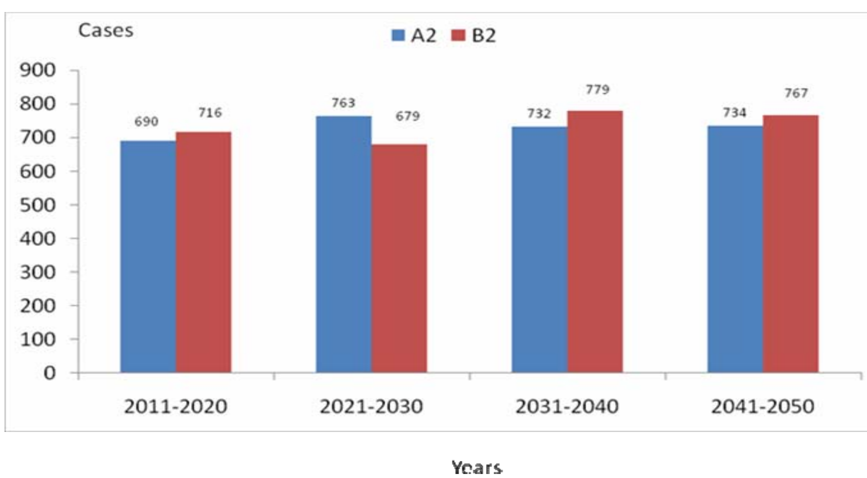
For Trinidad and Tobago, the projections show a steady increase in the number of leptospirosis cases for both the A2 and B2 scenarios (see figure 5.11) (ECLAC, 2011b). Both the A2 and B2 scenarios follow a similar path, with a total number of new cases by 2050 projected to be 9,727 and 9,218, respectively. Guyana is projected to have fewer cases over the same time period, averaging between 690 and 760 cases per decade under the A2 scenario, and between 700 and 780 cases under the B2 scenario (figure 5.12) (ECLAC, 2011). Consistent with the literature (Storck & Herrmann, 2008), both the models in Guyana and Trinidad and Tobago demonstrated that, as rainfall increases, the expected number of cases of leptospirosis will also increase.

Figure 5.12: Leptospirosis cases by scenario, Trinidad and Tobago



Source: ECLAC (2011b).

Figure 5.13: Projected leptospirosis cases by scenario and decade, Guyana



Source: ECLAC (2011).

4. Summary: Climate change impacts relative to the business as usual case

(a) Guyana, Jamaica, and Trinidad and Tobago

Tables 5.5 and 5.6 show the excess number, or percentage difference, in cases of disease that could occur under either the A2 or B2 scenarios compared to the BAU case for Guyana, Trinidad and Tobago, and Jamaica. In general, between 2011 and 2050 (2008 through 2050 in the case of Trinidad) disease incidence is projected to be higher under both emissions scenarios compared to the BAU case. For example, in Guyana, climate change is expected to result in between 300,000 and 400,000 additional cases of malaria - a 35% to 48% increase over BAU. Most startling is the expected increase in the number of cases of leptospirosis in Jamaica. Under the two climate change scenarios, the incidence of leptospirosis is projected to be approximately 500% higher (between 31,000 and 34,000 additional cases) than under BAU.

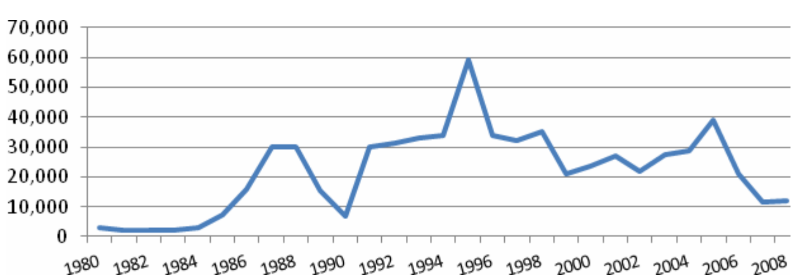
Table 5.4: Number of excess (or deficit) cases projected under A2 and B2 relative to BAU by disease

Projection Time Period	Guyana		Trinidad and Tobago		Jamaica	
	2011-2050		2008-2050		2011-2050	
	A2	B2	A2	B2	A2	B2
Dengue fever	(2 132)	(2 171)	(51 061)	(72 896)	4 897	3 819
Malaria	296 450	404 060	n.a.	n.a.	n.a.	n.a.
Gastroenteritis in total population	258 802	286 677	115 421	457 919	n.a.	n.a.
Gastroenteritis in children under 5 years	92 628	102 277	n.a.	n.a.	8 926	14 801
Gastroenteritis in individuals over 5 years	166 174	184 400	n.a.	n.a.	n.a.	n.a.
Leptospirosis	n.a.	n.a.	2 389	1 880	34 079	30 851

Sources: ECLAC (2011) : ECLAC (2011a) : ECLAC (2011b)

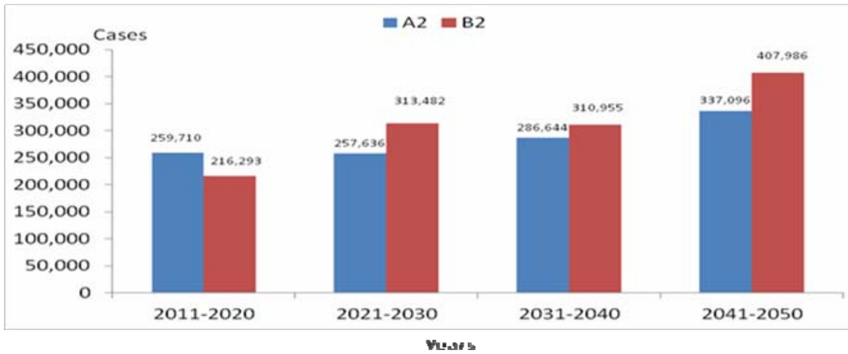
Unlike other Caribbean nations, malaria remains one of the most common vector- borne diseases in Guyana. The average number of malaria cases between 1991 and 1998 was about 49,000. In 1996, the number of cases peaked at about 60,000 (see figure 5.14.) However, by 2009 the annual incidence was just under 12,000. The disease is endemic in the interior regions of the country including Regions 1, 7, 8, and 9, which see higher incidence rates compared to the rest of the country. Increased mining and logging activities are some of the major causes of the higher prevalence rates in these regions (ECLAC, 2011).

Figure 5.14: Total registered malaria cases in Guyana, 1980 – 2008



Source: ECLAC (2011).

Figure 5.15: Projected malaria cases by scenario and decade, Guyana



Source: ECLAC (2011).

Projections through to 2050 show that, under both the A2 and B2 scenarios, the number of malaria cases is expected to increase. With the exception of the first decade, projections indicate more cases of malaria under the B2 scenario compared to the A2 scenario (see figure 5.15).

Table 5.5: Number of excess (or deficit) cases projected under A2 and B2 relative to BAU by disease

Projection Time Period	Guyana		Trinidad and Tobago		Jamaica	
	2011-2050		2008-2050		2011-2050	
	A2	B2	A2	B2	A2	B2
Dengue fever	(2 132)	(2 171)	(51 061)	(72 896)	4 897	3 819
Malaria	296 450	404 060	n.a.	n.a.	n.a.	n.a.
Gastroenteritis in total population	258 802	286 677	115 421	457 919	n.a.	n.a.
Gastroenteritis in children under 5 years	92 628	102 277	n.a.	n.a.	8 926	14 801
Gastroenteritis in individuals over 5 years	166 174	184 400	n.a.	n.a.	n.a.	n.a.
Leptospirosis	n.a.	n.a.	2 389	1 880	34 079	30 851

Sources: ECLAC (2011) : ECLAC (2011a) : ECLAC (2011b)

Table 5.6: Difference in the number of forecast cases under A2 and B2 relative to BAU, 2011-2050 (%)

Disease	Guyana		Trinidad and Tobago		Jamaica	
	A2	B2	A2	B2	A2	B2
Dengue fever	-11.18	-11.38	-24.93	-35.60	51.09	39.84
Malaria	35.09	47.83	n.a.	n.a.	n.a.	n.a.
Gastro - total population	22.02	24.40	11.80	46.80	n.a.	n.a.
Gastro under age 5	19.90	21.97	n.a.	n.a.	1.19	1.20
Gastro over age 5	23.42	25.99	n.a.	n.a.	n.a.	n.a.
Leptospirosis	n.a.	n.a.	32.55	25.62	531.15	480.84

Sources: ECLAC (2011) : ECLAC (2011a) : ECLAC (2011b)

b) Saint Lucia and Montserrat

Table 5.7 depicts the excess disease burdens for Saint Lucia and Montserrat. The excess disease burden expected under the two climate change scenarios compared to baseline estimates show relatively little change in the case of Montserrat throughout the 40 year period. However, for Saint Lucia, approximately

25,000 additional cases of gastroenteritis among children under the age of 5, and 12,000 additional cases of respiratory disease are projected.

Table 5.7: Excess disease burden 2010-2050 relative to baseline

2010-2050 total mean disease burden anomaly	Morbidity anomaly Saint Lucia		Morbidity anomaly[50] Montserrat	
Diseases	A2	B2	A2	B2
Dengue Fever	209	168	n.a.	n.a.
Gastroenteritis				
• <5 years of age	24 237	19 180	n.a.	n.a.
• >5 years of age	5 193	4 517	n.a.	n.a.
• Total population	29 430	23 697	484	427
Respiratory Disease	12,279	9.894	253	203

Sources: ECLAC (2011c): ECLAC (2011d)

5. Economic impact

(a) Guyana, Jamaica and Trinidad and Tobago

Table 5.8 shows the expected treatment costs[50] in United States dollars under the A2 and B2 scenarios, assuming a 1% discount rate. Comparing the A2 and B2 scenarios within each country, treatment costs are fairly similar. For example, in Guyana, under both the A2 and B2 scenarios, treatment costs for dengue fever are around US$ 13 million, while in Jamaica the costs are between US$ 25 million and US$ 26 million. For the conditions reported in table 5.10, Jamaica and Guyana can expect to pay a minimum of US$ 280 million for the treatment over the next 40 years, whereas Trinidad and Tobago can expect to pay around US$ 36 million for the treatment of these conditions that are highly susceptible to climate change.

Table 5.8: Total treatment costs under (A2) and B2 scenarios 2011-2050 (NPV at 1% discount rate, $US million)

Disease	Guyana		Trinidad and Tobago		Jamaica	
	A2	B2	A2	B2	A2	B2
Dengue fever	$13.871	$13.839	$24.255	$20.840	$26.280	$25.175
Malaria	$0.125	$0.137	n.a.	n.a.	n.a.	n.a.
Gastroenteritis - total population	$283.912	$289.431	$9.405	$12.276	n.a.	n.a.
Gastroenteritis under age 5	$110.511	$112.422	n.a.	n.a.	$239.597	$241.361
Gastroenteritis over age 5	$173.401	$177.010	n.a.	n.a.	n.a.	n.a.
Leptospirosis	n.a.	n.a.	$3.168	$3.069	$19.487	$18.864
Total costs	$297.908	$303.408	$36.828	$36.185	$285.364	$285.400

Country analysis also included indirect and treatment costs which are not included in table 5.10. Sources: ECLAC (2011): ECLAC (2011a): ECLAC (2011b):

Table 5.9 compares treatment costs associated with the A2 and B2 scenarios to the BAU case for select conditions. This table shows that countries can expect treatment costs to be generally higher under

[50] Treatment costs were calculated differently in each country report. Guyana: dengue fever per patient treatment was assumed to be US$ 828; anti-malaria medication was estimated at US$ 0.011 for the cost of chloroquine, and US$ 200 for treatment of gastroenteritis. Trinidad and Tobago: Dengue fever treatment per patient costs estimated at US$ 1,596; food-borne illness US$ 77 for an uncomplicated case and US$ 168 average cost per bed day; leptospirosis US$ 70 per outpatient visit, US$ 874 median cost per inpatient day in the ICU; gastroenteritis US$ 70 per outpatient visit, US$ 168 average cost per bed day. Jamaica: dengue fever per patient treatment estimates were US$ 828; gastroenteritis US$ 285; and leptospirosis US 195. Saint Lucia: US$ 300 cost per case regardless of disease, assuming a 10% increase per annum.

climate change compared to the status quo. However, as would be expected, treatment costs for dengue fever under A2 and B2 are likely to be lower than the BAU case for both Guyana and Trinidad and Tobago. In Guyana, treatment costs for dengue fever will be lower by about 11 % under both scenarios, and in Trinidad, costs will be lower by about 33 % and 55 % for A2 and B2, respectively.

For all three countries, climate change may result in higher gastroenteritis treatment costs compared to the BAU. For example in Guyana, treatment associated with gastroenteritis in populations over the age of 5 will be about 19% higher under A2 and 26% higher under B2. Jamaica, unlike Guyana, and Trinidad and Tobago will see higher dengue fever related treatment costs under climate change and can expect about an additional US$ 6 million in costs for leptospirosis. Climate change will also result in a relatively small increase in malaria treatment costs in Guyana.

(b) Saint Lucia and Montserrat

As shown in Table 5.9 both Saint Lucia and Montserrat can expect additional treatment costs associated with climate change. Excess treatment costs for Saint Lucia will range between US$ 2.4 million and US$ 4 million. In comparison, Montserrat can expect to incur approximately no more than US$ 300,000 in additional expenditures. Most of the additional expenditures in Saint Lucia can be attributed to an increase in the number of cases of gastroenteritis under climate change.

Table 5.9: Excess treatment costs associated with A2 and B2 scenarios relative to the BAU case 2011-2050 (NPV 1% discount rate, US$)

Disease	Guyana		Trinidad and Tobago		Jamaica	
	A2	B2	A2	B2	A2	B2
Dengue fever	($1747 434)	($1 779 209)	($80 982 000)	($115 137 000)	$5 018 681	$3 913 895
Malaria	$32 580	$44 407	n.a.	n.a.	n.a.	n.a.
Gastroenteritis total population	$51 247 875	$56 767 660	$10 494 000	$39 798 000	n.a.	n.a.
Gastroenteritis under age 5	$18 342 144	$20 252 857	n.a.	n.a.	n.a.	n.a.
Gastroenteritis over age 5	$32 905 731	$36 514 803	n.a.	n.a.	$2 679 270	$4 442 997
Leptospirosis	($12)	($33)	$792 000	$693 000	$6 685 442	$5 961 823
Total (Net)	**$100,780,884**	**$111,800,485**	**($69,696,000)**	**($74,646,000)**	**$14,383,393**	**$14,318,715**

Note: Country analysis also included indirect and treatment costs which are not included in this table. Refer to country reports for cost assumptions and calculations. Sources: ECLAC (2011): ECLAC (2011a): ECLAC (2011b):

Table 5.10: Excess treatment costs associated with A2 and B2 scenarios relative to the BAU case 2011-2050 (assuming a 1% discount rate; US$)

	Saint Lucia		Montserrat	
Disease	**A2**	**B2**	**A2**	**B2**
Dengue fever	$33 601	$9 494	$33 601	$9 495
Malaria	$31 214	$30 449	$441	$437
Gastro	$3 372 881	$2 070 204	$228 930	$204 471
Cardio and respiratory	$592 155	$370 060	$42 167	$19 417
TOTAL	**$4 029 851**	**$2 480 207**	**$305 139**	**$233 820**

Cost per case is estimated at US$300 rising at 10% per annum to 2050. Sources: ECLAC (2011c): ECLAC (2011d):

E. HEALTH SECTOR ADAPTATION STRATEGIES

Adaptation policies are strategic actions intended to result in the reduction of vulnerabilities associated with the effects of climate change (Sanderson and Islam, 2007). Health sector adaptation responses to climate change tend to be population-based public health approaches to disease prevention and health promotion. In developing services to reduce the potential impact of climate change, Caribbean public health professionals must be cognizant of several practical realities (Frumkin, Hess, Luber, Malilay and

McGeehin, 2008). First, as demonstrated throughout the country studies, the effects of climate change will vary across locations. Change in disease incidence and prevalence will not be uniform across locations sharing similar cultures, geography, and economic realities. Second, complexity is a key reality when considering climate change and health. Estimating the adaptation costs in the health sector is challenging not only because of the large existing uncertainties about how the climate will evolve over the coming century, but also because of the complex and often poorly understood chains through which health impacts are mediated.

The health outcomes that are linked to climate change also depend on a host of other factors, some of which are not likely to be currently anticipated, such as the emergence of new diseases, and others that are difficult to predict, such as the development of vaccines to address existing and new ailments. Third, climate change impacts will vary across population groups. Because of these three realities, health sector adaptation to climate change will have to be multidimensional (Frumkin, and others, 2008).

1. Sanitation and water supply

Country studies provided strong and convincing evidence of the link between improved sanitation and water supply and a reduction in the incidence of disease. For example, water and sanitation programmes will reduce the number of gastroenteritis cases in the population by 30 % resulting in a reduction in treatment costs and productivity losses. Empirical results of the dengue fever, leptospirosis, and gastroenteritis models for Trinidad and Tobago show that the disease incidence is quite sensitive to the availability of sanitation facilities (ECLAC, 2011b). The estimates show that a 1% increase in the population with access to improved sanitation facilities, results in a reduction in the incidence of dengue fever by about 453 cases[51] and of leptospirosis incidence by 10 cases. In Jamaica, significant cost savings associated with the prevention of dengue fever, gastroenteritis, leptospirosis are to be achieved by improving access to potable water and improved sanitation (table 5.11).

Table 5.11 Summary Table of adaptation strategies recommended increasing savings and averting/preventing the most cases of disease, Jamaica

Projected time (2011-2050)	Adaptation strategy	Impact
Dengue fever	Improve sanitation by 5%	Will reduce the number of expected cases by between 6,000 and 7,000 cases in both the A2 and B2 scenarios. Will save approximately between US$ 5.2 million and US$ 5.5 million.
Gastroenteritis	Improve access to potable water by 5%	Will reduce the number of cases under both scenarios by over 74,000. This will result in about US$ 21 million in cost savings.
Leptospirosis	Improve sanitation by 5%	Will reduce the number of cases by about 7,000 in both scenarios, resulting in over US$ 600,000 in cost savings.

Source: ECLAC (2011a)

The vaccine to prevent gastroenteritis caused by the rota-virus has shown effectiveness in reducing the incidence of the disease. However, the Jamaica country analysis showed it costs twice as much to prevent the disease using this method than it does to treat the disease (ECLAC, 2011a). Thus, to prevent gastroenteritis the best gains are likely to be achieved by increasing access to potable water rather than in making the vaccine available through a government funded public health immunization schedule.

2. Bed nets and spraying programmes

[51] If the population is further segmented into rural and urban, a 1% increase in improved water sources in rural areas could reduce dengue fever by about 306 cases.

The provision of impregnated bed nets and the implementation of a pesticide spraying programme are two key adaptation strategies associated with the prevention of malaria. Analysis using data from Guyana showed that the introduction of a bed net programme will generate both tangible and intangible benefits in the form of lower treatment and productivity losses associated with the incidence of malaria in that country (ECLAC, 2011). Similar analysis showed that a spraying programme would also likely reduce the number of cases of malaria within the population to whom the programme is administered. This would also result in a reduction of treatment costs and productivity losses associated with the disease. However, the spraying programme was found to have a much shorter payback period relative to the provision of bed nets (ECLAC, 2011).

F. CONCLUSIONS AND RECOMMENDATIONS TO POLICYMAKERS

The effects of climate change on health will very likely be different from country to country depending on the specific level of vulnerabilities. However, these analyses have shown that for all countries will likely experience increasing incidence of disease under the two climate change scenarios. A country's ability to adapt to climate change will depend, on the availability of local resources, the ability to spread and manage risk, public awareness, local attitudes towards the problem, the degree to which a climate change agenda is interwoven with other national and regional sectors and political will. In addition, sound strategic planning and program development cannot occur without the availability of reliable long-term data suitable for making accurate and valid projections on climate change's impact on the public's health.

1. The case for a regional Caribbean response

Countries are going to have to develop sound public health strategies aimed at mitigating the effects of changes in temperature and rainfall. Each country will need to ensure that climate change becomes a significant component of respective national strategic plans. A country's individual ability to efficiently and successfully adapt to the threats posed by climate change will depend on the consideration afforded, and resources allocated to, the health sector in comparison to other sectors.

Caribbean nations share common cultures and values, have similar underlying public health and health care delivery infrastructures, have comparable economic resource constraints, and are bonded by relatively short travel distances. In addition, the region already operates within a collaborative public health framework (CAREC, PAHO, CARICOM, and UWI). Although approaches to adaptation will have to be appropriately tailored to address the unique needs of each nation, a Caribbean strategy will ensure that countries are able to take advantage of regional synergies. Building adaptive capacity in the Caribbean will require cross-national and cross-disciplinary dialogue between policymakers, public health officials, and the climate change research community.

2. Monitoring and surveillance information

Good data are important to ensuring a responsive public health system. High quality public health surveillance and disease tracking systems will enable policymakers to better determine disease burdens, the identification of particularly vulnerable populations, to better engage researchers in the studies of the effect of climate change, and to plan and implement appropriate interventions (Frumkin, and others, 2008). Specific to climate change and health, surveillance systems need to capture meteorological data (e.g. temperature trends), ecological data (e.g. mosquito density), and indicators of vulnerability (e.g. urban infrastructure, poverty) (Frumkin, and others, 2008). Such data collection must be continuous and in combination will provide a comprehensive picture of how and when climate change will make an impact on public health.

3. Mobilizing and enabling communities

The health effects of climate change will be felt most intensely at the local community level. Communities are going to need data, tools, and resources to mobilize public health strategies such as improved access to enhanced sanitation facilities and potable water. In addition, communities are going to need a sound health care delivery infrastructure that can not only address extreme events, but can also provide prevention, acute, and chronic care services to populations.

4. Developing effective communication strategies

Community mobilization will not occur unless the public understands and accepts the risks associated with changing weather patterns. Communication strategies that: frame climate change as a human health problem (as opposed to an environmental problem), localizes the issue, and emphasizes immediate health benefits resulting from action are key to ensuring that the public is engaged and activated on this issue (Maibach, and others, 2011).[52]

5. Research

Given that serious concern about the impact of climate change on human society is a relatively recent phenomenon it is not surprising that research on the effect of climate change on health among Caribbean nations is relatively sparse. For example, for low and middle-income countries, a recent review by the World Health Organization (WHO) found very few examples of studies estimating the costs of adaptation (Markandya & Chiabai, 2009). This series of reports highlights the critical need for additional inquiry in a number of areas including: empirical studies of current health effects, scenario analysis of future health effects, effectiveness studies of various adaptation strategies, assessments of the health sector's contribution to climate change, and communications research that tests the best methodologies for engaging the public on issues related to environmental change and health (Frumkin, and others, 2008). Leadership in the development of research should likely continue to emerge from both the regional public health agencies (e.g. CAREC, PAHO), and tertiary educational institutions.

[52] Maibach and others (2011) provides a good overview of key components of a climate change communication strategy.

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Appendices

Table A5.1: Methods used to forecast future health impacts of climate change

Methodology	Measurement	Function
Analogue Studies	Qualitative of quantitative	Describe basic climate/health relationship e.g. correlation of interannual variation in malaria incidence with minimum November temperature
		Analogue of a warming trend, e.g. Association of changes in malaria incidence in highland areas with a trend in temperature
		Impacts of extreme event, e.g. assessment of mortality associated with a heat wave
		Geographical analogue e.g. comparison of vector activity in two locations, the second location having a climate today that is similar to that forecast for the first location
Early effects	Empirical	Analysis of relationships between trends in climate and indicators if altered health risk (e.g. mosquito range) or health status (e.g. heat attributable mortality)
Predictive models	Empirical-statistical models	Extrapolation of climate/disease relationship in time (e.g. Monthly temperature and food-poisoning in a population) to estimate change in temperature-related cases under future climate change
		Extrapolation of mapped climate/disease (or vector) relationship with future change in climate
	Process-based/biological models	Models derived from accepted theory. Can be applied universally, e.g. vector-borne disease risk forecasting with model based on vector capacity
	Integrated assessment models	Comprehensive linkage of models: "vertical" linkage in the causal chain and "horizontal" linkage for feedbacks and adaptation adjustments and the influences of other factors (population growth, urbanization and trade). Egg modeling the impact of climate change on agricultural yield, and hence on food supplies and the risk of hunger

Source: McMichael, A. J., Haines, A., & Kovats, R. (2001). *Methods to Assess the Effects of Climate Change on Health*

Table A5.2: Caribbean: Malaria cases by country 2001 – 2009

Bottom of Form Country	2001	2002	2003	2004	2005	2006	2007	2008	2009
Anguilla	-	-	-	...	...	-	...	-	-
Antigua and Barbuda	-	-	-	...	...	...	1	-	-
Bahamas (the)	4	...	3	2	1	49	...	14	...
Barbados	5	...	...	...	3	...	...	...	...
Cayman Islands	-	...	...	...	2	1	...	...	1
Cuba	-	29	30	26	9	33	19	...	7
Dominica	-	-	-	...	...	...	-	...	-
Dominican Republic (the)	531	1,296	...	2,355	3,837	3,525	2,711	1,840	1,643
French Guiana	3,823	...	...	3,037	...	4,074	...	3,264	...
Grenada	-	...	...	...	1	-	-	-	1
Guadeloupe	7	12	...	7	...	6	...	12	-
Guyana	27,122	21,895	27,627	28,866	38,984	21,064	11,657	11,815	13,673
Haiti	9,837	...	...	10,802	21,778	32,739	23,452	36,774	49,535
Jamaica	-	7	113	140	379	382	...	22	22
Martinique	11	12	16	10	...	10	...	14	11
Montserrat	-	-	-	...	...	-	...	-	-
Saint Kitts and Nevis	-	-	-	...	...	...	...	-	1
Saint Lucia	-	2	1	...	...	...	-	...	1
Saint Vincent and the Grenadines	-	-	-	...	...	-	-	1	...
Suriname	17,056	13,091	14,657	8,021	9,014	3,631	1,104	2,086	...
Trinidad and Tobago	-	8	10	15	8	8	14	...	...
Turks and Caicos Islands	-	...	...	...	...	...	...	...	...
Virgin Islands (UK)	-	-	...	-	...	-	...	-	...
Virgin Islands (US)	2	...	-	...	-	...	-	...	...

- Magnitude is zero;

0 Magnitude is less than half the measurement unit;

... Data not available

Source: Pan American Health Organization, Health Information and Analysis Project. Regional Core Health Data Initiative. Washington DC, 2010.

Table A5.3: Caribbean: Dengue fever cases by country 2001 – 2009

	2001	2002	2003	2004	2005	2006	2007	2008	2009
Anguilla	25	5	2	-	-	-	-	9	-
Antigua and Barbuda	20	5	1	-	-	-	1	17	-
Aruba	-	25	...	214	...	5	-	-	2 791
Bahamas (the)	-	-	180	1	-	1	-	1	-
Barbados	1 043	740	557	349	320	1	1 426	1	91
Cayman Islands	-	1	1	-	1	-	...	1	2
Cuba	1 303	3 011	-	-	212	...	70	...	96
Dominica	5	-	-	4	11	19	111	80	2
Dominican Republic	3 592	3 194	6 163	2 476	2 860	6 143	9 628	4 654	8 292
French Guiana	2 830	280	2 178	3 147	4 365	15 930	661	704	11 330
Grenada	12	84	3	7	-	22	-	6	23
Guadeloupe	-	93	496	529	3 364	2 948	3 266	316	2 234
Guyana	60	202	33	...	178	118	352	324	994
Haiti	...	1 161	...	...	...	...	...	...	...
Jamaica	39	90	52	9	46	79	1 448	359	70
Martinique	4 471	392	791	986	6 083	4 086	5 082	601	1 378
Montserrat	1	1	1	-	-	-	-	2	-
Netherlands Antilles	...	...	...	...	265	-	...	1 030	-
Puerto Rico	5 233	2 906	3 735	3 288	5 701	3 039	11 012	3 384	6 651
Saint Kitts and Nevis	89	20	2	4	-	1	-	49	2
Saint Lucia	292	44	5	11	1	30	39	98	18
Saint Vincent and the Grenadines	3	125	3	4	8	5	2	6	10
Suriname	760	1 104	285	375	2 853	285	41	79	120
Trinidad and Tobago	2 244	6 246	2 289	546	411	481	47	2 366	24
Turks and Caicos Islands	-	-	2	1	1	-	-	-	-
Virgin Islands (UK)	23	-	-	-	-	-	6	15	65
Virgin Islands (US)	...	...	...	...	...	...	73	...	-

Notes:
- Magnitude is zero;
0 Magnitude is less than half the measurement unit;
… Data not available

Source: Pan American Health Organization, Health Information and Analysis Project. Regional Core Health Data Initiative. Washington DC, 2010

Table A5.4: Gastroenteritis and Rate per 100 000 Population 1989 to 2005. Trinidad and Tobago

Year	Cases	Rate per 100 000 population
1989	17 033	1 406
1990	15 632	1 283
1991	16 883	1 375
1992	21 858	1 767
1993	18 222	1 461
1994	15 355	1 222
1995	15 684	1 240
1996	16 187	1 273
1997	16 026	1 253
1998	14 101	1 098
1999	19 796	1 534
2000	17 365	1 341
2001	22 694	1 746
2002	16 897	1 295
2003	18 597	1 421
2004	22 231	1 692
2005	20 770	1 576

Source: Caribbean Epidemiology Center (CAREC) *Morbidity Review of Communicable Diseases in CAREC Member Countries. 1980-2005.* Port of Spain, Trinidad and Tobago

Table A5.5: Regression models used to predict disease incidence. Control Variables

Disease	Guyana	Trinidad and Tobago	Jamaica
Dengue fever	Rainfall Time trend Seasonal control Human development index	Rainfall above average (dummy) Maximum temperature % rural population with access to potable water % rural population with access to sanitation facilities	Rainfall Maximum temperature % households with pit latrines % households with access to potable water Mean household expenditures on health Seasonal control n=156
Malaria	Rainfall Maximum temperature Time trend Seasonal control Human development index	n.a.	n.a.
Gastroenteritis in total population (separately for children under 5 years and population over 5 years)	Rainfall Minimum temperature Time trend Date dummy variables	% rural population with access to potable water Relative humidity at 8 am	Rainfall Maximum temperature % households with pit latrine % households with access to potable water Mean household expenditures on health n=156
Leptospirosis	Rainfall Time trend Seasonal control Sanitation	Rainfall Maximum temperature % total population with access to sanitation facilities % of land covered by forest	Rainfall Maximum temperature % households with pit latrine % households with potable water Mean household expenditures on health

CHAPTER VI.
THE ECONOMIC IMPACT OF CLIMATE CHANGE ON TOURISM

A. TOURISM: A CLIMATE-SENSITIVE SECTOR

Climate change will have far-reaching consequences for tourism businesses and destinations and the impacts are expected to vary by market and geographic region (Simpson and others, 2008).[53] The United Nations World Tourism Organization (UNWTO) categorizes the potential impacts of climate change on the tourism sector into four broad groupings (UNWTO-UNEP-WMO, 2008), based on the transmission channels through which tourism demand, competitiveness and sustainability of destinations and businesses are likely to be affected. These are: direct impacts; climate induced environmental changes; policy-induced impacts of mitigation efforts, and indirect impacts on economic growth in source markets.

1. Direct impacts

Direct impacts derive from the view of climate as an economic resource for tourism. Climate co-determines the global seasonality of tourism demand and represents an important financial consideration for both tourism operators and the personal experiences of tourists. For example, financial losses may result from weather variations or unexpected conditions: rainy summers or less snowy winters can have significant impacts on tourism demand, because it affects the natural environment in ways that can either attract or deter visitors (de Freitas, 2003). In the long run, the climatic features of a destination form part of its product offering and can either deter or attract visitors.

Changes in the length and quality of climate-dependent tourism seasons could also have implications for competitive relationships between destinations, and therefore, climatic variations can potentially impact the profitability of tourism enterprises. Climate variability also directly influences operating costs, such as heating and cooling, irrigation, food and water supply, and insurance costs. Other potential direct impacts to the industry include increased infrastructural damage, additional emergency preparedness requirements and business interruptions (Simpson and others, 2008), due to sea-level rise, floods, coastal inundation and extreme events.

2. Climate-induced environmental changes

Climate-induced environmental changes are indirect effects related to the importance of environmental conditions for tourism. Warmer temperatures and sea-level rise may decrease the quality of terrestrial and coastal ecosystems, resulting in biodiversity loss. Changes in water availability, due to droughts and salt-water intrusion of underground aquifers may result in altered agricultural production, with consequences for crop, livestock and fisheries production which complement the industry's tourism product. Additionally, changes to landscape aesthetics, increased natural hazards, coastal erosion and inundation, damage to infrastructure, and increasing incidence of vector-borne diseases, will all impact tourism to varying degrees. Most climate-induced environmental changes are anticipated to be largely negative and are expected to vary by region.

[53] http://www.uneptie.org/shared/publications/pdf/DTIx1047xPA-ClimateChange.pdf

3. **Policy-induced impacts of mitigation efforts on tourist mobility**

Policy-induced impacts of mitigation efforts on tourist mobility may result in upward pressure on transportation costs and changes in attitudes to travel, that may have indirect consequences due to changes in destination choices or travel mode (for example due to environmental attitudes). The air transportation and cruise ship industries provide key services to tourism, but there is increasing concern about the contribution of these forms of travel to global GHG emissions. Over half of all travellers arrive at their destinations by air transport (53% in 2009) and, over time, the growth in air transport has been slowly exceeding that for surface transport, so the share of air transport is gradually increasing (UNWTO, 2010).

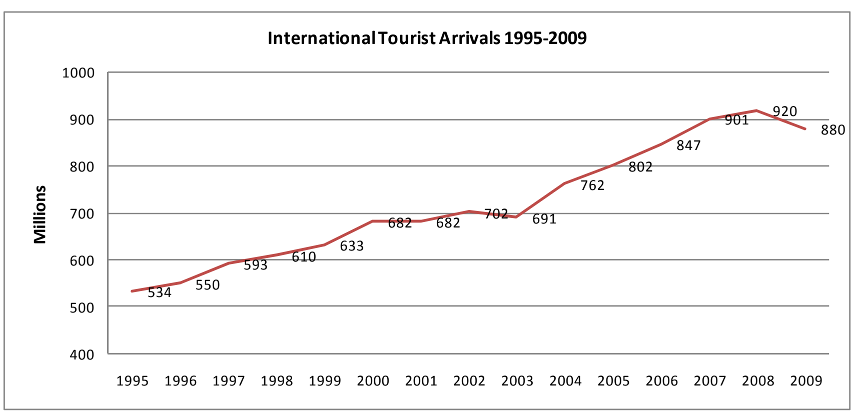
Air travel is currently responsible for approximately 2% to 3% of GHG emissions, and carbon dioxide emissions are expected to increase as the tourism industry grows. As such, policy proposals are being considered to reduce emissions from air transport – these include taxation schemes and other behaviour- modifying practices such as carbon footprinting, which may all have the effect of deterring long haul travel. The recent increase in the aviation passenger duty (APD) for all travellers from the United Kingdom to destinations around the world is one such example.

The European Union (EU) is set to become the first to require all flights in and out of its airports to account for emissions as a part of the EU cap and trade programme.[54] The United States of America is also discussing similar policies. These moves to establish emission caps and reduction targets for airlines, coupled with projected increases in global oil prices, are expected to result in higher prices for air travel. Long haul destinations such as Southeast Asia, Australia, New Zealand, Africa and the Caribbean are potentially more at risk.

4. **Indirect adverse impacts on economic growth in source markets**

Indirect adverse impacts on economic growth in source markets**,** which would reduce the discretionary income of consumers, would also negatively affect tourism. For example, international tourist arrivals grew at a sustained rate of 7 % on average between 2004 and 2007, with a peak in global arrivals of 920 million in 2008, but the industry suffered a dramatic falloff in tourism arrivals (4%) and receipts (6%) in 2009 as a result of the global economic crisis (see figure 4.1) (UNWTO, 2009). Climate change is thus considered a national and international security risk, since fallouts in the tourism sector could potentially lead to instability (Stern, 2006; Simpson and others, 2008).

Figure 6.1: International tourist arrivals 1995-2009



Source: (UNWTO, 2009)

[54] http://ecohearth.com/eco-zine/green-issues/448-emission-possible-cutting-greenhouse-gases-part-1-cap-and-trade-.html

B. Implications for the Caribbean

For many developing countries, tourism is one of the main sources of foreign exchange income and the leading export, creating much-needed employment and opportunities for development (UNWTO, 2010).[55] The tourism sector is a key engine of growth in the Caribbean, representing an average of 12.9 % of subregional GDP and accounting for 14.1% of employment (see table 6.1).[56] If employment in related industries and support services (indirect employment) in tourism are also taken into account, the estimated contribution is three times as large (see appendix for individual country data).

Table 6.1: Caribbean - Summary tourism economic indicators 2010

Indicator	Caribbean estimate (%)
Share of Tourism in GDP - Direct contribution (%)	12.9
Share of Tourism in GDP - Direct and indirect (%)	38.8
Direct contribution to employment (%)	14.1
Share of Tourism in total employment - Direct and indirect (%)	39.6

Source: WTTC Tourism Satellite Accounts sourced online at:
http://www.wttc.org/eng/Tourism_Research/Economic_Data_Search_Tool/

1. Species ecosystems and landscapes

For several Caribbean countries the tourism product is a derivative of the climate-sensitive ecosystems and natural environment (for example reefs, beaches and rivers, mangroves), making Caribbean tourism particularly vulnerable to climate change. Coral reefs, a main features of the Caribbean tourism product, and associated activities (including diving, snorkelling), are particularly at risk, due to ocean acidification and sea surface temperature rise. On average, 25% to 40% of visitors to the Caribbean engage in reef-related activities, thus coral reef-associated tourism (directly and indirectly) accounts for a significant proportion of total tourism receipts for the subregion (Burke and others, 2008).

In addition to its tourism function, coral reefs also perform an important role in protecting the islands' coasts and providing a habitat to a diversity of marine species, thereby contributing to food security and employment for fishers. Burke and Maidens (2004) estimated that the annual net economic value of reef ecosystem goods and services to the Caribbean (including fisheries, dive tourism and shoreline services), was in excess of US$ 3.1 billion in 2000.

Large proportions of coral reefs in the Caribbean have already been lost to pollution, disease, over-fishing, unregulated tourism and bleaching (World Resources Institute (WRI), 2011). In Montserrat, for example, direct deposits of ash and waterborne sediment have resulted in coral bleaching and an increase in coral diseases, primarily to the south and east of the island. Warmer waters have also been shown to lead to bacterial blooms resulting in fish kills. Table 6.2 summarizes the potential losses from coral reef degradation in the wider Caribbean**.**

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[55] http://www.unwto.org/facts/eng/pdf/highlights/UNWTO_Highlights10_en_HR.pdf

[56] Tourism contributes about 5 % of global economic activity worldwide and accounts for about 6% to 7 % of total employment (direct and indirect).

Table 6.2 Economic losses from coral reef degradation in the wider Caribbean

Ecosystem good or service	Estimated annual benefit (2000)	Estimated future annual losses up to 2015
Fisheries	US$ 312 million	Fisheries productivity could decline an estimated 30%-45 % by 2015 with associated loss of net annual benefits valued at US$ 100 million- US$140 million (in constant –dollar terms, standardized to 2000).
Dive tourism	US$ 2.1 billion	Growth of Caribbean dive tourism will continue, but the growth rate by 2015 could be 2%-5 % lower as a result of coral reef degradation. Region-wide losses of net annual benefits are valued at an estimated US$ 100 million to US$ 300 million (in constant-dollar terms, standardized to 2000).
Shoreline protection	US$ 0.7 billion – US$ 2.2 billion	Over 15,000 km of shoreline could experience a 10%-20 % reduction in protection by 2050 as a result of coral reef degradation. The estimated loss in net annual benefits is estimated at US$ 140 million – US$ 420 million (in constant-dollar terms, standardized to 2000).
Total	**US$ 3.1 billion – US$ 4.6 billion**	**US$ 350 million – US$ 870 million**

Source: Burke and others, 2004 in Simpson (2011)

A study by Hoegh-Guldberg and others (2007) concluded that, if the level of carbon dioxide in the atmosphere reaches 450 to 500 ppm (up from current levels of 380 ppm) the diversity of coral reefs in the Caribbean Sea will decline, resulting in a fall in habitat complexity and a general loss of biodiversity; if, however, carbon dioxide emissions increase to levels above 500 ppm, coral reef ecosystems could be reduced to crumbling frameworks with few calcareous corals.[57]

2. Land loss, beach loss and tourism infrastructure damage

The major impacts of sea-level rise are considered to be coastal inundation,[58] coastal erosion, and inland flooding due to storm surges. These impacts are, in turn, expected to result in losses to tourism stemming from loss of land, beach loss, and costs to replace or rebuild infrastructure.[59] For many of the Caribbean SIDS, there is an intrinsic vulnerability of their tourism sectors to climate change because most of the infrastructure for the industry (such as hotels and resorts) are on or near the coast and are thus subject to sea-level rise and extreme climatic events (e.g. hurricanes and floods).[60]

In fact, sea-level rise and consequent erosion are likely to result in some of the more costly long-term consequences of climate change, even if GHG emissions are stabilized and global temperature increases are kept below 2°-2.5° C (Simpson and others, 2010). In Barbados, for example, over 90 % of the island's hotel rooms are built less than 0.5 miles (0.8 km) from the high-water mark and less than 20 m above mean sea level. Storm surge models estimate that over 50 % of the rooms may be vulnerable to Category 3 hurricanes (Simpson, 2011). In the Caribbean, the beach is a primary component of the tourism product; many susceptible beaches have experienced accelerated erosion in recent decades (Simpson and others, 2010) with economic implications for coastal tourism properties, which may have lost their marketing appeal on this basis.

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[57] The study also estimates that, without further impacts due to climate change, there will still be a 10 % loss of coral reefs by 2050 (Moore, 2011).

[58] Coastal inundation is the flooding of coastal lands, including wave action, usually resulting from riverine flooding, spring tides, severe storms, or seismic activity (tsunami).

[59] A one-metre sea-level rise is estimated to result in a total cost of US$ 2 billion per year for Latin America and the Caribbean, based on combined information on coast length and various assumptions regarding key policy variables (Tol, 2002).

[60] Vulnerability is defined as the "ability to manage climate risks without potentially irreversible loss of welfare". It is linked to a level of risk defined as "exposure to external dangers over which people have little control", and reveals the degree of development of a particular area or region, i.e. the capacity of the transient poor who will face the disasters caused by climatic variations to cope (UNDP, 2007).

3. Extreme events

There has been an increase in the frequency and severity of tropical cyclones (including hurricanes) and windstorms in the Caribbean since 1995 (Goldenberg and others, 2001) and there is increasing evidence of a relationship between increasing hurricane intensity and climate change. Observed and projected increases in SSTs indicate potential for continuing increases in hurricane activity, and model projections (although still relatively primitive) indicate that this may occur through increases in intensity of events (including increases in near storm rainfalls and peak winds), but not necessarily though increases in frequency. RCM projections for the Caribbean indicate potential decreases in the frequency of tropical cyclone-like vortices under warming scenarios due to changes in wind shear. According to Moore and others, (2010) the estimates of potential damages derived from hurricanes are assumed in table 6.3.

Table 6.3: Potential damages from hurricanes by category

Saffir/Simpson (SS) scale	*Maximum Sustained Wind Speed (m/s)*	*Storm Surge(m)*	*Potential Infrastructural Damage*
Category 1	33-42	1.0-1.7	No major damage to buildings (5%)
Category 2	43-49	1.8-2.6	Moderate damage to buildings (10%)
Category 3	50-58	2.7-3.8	Extensive damage to buildings (35%)
Category 4	59-58	3.9-5.6	Extreme damage (50%)
Category 5	>69	>5.6	Catastrophic damage (75%)

Source: Moore and others, 2010.

4. Availability of water resources

Tourism is a water-intensive sector. This is due, in part, to the high rate of water consumption by tourists compared to residential households and partly to demand for water by related services and products. Essex and others, (2004) estimated the per capita water demand by tourists in Barbados to be 6 to 10 times greater than that used by residents, which, given the projected expectations of drought conditions and the potential for salt water intrusion into the ground water aquifers, could result in competition for water resources among sectors. Additionally, golf courses notably have a high impact on water withdrawals – an eighteen-hole golf course is estimated to consume more than 2.3 million litres per day (UNESCO, 2006).

5. Policy changes

The Caribbean tourism industry is highly dependent on carbon-based fuels, both for bringing tourists to the subregion as well as for providing support services, and is thus a major contributor to GHG emissions. The main sources of emissions and of overall energy demand in the tourism sector are in air and sea travel, accommodation and hotel facilities for guests, and ground transportation. Most visitors to the Caribbean arrive by air transport (65%) and the recent increase in Air Passenger Duty (APD) for travellers from the United Kingdom is likely to adversely impact the Caribbean, since the United Kingdom is one of the subregion's major source markets.[61] For example, a family of four travelling to Barbados in standard class is now required to pay GB£ 240 in APD (in 2011), a tax that did not exist in previous years. Any similar type of action towards mitigation that considers taxing flights in the United States of America, or in any other main source market country, will generate important negative impacts on numbers of arrivals to the subregion (ECLAC, 2011c).

The use of energy in the tourism accommodation subsector represents a major cost and presents a policy challenge. In Jamaica, for example, electricity sales to the accommodation subsector is estimated at

[61] The United Kingdom accounts for 26 % of total arrivals to the Caribbean and the United States of America accounts for 35% (Source: Caribbean Tourism Organisation http://www.onecaribbean.org/statistics/marketstats/.

40 % of total sales to the commercial segments of the economy and a breakdown of expenditure shows that air conditioning accounts for 39 % of all electricity consumed, while fans, pumps, lighting and refrigeration account for 14 % (ECLAC, 2011b). The challenge is to find target behavioural changes that will allow the industry to benefit from some amount of mitigation, while at the same time not deterring tourists from wanting to travel to long-haul destinations such as the Caribbean.

C. Approach to measuring the economic impact of climate change on tourism

The impact of climate change on tourism in the Caribbean is valued separately for each of the four transmission channels discussed above, and these estimates are layered to arrive at a total potential impact. The following economic impacts are each considered in turn:

1. Impacts on arrivals due to changes in climate attractiveness of the destination.
2. Impacts on arrivals due to climate policy changes, fuel price increases and other policies that will impact on tourist mobility
3. The impact of climate change on coral-reef related tourism.
4. The impact of sea-level rise and extreme events.

The likely impacts are estimated for two scenarios - a high-impact scenario (A2) and a low-impact scenario (B2) - and the results compared to a business as usual (BAU) scenario without climate change.

A tourism climate index (TCI), which captures the combined effect of changes in the elements of climate that impact on a destination's attractiveness, was used to estimate the impact on arrivals. This index consists of weighted combinations of climate variables, including temperature, precipitation, humidity, hours of sunshine and wind speed (see table 6.4).[62] The advantage of this approach is that the combined effects of changes in climatic variables on the demand for travel to a particular destination can be examined.

Table 6.4: Components of the tourism climate index

Sub-Index	*Variables*	*Influence on TCI*	*Weight*
Daytime Comfort Index (CID)	Maximum daily temperature; Minimum daily relative humidity	Represents thermal comfort when maximum tourist activity occurs	40%
Daily Comfort Index (CIA)	Mean daily temperature; Mean daily relative humidity	Represents thermal comfort over the full 24 hour period, including sleeping hours	10%
Precipitation (P)	Total precipitation	Reflects the negative impact that this element has on outdoor activities and holiday enjoyment	20%
Sunshine (S)	Total hours of sunshine	Positive impact on tourism; (risk of sunburn and discomfort from heat)	20%
Wind (W)	Average wind speed	Variable effect depending on temperature (evaporative cooling effect in hot climates rated positively, while wind chill in cold climates rated negatively)	10%

Source: Adapted from Mieczkowski (1985)

Analysis of historical data for the Caribbean confirms that periods when the TCI is "favourable" correspond to the traditional peak periods for arrivals to the subregion. Between December and April, the subregion usually receives more than 60 % of its visitors. This peak also matches fairly closely with a

[62] The Mieckzowski (1985) TCI is calculated as $TCI = 2[(4 \times CID) + CIA + (2 \times P) + (2 \times S) + W]$. The calculated TCI ranges from -20 (impossible) to 100 (ideal), with the following further descriptive rating categories: 90-100 = ideal; 80-89= excellent; 70-79=very good; 60-69=good; 50-59=acceptable; 40-49=marginal; 30-39=unfavourable; 20-29=very unfavourable; 10-19=extremely unfavourable; and -20-9=impossible. The TCI can be an effective tool to assess the quality of climate resources for tourism and provides researchers with a numerical measure of the effects that climate can have on a visitor's experience.

deterioration of the TCIs for many North American and Western European nations and explains why most of our visitors originate from in these regions (Moore, 2011a).

The historical TCI for the Bahamas, for example, is favourable (above 60) from February to April, however, the TCI falls rapidly during the subsequent period and between June and September, its ranking deteriorates to less than 50 – a rating which lies somewhere between "marginal" and "unfavourable" for the attractiveness of the destination in terms of climatic features. This trend closely resembles the monthly arrivals pattern for the Bahamas.

Similarly, the results for the historical TCI for Montserrat confirm that the best time to visit that island is between December and April when climatic conditions would be rated "good" and "very good", while the remainder of the year ratings fall to 'marginal' and 'acceptable'. The comparative unattractiveness of the May – November period stems from the increase in precipitation received during this period, coupled with the rise in temperature associated with the 'summer' months.[63] Including this index in models of tourism demand captures the impact of changing climatic factors on tourism arrivals and earnings from tourism (tourist expenditure).

Additional layers of losses related to sea-level rise and sea surface temperature rise are also estimated. Here the losses related to coral reef ecosystem services and coral reef related tourism are considered, as well as land and infrastructural losses due to sea-level rise, erosion of beaches and damage to coastal tourism plant. There is also an attempt to estimate the impact of policy changes in source markets, with particular reference to the United Kingdom, the United States of America and Canada.

D. IMPACT ON TOURIST ARRIVALS

The results suggest that, under both scenarios, the subregion's key tourism climatic features are likely to decline and thus will negatively impact on the destination experience of visitors.[64]

1. Impact on forecast arrivals based on destination attractiveness

Forecasts of tourist arrivals for each of the two scenarios were compared to the expected arrivals under a BAU scenario, which represents a benchmark against which the impacts of climate change on tourist arrivals can be measured.[65] The results show that, across the subregion, tourist arrivals are expected to decline for both scenarios, but the degree to which climate change adversely affects arrivals depends on the specific country.

Data for three Caribbean countries show that tourist arrivals are likely to fall by an average of approximately 6 % over the next four decades under the low emissions scenario, and by approximately 9% under the A2 scenario. However, the way in which individual countries are impacted differs depending on the actual climatology (which is related to their geographic location) and the degree of sensitivity of the tourism sector to climatic variability (see table 6.4).

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[63] Notes: Historical TCI for Bahamas (Average 1981-2010); Source: ECLAC (2011f); B: Historical TCI for Montserrat (1980-2009); Source: Moore 2011; C: Historical TCI for Barbados (1977-2009); Source: ECLAC (2011c); D: Historical TCI for St Lucia (1977-2009)

[64] While changes in weather patterns on a daily basis are unlikely to impact a traveller's decision to visit the Caribbean, it is the long term changes in average weather conditions and trend, reflected in changing climatic variations over multiple years that are likely to impact the changes in arrival patterns which are of interest.

[65] The BAU was generated by extrapolation of historical time series data of tourist arrivals.

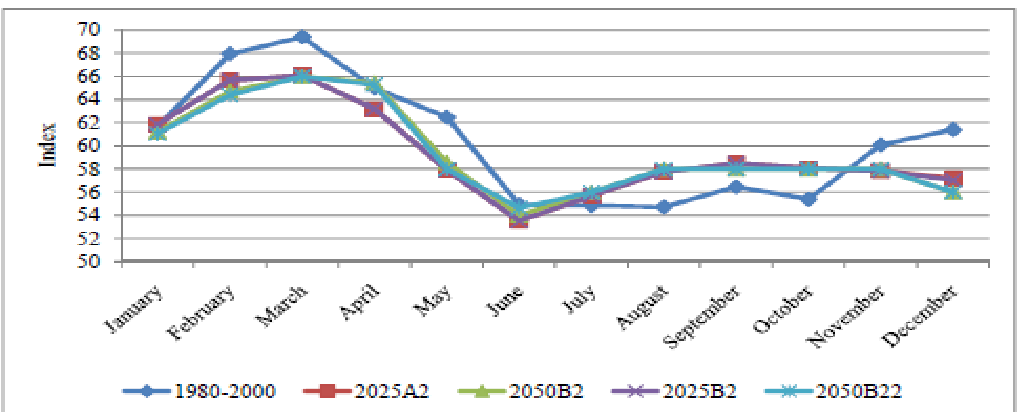
Table 6.5: Selected countries: Change in tourist arrivals due to changes in tourism climate index

Period	Montserrat		Saint Lucia		Bahamas		Caribbean Average	
	% change A2	% change B2	% change A2	% change B2	% change A2	% change B2	% change A2	% change B2
2011-2020	-7.5	-5.3	-10.3	-7.7	7.6	-1.5	-3.4	-4.8
2021-2030	-9.2	-7	-11.3	-8.5	-8.6	-3.1	-9.7	-6.2
2031-2040	-10.4	-8.2	-11.9	-9.2	-11.1	4.5	-11.1	-4.3
2041-2050	-11.6	-9.4	-12.6	-9.9	-8.8	2.7	-11.0	-5.5
Total (Average 2011-2050)	-10.1	-8.0	-11.9	-9.2	-5.8	0.8	-9.3	-5.5

Sources: ECLAC (2011f); ECLAC (2011d); ECLAC (2011e)

In the case of both Saint Lucia and Montserrat, climatic conditions under A2 are expected to deteriorate more rapidly than under B2, and on average, tourist arrivals fall by about 2 percentage points more under the A2 scenario than under the B2 scenario. Additionally, arrivals fall at an increasing rate over the four decades. For example, over the forecast period, the TCI for Saint Lucia shows a clear downward shift in future years, during the peak tourist season, under both the A2 and B2 emissions scenarios (see figure 6.2).

Figure 6.2: Projected TCI for Saint Lucia in 2025 and 2050



Source: ECLAC (2011d)

However, in the case of the Bahamas, tourist arrivals first increase by 8% under the A2 scenario in the first decade (2011-2020) as the combination of temperature, precipitation, humidity, hours of sunlight and general comfort levels improve; conversely, arrivals decrease by 2% under the B2 scenario. This situation is reversed in the subsequent decades, when the daytime comfort index and other climatic features start to deteriorate more rapidly under the A2 than under the B2 scenario. From the decade of 2031- 2040 onwards, the climatic conditions in the Bahamas are actually more favourable under the B2 scenario than in the business as usual case, and this is reflected in the positive changes in arrivals under the B2 scenario (see table 6.4).

Importantly, the overall long-run impact is a deterioration of the TCI under both scenarios. This is reflected in the average TCI for the next four decades, which lies below the historical TCI (see figures 6.3a and 6.3b).

Figure 6.3: Projected TCI for the Bahamas, A2 and B2 compared

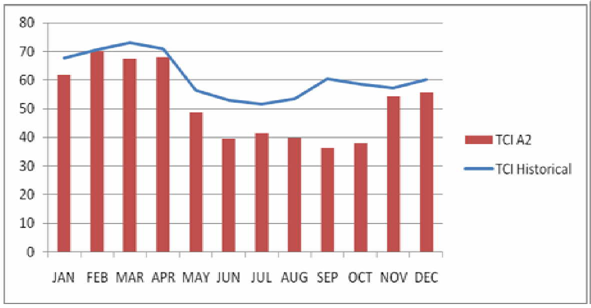


Figure 6.3a: TCI comparison between historical and A2 scenario averages
Source: Data from Department of Meteorology, the Bahamas and PRECIS RCM.
Figure 6.3b: TCI comparison between historical and SRES B2 scenario. Source: Data from Department of Meteorology, the Bahamas, and PRECIS RCM

2. Impact on cruise arrivals

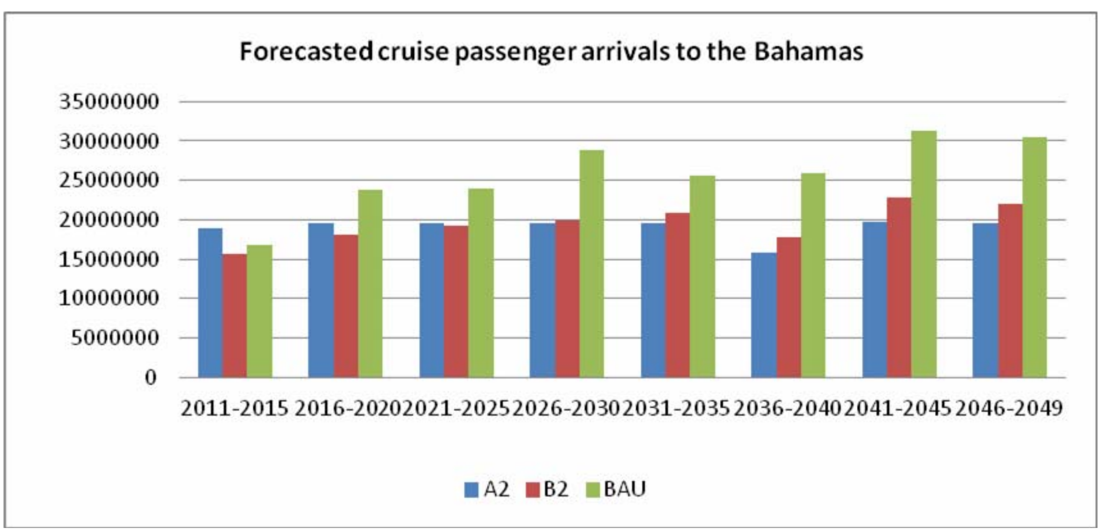
If cruise arrivals are taken into account, the decline is even more precipitous over the four decades. In the case of the Bahamas, which is a popular cruise destination, cruise arrivals can be expected to fall by 26 percentage points and 24 percentage points, in the A2 and B2 scenarios, respectively (see table 6.6 and figure 6.4).

Table 6.6: Change in cruise passenger arrivals under A2, B2, for the Bahamas (%)

Period	Estimated Passengers under BAU	% Change under A2	% Change under B2
2011-2020	40.6	-5.2	-16.7
2021-2030	52.9	-25.8	-26.1
2031-2040	51.5	-31.4	-25.2
2041-2050	61.7	-36.4	-27.5
Total	206.8	-26.3	-24.4

Source: ECLAC (2011f)

Figure 6.4: The Bahamas: Estimated number of cruise passengers per scenario, 2010-2050



Source: ECLAC (2011f)

BOX 1
CASE STUDY FOR BARBADOS

If the Tourism Climate Index is used and assumed to be the only factor that influences future tourist arrivals, the impact of climate change is even more pronounced.[66] Arrivals to Barbados in the year 2020, for example, are projected to decrease by 10% under the low emission scenario (falling to 523,000 compared to 665,000 under a BAU scenario with no climate change) and by as much as 21% in the A2 scenario. By 2050, arrivals are projected to fall by 50% and 40% under the A2 and B2 scenarios, respectively, compared to the business as usual case with no climate change (see table 6.7 and figure 6.5).

Table 6.7: Projected change in arrivals for Barbados in specific years under high and low emissions scenarios

Period	Projected arrivals BAU ('000)	% change A2 scenario	% change B2 scenario
2020	665	-21.3	-10.0
2030	748	-33.4	-23.1
2040	831	-41.8	-32.8
2050	913	-49.0	-40.0

Source: ECLAC (2011c)

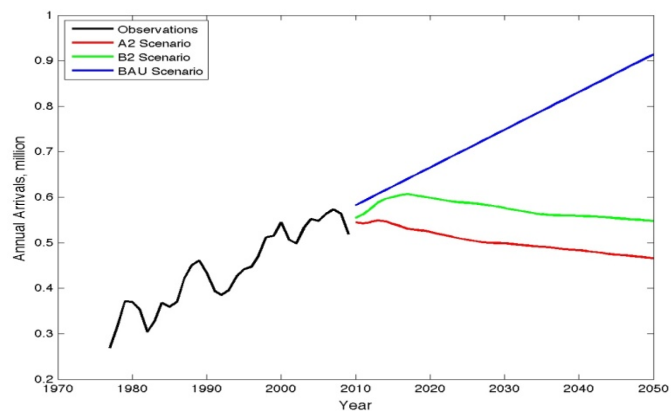


Figure 6.5 : Annual arrivals and forecasts for each of the three scenarios (A2, B2 and BAU)

Source: ECLAC (2011c)

3. Impact on tourism revenues

Deterioration of destination attractiveness on the basis of climatic variation can potentially result in considerable fallout in tourist arrivals, with significant revenue implications for these economies. The conversion of arrivals forecasts into revenue streams is based on some typical assumptions about the levels of expenditure per tourist.

The degree of impact in terms of financial loss varies from country to country depending on the relative size of the tourism industry and the size of the economy. For example, the value of tourism receipts in Montserrat anticipated under a BAU scenario for the period under consideration is US$ 564 million, while the Bahamas would have expected to earn approximately US$ 95 billion from tourism over the same period under BAU (at present value using a 4 % discount rate) (see table 6.8).

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[66] This represents the case where other variables known to influence tourist arrivals are not controlled for in the econometric model.

Table 6.8: Value of tourism receipts and losses due to deterioration of climate attractiveness (2011-2050)

Losses *(NPV, 4% Discount Rate; US$ million)*	Value of tourism receipts under BAU (2011-2050) US$ Million	Losses under A2 US$ Million	Losses Under B2 US$ Million
Bahamas (the)	94 912	-15 967	-14 025
Barbados	53 574	-18 309	-13 224
Montserrat	564	-57	-45
Saint Lucia	32 714	-3 897	-3 023

Sources: ECLAC (2011c); ECLAC (2011d); ECLAC (2011e); ECLAC (2011f)

Based on the sample of countries studied, the net present value of potential losses (using a 4 % discount rate) range from US$ 57 million (Montserrat) to US$15 billion (the Bahamas), under the A2 scenario and from US$ 45 million (Montserrat) to US$ 14 billion (the Bahamas) under the B2 scenario.

Box 2
Alternative Approach to Estimating Impact on Tourism Revenues

The impact of climate change on the tourism sector in Aruba and in Curacao was estimated by application of a tourism demand model, which uses tourism expenditure (te) as its outcome variable.

$$te = f\,(pcy, sgdp, op, t, p)$$

Where,

te is the total tourist expenditures
pcy is the per capita income in the destination country
sgdp is the Gross Domestic Product in the source country
op is the price of oil
t is the temperature
p is the precipitation

The model was then used to forecast tourism expenditure for the period 2011 to 2050 and the data used to obtain the cost of climate change to the tourism sector under the A2 and B2 scenarios. In terms of climate-induced changes in temperature and precipitation, it was found that the predicted variations will cost the tourism industry in Aruba and Curacao at least US$ 144 million and … respectively by 2050.

Cumulative Losses in tourism expenditure due to temperature and precipitation change under A2 and B2 Scenarios (US$ millions)

Country	Aruba		Curacao	
Year	A2	B2	A2	B2
2020	13.62	18.63	9.1	8.4
2030	46.89	53.40	15.1	15.8
2040	94.01	100.98	19.2	22.1
2050	144.34	151.43	22.1	27.4

Note: Similar to Moore (2011), the BAU scenario is determined by assuming that tourist arrivals continue to grow based on historical trend growth rates and represents a situation of no climate change. Calculations are in constant 2008 dollars.
Source: Sookram (2011a and 2011b) or RECCC National Reports for Aruba and Curacao, 2011

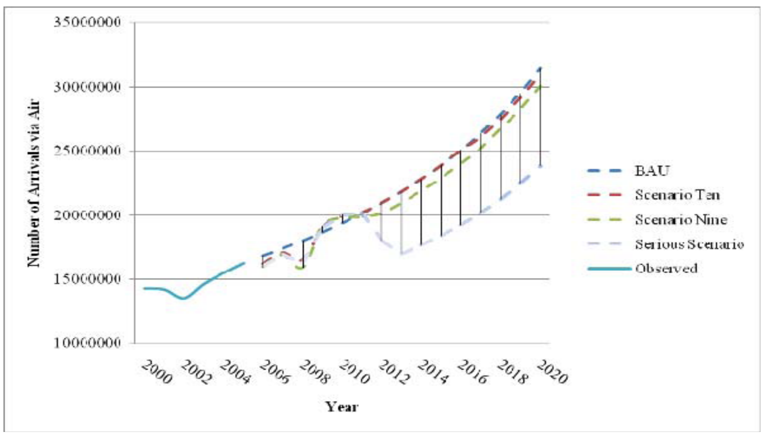
(a) Impact of climate policy changes on arrivals

The response of tourist arrivals to climate policy changes is related to the willingness of tourists to purchase travel to Caribbean destinations, given the cost (or behavioural) impact of the new policy. For example, the recent APD policy, which places a tax on all persons travelling out of the United Kingdom, is expected to have an immediate impact of reducing arrivals to Barbados by about 6 % by 2020 and by as much as 25 % by 2050 (Simpson, 2011). Increases in oil prices can have a similar effect.

When climate policy and future oil prices are taken into consideration, the Caribbean subregion can be expected to have fewer visitors on average in this decade (2011- 2020) compared to a BAU case with no climate change. On average, arrivals to the subregion were projected to decline by an additional 1.3% to 4.3% by 2020 due to the impact of climate policies and, in the worst case scenario, that is if a 'serious' climate policy is assumed, arrivals could be expected to fall by as much as 24% below BAU levels[67] (see figure 6.6).

Barbados is expected to experience a decline in arrivals compared to BAU somewhere in the range of 1.8% to 6.3% under various scenarios, and a significant reduction in arrivals of about 40% can be expected under the worst case (climate policy) scenario.

Figure 6.6: Projected growth in tourist arrivals to the Caribbean by air, 2008)



Source: (Scott and others, 2008)

The impact on tourism expenditure due to these policies for Barbados amounts to potential economic losses under the low emissions scenario (B2) of US$ 1,117 million and US$ 964 million for the A2 scenario compared to a business as usual scenario with no climate policy (see Table 6.9:)

Table 6.9: Tourism mobility impacts as measured by implied losses to tourism expenditure

Year \ Scenario	A2 Scenario	B2 Scenario
Loss by 2050, US$ million	4 626	5 361
Present Value, US$ million	964	1 117

*compared to a BAU scenario with no climate policy
Source: ECLAC (2011c)

Including these policy change impacts alongside the impacts due to changes in the destination attractiveness (measured by the TCI) can be shown to have significant implications for Caribbean SIDS,

[67] These results are based on a number of studies that have looked at the potential impact of increased air travel and climate policy shifts on Caribbean economies. Pentelow and Scott (2009) modelled the impact that the EU Emissions Trading System (ETS), an identical ETS in North America (United States of America and Canada), and future oil price projections would have for air travel costs and the resulting impact on tourist arrivals in CARICOM Member States, through to 2020. A serious climate policy, with much deeper emissions cuts and carbon costs that are considered more indicative of the social cost of carbon, was also modelled.

especially for countries that are heavily tourism dependent (where tourism contributes more than 20% to GDP).

4. Coral reef loss and other environmental impacts

Coral reefs are one of the most important components of the subregional tourism product. The World Resources Institute recently published a study entitled "Reefs at Risk: An Evaluation" (WRI, 2011). The study analysed the Caribbean area, evaluating how endangered coral reefs were impacted by local threats including overfishing and unregulated tourism (table 6.10). The report also estimated levels of risk for coral reefs if today's use patterns should continue up to the year 2050.

The estimated impact of coral-reef loss to the Caribbean tourism sectors under the A2 scenario ranged from US$ 4.125 billion to US$ 1.1 billion (using 1 % discount rates).[68]

A case study for Barbados, estimated direct economic impacts from tourist expenditure associated with coral reefs as US$ 206.25 million in 2009, and the losses due to reef-related tourism services over the four decades (to 2050) was estimated at US$ 1,333 million (A2 scenario) and US$ 667 million (B2 scenario) in present value terms (using a 4% discount rate). For the Caribbean, the total economic loss arising from damage to the coral reefs by 2050 was estimated at approximately US$ 8 billion.

Table 6.10: Estimated value of coral reef loss (to 2050) in NPV terms based on a 4% discount rate (US$ million)

Country	Losses under A2 US$M	Losses under B2 US$M	Loses under BAU US$M
Barbados*			
Nominal	6 400	3 200	0
Present Value (4%)	1 333	667	0
Montserrat			
Nominal	600	300	75
Present Value (4% discount rate)	125	63	50
St Lucia			
Nominal	5 120	2 560	3 840
Present Value (4% discount rate)	1 066	533	133

- *St Lucia estimates are adopted from Burke and others(2008);*
- **Losses expressed for A2 and B2 for Barbados are expressed in relation to BAU losses.*

Sources: ECLAC (2011c): ECLAC (2011d): ECLAC (2011e):

5. Sea-level rise: loss of beaches, land and tourism infrastructure

The coastline is a major part of the tourism product for many Caribbean destinations. Beachfront properties are valued higher than those further inland and hotels can charge more for beachfront or ocean view rooms. In addition, many other major economic institutions, buildings and investments also tend to be located along the coastline (for example, government offices, and electricity generation plants).

The impact of a 1m and 2m sea-level rise are assumed to correspond to the B2 and A2 scenarios respectively. Moore and others, (2010) estimated the impact of sea-level rise and increased extreme

[68] These figures are derived from a methodology that follows the WRI approach of valuation and assumes that 25% of tourist activities are reef-related. For example, this estimate is based on 25% of the total estimated tourism expenditure, which was US$ 825million in 2009. The economic losses suffered due to climate change, expressed as a percentage of the value of the coral reef, is taken as 80% for the A2 scenario and 40% for the B2 scenario.

events on Barbados and offered estimated losses in the range of US$ 355.7 million under a low impact scenario and US$ 2 billion in the worst case (A1) scenario. Another study conducting preliminary analysis for Barbados in 2009 revealed that all of the beaches were vulnerable to sea-level rise. Approximately 80% of the total beach area in Holetown would be affected by a high impact (2 m sea-level rise) scenario, while a rise of 3.5 metres would result in 100% beach loss (Simpson, 2011). Additionally, more than 80% of beachfront properties would experience significant property and structural damage. The permanent or temporary loss and relocation of these major resorts could have significant implications for the livelihoods of thousands of employees.

The present value of land loss for the Caribbean over the next four decades, using discount rates of 1 % and 4 % is presented in table 6.11. The results confirm that the amount of land lost and the value of the losses varies widely by country. This is depending on the geography of the country under consideration, in terms of the size of the low elevation coastal zone relative to the total land area, and other factors such as soil type and water tables, which determine whether lands are prone to flooding.

For Montserrat, the present value of land loss (1.02 km or 1% of total land area) was estimated at US$ 25 million (47% of GDP) under the A2 scenario and US$ 13.4 million (25% of GDP) for the B2 scenario (at 1% discount rate) (see table 6.8). For Saint Lucia, the annual costs of sea-level rise were estimated at US$ 41 million (4% of GDP) under B2 and US$ 80 million (8.5% of GDP) in the A2 scenario. In addition to these annual costs, the capital costs associated with sea-level rise ranged between US$ 367 million (39% of GDP) and US$ 709 million (75% of GDP) under the two scenarios (see table 6.8). The value of land loss due to sea-level rise was US$ 3.2 billion (3.4 times GDP) under the B2 scenario and US$ 3.5 billion (3.7 times GDP) under the A2 scenario.

Table 6.11: Estimated value of land loss due to sea-level rise

Montserrat	**A2**	**B2**
Land area (km)	102	102
Expected land loss (km)	1.02	1.02
Nominal value of land loss (US$ million)	37.0	20.0
Present value of land loss (US$ million); 1% discount rate	24.9	13.4
Present value of land loss (US$ million); 2% discount rate	16.8	9.06
Present value of land loss (US$ million); 4% discount rate	7.71	4.17
Saint Lucia	**A2**	**B2**
Land area (km)	616	616
Expected land loss (km)	6.16	6.16
Nominal value of land loss (US$ million)	5 190.9	3 210.9
Present value of land loss (US$ million); 1% discount rate	3 486.50	3 210.29
Present value of land loss (US$ million); 2% discount rate	2 350.92	1 453.91
Present value of land loss (US$ million); 4% discount rate	1 081.21	668.67

Note: estimates were not made for sea-level rise in the case of the Bahamas
Source: ECLAC (2011f).

6. Extreme events

Due to the uncertain link between climate change and hurricane activity, many of the RECCC studies made no attempt to forecast future hurricane and windstorm activities and to estimate the economic losses related to such extreme events. In the case of the Bahamas, based on an assumption that a hurricane class cyclone of varying intensity hits the country once every five years (up to 2051), an estimate is made for the cumulative economic impact of sea-level rise, flooding, storm surge and maximum wind speeds (see table 6.12). Based on these assumptions, the estimated cost of extreme events (specifically hurricanes) for the Bahamas is more than US$ 2.400 billion for the 40-year period 2011-2050.

Table 6.12 Scenario percentage damages

Period	Hurricane category	Potential damage	Potential damage to structures	Adjustment
2011-2015	4	50%	MTR*(35%), airports (81%), roads (30%)	40%
2015-2020	1	5%	MTR(10%), airports (19%), roads (4%)	10%
2021-2025	5	75%	MTR(50%), airports (91%), roads (43%)	50%
2026-2030	1	5%	MTR(13%), airports (22%), roads (5%)	10%
2031-2035	4	50%	MTR(35%), airports (81%), roads (30%)	40%
2036-2040	1	5%	MTR(13%), airports (22%), roads (5%)	10%
2041-2045	5	75%	MTR(50%), airports (91%), roads (43%)	50%
2046-2050	1	5%	MTR(13%), airports (22%), roads (5%)	10%

*MTR- Major tourism resorts; Source: Developed from projected SLR data, Simpson and others (2009), and scenario conditions.

E. Summary of economic impact to 2050

1. Summary of losses

The total cost of climate change to the tourism sector was calculated by combining the impacts of reduced tourist arrivals (the outcome of both changes in weather patterns and new climate policies where estimates were available), loss of coral reefs and adverse impacts due to sea-level rise (and extreme events, in the case of the Bahamas).

Given the above estimates, the total cost of climate change to the tourism product in Montserrat (using a discount rate of 4 %) was estimated at US$ 190 million under the A2 scenario, or 9.6 times the value of 2009 GDP, and US$ 112 million for the B2 scenario, or 5.2 times the value of 2009 GDP (see table 6.13). In the case of Saint Lucia, the total cost was estimated at US$ 6.05 billion (12 times 2009 GDP) under the A2 scenario, and US$ 4.2 billion for the B2 scenario (3.6 times 2009 GDP). In the case of the Bahamas, it is projected that between US$ 16 billion to US$ 18 billion will be lost due to the impacts of climate change on the tourism sector.

For Barbados, losses were estimated to range from US$ 5.1 billion (B2 scenario) to US$ 7.6 billion (A2 scenario) in present value terms (using a 4% discount rate).

Table 6.13: Total Estimated Impact of Climate Change on Tourism relative to BAU in NPV terms based on a 4% discount rate (US$ Million)

Country	Tourism Arrivals		Coral Reef and Land Loss		Total	
	A2	**B2**	**A2**	**B2**	**A2**	**B2**
Aruba	n/a	n/a	n/a	n/a	6,397	6,599
*Bahamas	n/a	n/a	n/a	n/a	18,324	16,381
Barbados	4,778	3,871	2870	1256	7,648	5,127
Curacao	n/a	n/a	n/a	n/a	5,287	6,560
Montserrat	57	45	133	67	190	112
Saint Lucia	3,897	3,023	2147	1202	6,045	4,225

*breakdown not available for Aruba, the Bahamas and Curacao; *Note: These losses are relative to BAU*
Sources: ECLAC (2011c): ECLAC (2011d): ECLAC (2011e): ECLAC (2011f)

The research describes the diverse effects of climate change on the tourism sector in the Caribbean.

F. ADAPTATION STRATEGIES

The First International Conference on Climate Change and Tourism, held in Djerba, Tunisia in April 2003, focused on two central issues: all Governments were urged to subscribe to agreements on climate change; and to encourage tourism stakeholders both to further support the study and research of the reciprocal implications between tourism and climate change, and to promote the use of more energy-efficient and cleaner technologies and logistics, in order to minimize as much as possible their contribution to climate change (UNWTO, 2003).

However, planned adaptation initiatives are not usually undertaken as stand-alone measures, but rather, are embedded within broader sectoral initiatives such as water resource planning, coastal defence and disaster management planning (Adger and others, 2007). Therefore, mainstreaming of climate change strategies into national policies and sectoral plans must be considered a pillar of any response to climate change, in particular those of the health sector pertaining to the present study. Some existing national policies will need to be reviewed in order to incorporate the varying facets of climate change. It is through the revision of these policies and plans that the adaptation response will be clarified (table 6.14).

G. MITIGATION

UNWTO (2009) listed a number of mechanisms that could be used to diminish GHG emissions, such as reducing energy use, improving energy efficiency, increasing the use of renewable energy, among others. A carbon neutral tourism initiative is being launched in the Caribbean to lower emissions and enhance the subregion's position as a 'clean and green' tourism destination. This has the potential to increase the attractiveness and sustainability of the subregion, resulting in an increase of 'climate aware' tourists and increased revenue.

Significant emissions reductions in the tourism industry, particularly those associated with aviation can be made by implementing a marketing policy that focuses on environmentally and climate aware tourists and on closer source markets. In addition to the possibility of reducing absolute emissions by shorter routes, this would reduce the subregion's exposure to the climate policies of traditional markets and fuel price volatility. In terms of on-the-ground transportation for visitors, encouraging the use of the public transport system could reduce vehicle emissions by reducing the number of vehicles being driven. Increasing the attractiveness of public transportation may be done through improvement of its reliability and comfort. Other emissions reductions could be secured by, for example; embracing renewable energy, improved building design (accounting for 'natural' cooling), by saving and/or recycling water, reducing energy use, investigating advanced engineering techniques and ultimately off-setting remaining emissions.

H. CONCLUSION

This chapter describes the diverse effects that climate change can be expected to have on the tourism industry in the Caribbean. A tourism climatic index (TCI) was used to measure the influence that climate may have on the attractiveness of the destination. The TCI provides a means of building the impact of future changes in the weather into traditional tourism demand models. A linear extrapolation of the tourist arrivals was utilized to obtain a business as usual (BAU) scenario, which serves as a benchmark scenario and indicates what could happen without the impacts of climate change. Losses relative to this BAU scenario were calculated under a B2 scenario and an A2 scenario for tourist arrivals, coral reef -related services and sea-level rise. The implication is that the impact of climate change on tourism demand (arrivals) and the Caribbean tourism product will result in severe losses in income and Government revenues.

As small island developing States having low growth on GHG emissions, there is relatively small capacity to lessen emissions in the future. With a relative delay in the application of renewable energy systems, one solution may be to establish mitigation-related policies immediately. Alongside such efforts, and given the significant effects that are likely to arise, adaptation to climate change must be viewed, not just as a means of insurance, but also as an imperative to ensure the viability of these Caribbean economies.

Table 6.14 Potential adaptation strategies for the Caribbean

Risks	Risk mitigation or transfer options
Increased wind speed (Greater intensity of hurricanes)	Increase recommended design wind speeds for new tourism-related structures
	Offer incentives to retrofit tourism facilities to limit the impact of increased wind speeds
	Retrofit ports to accommodate the expected rise in wind speeds
	Catastrophe insurance for those government buildings that are used by tourists
	Insurance for adaptive rebuilding
Decreased availability of fresh water (Increased frequency of droughts)	Construction of water storage tanks
	Irrigation network that allows for the recycling of waste water
	Retrofit hotels to conserve water
	Build desalination plants
	Drought insurance
Land loss(Sea-level rise)	Build sea wall defences and breakwaters
	Replant mangrove swamps
	Raise the land level of low lying areas
	Build tourism infrastructure further back from coast
	Beach nourishment
	Limit sand mining for building materials
	Introduce new legislation to change planning policies, zoning and land use priorities as needed
Loss of coral reefs	Coral nurseries to help restore areas of the reef that have been damaged due to the effects of climate change
	Enhanced reef monitoring systems to provide early warning alerts of bleaching events
	Strengthen the scientific rigour and ecological relevance of existing water quality programmes
	Develop innovative partnerships with, and provide technical guidance to, landowners and users to reduce land-based sources of pollution
	Control discharges from known point sources such as vessel operations and offshore sewage
	Artificial reefs or fish-aggregating devices
	Enhancing coral larval recruitment
	Enhancing recovery by culture and transportation of corals
	Establish special marine zones
	Implement pro-active plans to respond to non-native invasive species
Extreme weather events	Provide greater information about current weather events
	Develop national guidelines
	Develop national evacuation and rescue plans
	More stringent insurance conditions for the tourism industry
	Flood drainage protection for hotels
	Accelerated depreciation of properties in vulnerable coastal zones
	Supporting infrastructure investment for new tourism properties
Reduction in travel demand Climate Change	Increase advertising in key source markets
	Fund discount programmes run by airlines
	Fund discount programmes run by hotels
	Introduce "green certification" programmes for hotels
	Conducting energy audits and training to enhance energy efficiency in the industry
	Introduce built attractions to replace natural attractions
	Recognition of the vulnerability of some eco-systems and adopt measures to protect them
	Introduction of alternative attractions
	Provide re-training for displaced tourism workers
	Revise policies related to financing national tourism offices to accommodate the new climatic realities

Sources: ECLAC (2011c): ECLAC (2011d): ECLAC (2011e): ECLAC (2011f)

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APPENDICES

Table A6.1: Tourism GDP and employment for selected Caribbean countries, 2010

Country	Share of tourism in GDP - direct contribution (%)	Share of tourism in GDP - direct and indirect (%)	Direct Contribution to employment (%)	Share of tourism in total employment - direct and indirect (%)
Anguilla	20.1	57.4	21.0	58.5
Antigua and Barbuda	17.1	74.1	17.8	69.2
Aruba	23.7	74.7	26.5	76.7
Bahamas (the)	21.0	46.1	28.6	53.7
Barbados	14.1	46.6	14.4	46.2
Belize**	29.7	n.a.	29.8	n.a.
British Virgin Islands	20.7	57.2	24.4	67.7
Cayman Islands	6.8	23.3	8.3	25.1
Dominica	7.5	24.9	6.9	22.9
Grenada	7.1	23.8	6.6	22.0
Guyana**	10.9	n.a.	9.0	n.a.
Jamaica	7.6	24.4	7.2	22.9
Puerto Rico	2.2	6.2	1.8	5.5
Netherland Antilles*	10.4	31.1	11.9	33.7
St Kitts and Nevis	7.4	27.3	7.3	25.8
St Lucia	15.3	45.7	17.3	45.3
St Vincent and Grenadines	7.2	25.5	6.6	23.3
Suriname**	4.4	n.a.	4.0	n.a.
Trinidad and Tobago**	12.8	n.a.	16.2	n.a.
US Virgin Islands	12.5	31.9	15.5	35.1
CARIBBEAN	**12.9**	**38.8**	**14.1**	**39.6**

**** ECLAC estimates (2008); all other countries WTTC Tourism Satellite Accounts sourced online at: http://www.wttc.org/eng/Tourism_Research/Economic_Data_Search_Tool/**

Table A6.2: Montserrat- Forecast arrivals and receipts under various climate change scenarios

Arrivals	**A2**	**B2**	**BAU**
2008-2020	118 116	120 946	127 753
2021-2030	146 921	150 516	161 818
2031-2040	194 872	199 530	217 470
2041-2050	258 416	264 655	292 262
Total	718 325	735 647	799 303
Earnings (US$ million)	**A2**	**B2**	**BAU**
2008-2020	123.34	126.29	133.40
2021-2030	153.42	157.17	168.97
2031-2040	203.49	208.35	227.09
2041-2050	269.84	276.36	305.19
Total	750.09	768.18	834.65
Present value of earnings (1% discount rate; US$ million)	**A2**	**B2**	**BAU**
2008-2020	111.66	114.33	120.77
2021-2030	138.89	142.29	152.97
2031-2040	184.22	188.62	205.58
2041-2050	244.29	250.18	276.28
Total	679.05	695.42	755.60
Present value of earnings (2% discount rate; US$ million)	**A2**	**B2**	**BAU**
2008-2020	101.18	103.61	109.44
2021-2030	125.86	128.94	138.62
2031-2040	166.93	170.92	186.29
2041-2050	221.37	226.71	250.36
Total	615.34	630.18	684.70
Present value of earnings (4% discount rate; US$ million)	**A2**	**B2**	**BAU**
2008-2020	83.32	85.32	90.12
2021-2030	103.64	106.18	114.15
2031-2040	137.47	140.76	153.41
2041-2050	182.30	186.70	206.17
Total	506.74	518.95	563.86

Source: ECLAC, 2011e

Table A6.3: Montserrat: Forecast tourism receipts and losses under various climate change scenarios

Montserrat			
Losses (NPV 2% discount rate; US$ million)	Value of Tourism Receipts(BAU)USMillions	Losses under A2 US Millions	Losses under B2 US Millions
2008-2020	109.44	-8.26	-5.83
2021-2030	138.62	-12.76	-9.68
2031-2040	186.29	-19.36	-15.37
2041-2050	250.36	-28.99	-23.65
Total	684.70	-69.36	-54.52
Losses(NPV, 4% Discount Rate; US$ million)			
2008-2020	90.12	-6.8	-4.8
2021-2030	114.15	-10.51	-7.97
2031-2040	153.41	-15.94	-12.65
2041-2050	206.17	-23.87	-19.47
Total	563.86	-57.12	-44.91

Source: ECLAC, 2011e

Table A6.4: Barbados: Cumulative tourist expenditure for specific years for BAU, A2 and B2 scenarios (US$ million)

Year \ Scenario	BAU scenario (US$ million)	Losses under A2 (US$ million)	Losses under.B2 (US$ million)
2011-2020	10 114	-1 410	-549
2011-2030	21 741	-4 761	-2 597
2011-2040	36 080	-10 254	-6 762
2011- 2050	53 574	-18 309	-13 224

Source: ECLAC, 2011 c

Table A6.5: Bahamas: Forecast tourism receipts and losses under various climate change scenarios

Bahamas			
Losses (NPV 2% discount rate; US$ million)	Value of tourism receipts (BAU) (US$ million)	Losses under A2 US$ million	Losses under B2 US$ million
2011-2020	25 219	-3 466	-3 876
2021-2030	25 489	-2 880	-2 973
2031-2040	24 062	-4 295	-3 625
2041-2050	21 857	-5 639	-3 819
Total	96 626	-16 280	-14 293
Losses(NPV, 4% discount rate; US$ million)			
2008-2020	24 832	-3 403.77	-3 808.49
2021-2030	25 098	-2 832.35	-2 924.78
2031-2040	23 571	-4 207.24	-3 550.75
2041-2050	21 411	-5 524.05	-3 740.84
Total	94 912	-15 967.4	-14 024.9

Source: ECLAC, 2011f

Table A6.6: Saint Lucia: Forecast arrivals under various climate change scenarios

Arrivals	**A2**	**B2**	**BAU**
2008-2020	3 802 891	3 912 211	4 240 253
2021-2030	5 696 107	5 871 781	6 420 754
2031-2040	9 215 774	9 492 190	10 458 732
2041-2050	14 895 507	15 354 062	17 036 173
Total	33 610 278	34 630 244	38 155 912
Earnings (US$ million)	A2	B2	BAU
2008-2020	4 826.30	4 965.04	5 381.36
2021-2030	7 229.01	7 451.96	8 148.67
2031-2040	11 695.87	12 046.67	13 273.32
2041-2050	18 904.10	19 486.06	21 620.85
Total	42 655.27	43 949.73	48 424.20
Present value of earnings (1% discount rate; US$ million)	A2	B2	BAU
2008-2020	4 369.19	4 494.79	4 871.68
2021-2030	6 544.33	6 746.16	7 376.88
2031-2040	10 588.12	10 905.69	12 016.17
2041-2050	17 113.63	17 640.47	19 573.07
Total	38 615.26	39 787.11	43 837.80
Present value of earnings (2% discount rate; US$ million)	A2	B2	BAU
2008-2020	3 959.25	4 073.06	4 414.59
2021-2030	5 930.31	6 113.20	6 684.75
2031-2040	9 594.69	9 882.47	10 888.75
2041-2050	15 507.94	15 985.35	17 736.62
Total	34 992.18	36 054.08	39 724.71
Present value of earnings (4% discount rate; US$ million)	A2	B2	BAU
2008-2020	3 260.48	3 354.20	3 635.46
2021-2030	4 883.66	5 034.28	5 504.95
2031-2040	7 901.31	8 138.30	8 966.98
2041-2050	12 770.93	13 164.08	14 606.27
Total	28 816.38	29 690.86	32 713.66

Source: ECLAC. 2011d

Table A6.7: Saint Lucia: Forecast tourism receipts and losses under various climate change scenarios

Saint Lucia			
Losses (NPV 2% discount rate; US$ million)	Value of tourism receipts (BAU) (US$ million)	Losses under A2 (US$ million)	Losses under B2 (US$ million)
2008-2020	4 414.59		
2021-2030	6 684.75		
2031-2040	10 888.75		
2041-2050	17 736.62		
Total	39 724.71	-4 732.53	-3 670.63
Losses(NPV, 4% discount rate; US$ million)			
2008-2020	3 635.46		
2021-2030			
2031-2040			
2041-2050			
Total	3 2713.66	-3 897.28	-3 022.8

Source: ECLAC, 2011d

CHAPTER VII.
THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE TRANSPORTATION SECTOR

INTRODUCTION

The international transportation sector comprises air, sea and land transportation networks and the support infrastructure on which they depend. Air transportation comprises airports and ground facilities, as well as aircraft that carry passengers and freight and the air traffic control system. Marine transportation infrastructure includes ports and harbours and supporting intermodal terminals and the ships and barges that use these facilities. Surface transportation includes road vehicles and rail networks and related infrastructure. International transportation is a growing source of GHG emissions while, at the same time, climate change has the potential to impact transportation networks and infrastructure and thus plays an important role in decision-making for the sector.

A. IMPACT OF TRANSPORTATION ON CLIMATE CHANGE

Climate science considers the period of the development of steam engines, allowing the conversion of fossil fuels into the movement of wheels, as the end of the pre-industrial time and the start of a significant human alteration of the natural greenhouse effect, namely the industrial revolution (Uherek, 2010). The transportation sector emits a wide variety of gases and aerosols, which influence climate directly and indirectly via chemical and physical processes (Fuglestvedt and others, 2010). Recent research conducted under the European Sixth Framework Project 'ATTICA' (European Assessment of Transport Impacts on Climate Change and Ozone Depletion) assessed the impacts of aviation, marine and land transportation on atmosphere and climate (Fuglestvedt and others, 2010, Lee and others, 2010, Eyring and others, 2010, and Uherek and others, 2010).[69] Emissions from the transportation sector include emissions from mobile air conditioners (MAC) in passenger vehicles or cooling/freezing systems of goods transport, but these are not included in the discussion here.

1. Aviation transportation

Aviation radiative forcing (RF) accounted for 3.5% of total anthropogenic forcing for 1992 - from both CO_2 emissions and non-CO_2 effects. More recent estimates suggest that global emissions from international aviation doubled between 1990 and 2005 and are projected to almost quintuple by 2050 (IPCC, 2007).[70] The scope of current aviation effects on climate remain the same as those outlined in the IPCC (1999) report: This comprises positive RF (warming) arising from emissions of CO_2, soot, H_2O, NO_x as an O_3 precursor, contrails and cirrus cloud enhancement from spreading contrails; and negative RF (cooling) arising from fuel conversion to sulphate particles and NOx emissions that result in reductions of ambient CH_4. 'New' effects being investigated include the potential RF from 'soot cirrus'

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[69] The climate impact of current and potential future aviation is, by convention, quantified using the metric 'radiative forcing of climate', since many climate experiments have found an approximately linear relationship between a change in global mean radiative forcing (RF) and a change in global mean surface temperature (Lee and others, 2010).

[70] The most complete and up-to-date assessment of aviation impacts on climate change and ozone (O_3) depletion was that undertaken by the Intergovernmental Panel on Climate Change (IPCC) and published as a Special Report; 'Aviation and the Global Atmosphere' (IPCC, 1999). It was the first assessment of the aviation sector that produced estimates of RF (defined specifically as the change in radiative forcing since the pre-industrial era) for all the forcing agents known to be pertinent to aviation.

(i.e. seeding of new clouds from particles or the alteration of existing cirrus properties) which may have a positive or negative radiative effect (Lee and others, 2010).

2. Land transport

Emissions, primarily from road vehicles and, to a smaller extent, from rail and inland shipping dominate the release of long-lived greenhouse gases from transportation (primarily CO_2), which have an impact on the total anthropogenic greenhouse effect. The current emissions from land transport are almost three times as large as the emissions from the aviation and shipping sectors combined (Eyring and others, 2005) and thus its relative contribution to RF is significant. Since 1910, road traffic has gained more and more importance in international transport, overtaking all other modes; road vehicles are now responsible for 75%-80 % of all CO_2 emissions from transport and the increasing fuel consumption in road transport is expected to generate more than one-fifth of the global CO_2 emissions in the near future (Uherek and others, 2010). Table 7.1 shows CO_2 emissions from transportation in the year 2000 and for the historical period 1900- 2000.

Table 7.1 Emissions of CO_2 from the transportation sector in year 2000 and cumulative emissions 1900-2000

	2000		Cumulative 1900-2000	
	Emissions (Teragrams CO_2)	Share (%)	Emissions (Teragrams CO_2)	Share (%)
Road	4 282	72.3	114 494	55.1
Rail	124	2.1	20 913	10.1
Maritime shipping	626	10.6	31 940	15.4
Aviation	688	11.6	16 890	8.1

Source: Uherek, Elmar and others (2010).

In many countries, the railway plays an important role in transportation of passengers and cargo, but there is, as yet, no global gridded inventory available for emissions via this mode of transport.[71] As an alternative, rail fuel consumption data, which show a large decline in coal consumption since 1971 alongside a 70% increase in electricity consumption and stable diesel consumption from 1971 to 2004, can be used to estimate global carbon dioxide emissions. The estimates suggest that rail emissions are small compared to the emissions from road transport. From a climate change perspective, rail transport will, compared to air and road transportation, imply less emissions per passengers and freight transported (European Environment Agency (EEA) TERM, 2003), since per passenger emissions from road transport are more than twice as high as those from rail, while emissions from air transport are 10%-20 % higher than those from road (Uherek and others, 2010).

3. Maritime transportation

Sea transportation facilitates more than 90% of world trade and contributes directly to a country's international competitiveness (ICTSD, 2010). Emissions of exhaust gases and particles from oceangoing ships are a significant and growing contributor to the total emissions from the transportation sector. Emissions from the international maritime industry doubled between 1994 and 2007, and are projected to possibly triple by 2050 (Lee and others, 2009). Oceangoing shipping emitted around 780 Tg CO_2 in the year 2000, which corresponds to a fuel consumption of 250 Mt and a contribution of around 2.7% of all

[71] European Monitoring and Evaluation Programme (EMEP) is a scientifically-based, policy-driven programme under the Convention on Long-range Transboundary Air Pollution for international cooperation to solve transboundary air pollution problems. EMEP prepares a gridded rail inventory for Europe, based on data reported by the Parties to the Convention, which is however, not fully complete (http:// www.emep.int/index_data.html). European rail emissions have also been estimated by the EEA TERM (2003), which reported that rail emissions in Europe make up for only 1%-3% of total transport emissions.

anthropogenic CO_2 emissions in 2000 (Eyring and others, 2010). Since 2000, annual growth rates in total seaborne trade have been higher than in the past (5.2% on average from 2002 to 2007) with a concomitant increase in fuel consumption.

One of the major findings of recent climate impact studies was that particle emissions from shipping can significantly modify the microphysical and optical properties of clouds (indirect aerosol effect). The results indicate that the cooling due to altered clouds far outweighs the warming effects from greenhouse gases such as carbon dioxide (CO_2) or ozone from shipping, overall causing a negative RF. The indirect aerosol effect of ships on climate is found to be far larger than previously estimated, contributing between 17% and 39 % to the total indirect effect of anthropogenic aerosols, depending on the ship emission inventory used. This contribution is high because ship emissions are released in regions with frequent low marine clouds in an otherwise clean environment and the potential impact of particulate matter on the radiation budget is larger over the dark ocean surface than in polluted regions over land (IMO, 2009 and Eyring and others, 2010).

B. CLIMATE CHANGE IMPACTS ON TRANSPORTATION NETWORKS AND INFRASTRUCTURE

IPCC (2007) identified five potential sources of impacts of climate change on transportation: increases in very hot days and frequent heat waves; increases in arctic temperatures; rising sea levels; increases in intense precipitation events; and increases in hurricane intensity. These changes may have severe consequences for traditional transportation routes, networks and existing transport infrastructure.

- Climate change could lead to potentially sudden or dramatic changes far outside historical experience (e.g. record rainfall and record heat waves). Transportation infrastructure, designed for typical weather patterns, may not be able to cope with these new extremes. The latest scientific findings suggest that forecasts about the intensity and frequency of extreme climatic events may be worse than previously thought, moving the issue of climate change to the forefront of the international agenda as one of the "greatest challenges of our time" (Allison and others, 2009). If design thresholds are frequently exceeded, or evacuation routes become vulnerable, historical climate projections used by transport professionals to guide transport operations and investments would no longer be a reliable guide for future plans.

- Long run decisions regarding the location of infrastructure help to shape development patterns far beyond the transport planning horizon of 20-30 years. Similarly, decisions about land use, zoning and development often generate demand for large investments in transport infrastructure. It is therefore important for transport decision makers to consider the potential impacts of climate change now, in making these important investment choices - rebuild, rebuild differently, or relocate critical transport infrastructure.

- International transportation is crucial for the sustainable development of trade and tourism in developing countries. The vulnerability of both air and sea transport infrastructure to climate change carries tremendous implications for Caribbean small island developing States (SIDS) which are very dependent on air transportation to bring most tourists from the main markets in North America and Western Europe to their shores, as well as very reliant on sea transportation to move nearly all of their merchandise trade.

- Finally, the growing consensus that future targets for emissions reductions in the post 2012 Climate Policy Framework must now include air and sea transportation could have important implications for Caribbean SIDS.[72]

C. VULNERABILITY OF CARIBBEAN TRANSPORTATION SYSTEM TO CLIMATE CHANGE

The Caribbean subregion is an archipelago of island States in relatively close geographical proximity situated between the large continental land masses of North and South America. Expanses of sea typically separate Caribbean economies, making air transportation the most practical mode for the vast majority of subregional travel needs, particularly in the tourism industry. Sea transportation is often the only mode of transportation for moving freight within the Caribbean. Other modes of transportation such as a road or rail transportation, or even the use of pipelines, are not feasible options.

1. Trade

For the past three decades, the Caribbean has pursued an external trade policy anchored on unilateral preferential access to the European and North American markets. These preferential agreements have helped to make Caribbean economies very open. Maritime transportation volumes, shipments to and from CARICOM countries, are relatively small. The deployed capacity per voyage for imports from the United States to the Caribbean is less than 50% of the World-USA average (see table 7.2). On average, 277 twenty-foot equivalent unit (TEU) containers were deployed per voyage on the Caribbean-Imports/USA trade in comparison to 584 TEU containers for the World-Imports/USA trade, for the period under review.[73] Low cargo volumes in many small Caribbean islands can only reasonably support one public port.

Sea transportation volumes attract only a few direct liner shipping lines from Asia, Europe or North America. A large part of the trade is moved either by chartered vessels or on regular shipping lines that connect to other lines via trans-shipment services. Four direct services from Europe and 13 direct services from North America call on countries such as Jamaica and Trinidad and Tobago, that have a larger trade volume, whereas there is no single direct service from Europe and only a few services from North America for the smaller countries of the Caribbean.

Insufficient sea transportation volumes lead to multiple port calls for a limited amount of cargo. These result in higher ocean freight costs and higher port charges, and hamper trade and the development of non-maritime industries and services (UNCTAD, 2010b). Less expensive transportation would directly promote foreign trade and, at the same time, more trade would also lead to a further reduction of transportation costs due to economies of scale. The global trend towards larger container ships means that these ships have to generate extra traffic to achieve appropriate capacity utilization. As a result, these global shipping carriers have built up a dense network of feeder services to support their trans-shipment schedules.

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[72] Even though air and sea transportation combined are currently responsible for just 3% of global GHG emissions, emission scenario calculations up to the year 2050 show that significant reductions would be needed to offset increased emissions due to the predicted growth in seaborne trade and cargo energy intensity. If no aggressive emission reduction strategies are introduced, CO_2 and SO_2 emissions from ships could double present-day values by 2050. Thus, policy proposals to mitigate emissions from international transportation are increasingly being promoted as a necessary solution (Eyring and others, 2010).

[73] TEU is an inexact unit of cargo capacity, often used to describe the capacity of container ships and container terminals. It is based on the volume of a twenty-foot (20') long (6.1metre) intermodal container, a standard-sized metal box which can be easily transferred between different modes of transportation, such as ships, trains and trucks.

Table 7.2: Deployed capacity per voyage for different trade lanes (Imports to the United States, 1996, Quarter 4)

Trade Lane	(TEUs) lifted	Capacity deployed per voyage (in TEU)	Capacity utilization (%)	Ranking
Africa	4 149	350	56	6
Caribbean	33 784	277	49	9
Central America	69 919	263	66	10
East Coast South America	60 432	347	58	7
India/Other Asia	12 637	188	39	11
Mediterranean	94 683	550	70	3
Mideast	1 616	78	63	13
Northern Europe	245 857	633	69	2
NE Asia	920 913	1 001	72	1
Oceania	16 877	485	58	5
Other Regions	2 075	129	57	12
SE Asia	122 145	293	77	8
West Coast South America	33 524	486	69	4
Total Imports	**1 618 611**	**584**	**69**	

Source: PIERS, On Board Review, Spring 1997

In the Caribbean, the major trans-shipment ports are Freeport (Bahamas), Rio Haina (Dominican Republic), Kingston (Jamaica), Manzanillo (Panama), and Cristobal (Panama). Port of Spain (Trinidad and Tobago) is a subregional hub port, from whence cargo is distributed mainly to the Southern Caribbean. Almost all big shipping carriers that operate in the Caribbean are at these trans-shipment ports, and, since they must fill their main line vessels and maintain market share, this puts additional pressure on ocean freight rates for cargo. For the other Caribbean countries, cargo must travel through two trans-shipment points until it reaches its final destination, which raises overall transportation costs. More port calls also raise the level of GHG emissions.[74]

2. Tourism

Air transportation services operating across small, island economies provide a vital social and economic link between peoples, countries and cultures. The air transportation sector not only impacts an economy in terms of its contribution to employment, but is also a catalyst, enhancing business efficiency and productivity by providing easier access to suppliers and customers. By opening up new markets for international travel, the air transportation sector is also a major driver of the tourism industry.

The Caribbean is arguably the most tourism-dependent region in the world, as tourism represents over 12% of GDP and exceeds 50% of GDP in several nations (World Travel and Tourism Council, 2007; United Nations Department of Economic and Social Affairs, 2010). The data in table 7.3 show that thirteen of the nineteen Caribbean countries listed are amongst the most heavily dependent on their respective travel and tourism industries in the world (in relation to GDP), with all thirteen ranking in the top 25 most tourism-dependent countries (WTTC, 2010). The Caribbean tourism industry attracted approximately 20 million visitors in 2009 (WTTC, 2010), showing a modest annual growth of around

[74] Substantial import/export trade imbalances in the Caribbean mean that many carriers must haul back empty containers, especially to North America. The Caribbean has the second worst capacity utilization of all United States imports when compared to other world regions. Just under half of the containers carry cargo; the rest of are empty container movements that contribute to increasing freight rates. Nevertheless, Caribbean exporters could benefit from this situation by shipping cargo relatively cheaply to other regional destinations.

1.5% over the past decade. Almost all the nineteen countries listed depend on air transportation to bring in long-stay visitors, who generally contribute more total tourism receipts than cruise passengers.

The air transportation sector in the Caribbean facilitates the tourism industry, primarily by acting as destinations for foreign carrier services and, in the case of the North American market, through the use of foreign hubs (Warnock-Smith, 2008). A number of Caribbean-based carriers also make a notable contribution to the tourism sector and to the travel needs of local residents.

Table 7.3: Socio-economic importance of travel and tourism in the Caribbean

Country	Travel & tourism, % of GDP (World Ranking, 2010)	% visitors arriving by air
Anguilla	61.0 (5)	84
Antigua & Barbuda	78.5 (1)	95
Bahamas (the)	46.5 (8)	88
Barbados	48.1 (6)	92
Belize	28.2 (17)	85
Bermuda	11.2 (65)	86
British Virgin Islands	43.7 (10)	94
Cayman Islands	23.3 (24)	67
Dominica	23.3 (23)	88
Grenada	24.4 (22)	96
Guyana	11.5 (63)	99
Haiti	7.0 (125)	n.a.
Jamaica	25.4 (20)	92
Montserrat	n.a.	99
St. Kitts & Nevis	30.5 (16)	91
St. Lucia	35.1 (13)	90
St. Vincent & the Grenadines	23.6 (23)	98
Suriname	4.6 (164)	93
Trinidad & Tobago	10.9 (66)	95

Sources: World Travel & Tourism Council, Caribbean Tourism Organization, CIA World Fact Book
Notes: n.a. means not available, * refers to 2004; ** represents 2002 data

In tourism-dependent economies such as Antigua and Barbuda, Montserrat, Barbados and the Bahamas, foreign visitors comprise a larger percentage of air arrivals, while airports in secondary industry-dependent economies, like Trinidad and Tobago, and Guyana, are more geared towards handling local residents. Countries with a relatively high volume of air passengers are usually supported by more sophisticated airport infrastructure and a national or regional carrier (Jamaica, Trinidad and Tobago, the Bahamas, Cayman Islands and Antigua and Barbuda).

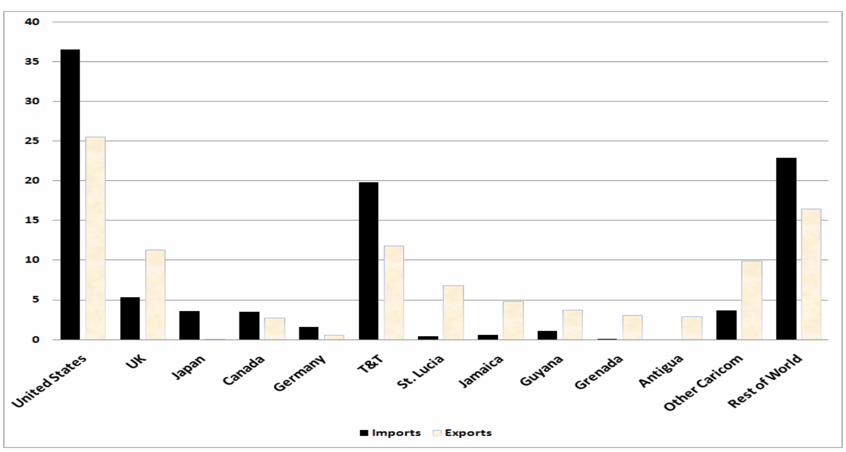
These tourism-dependent economies are becoming increasingly concerned about the inclusion of aviation in greenhouse gas mitigation policy for international bunker fuels and, more recently, adaptation policy proposals. The central concern is that such policies will increase the cost of travelling by air, therefore reducing visitor arrivals to long-haul, tourism-dependent destinations, often SIDS. However, the major findings of a recent study (Pentelow and Scott, 2011) indicate that, until deeper emission cuts and higher carbon costs are implemented in mitigation policy, there will be no “meaningful impact” on the growth of arrival numbers to the Caribbean.[75] This result is consistent with work done by Gössling and others (2008) and other studies that have examined the impact of mitigation policy on air travel (Rothengutter, 2009).

Related to this, socio-economic changes in the United States of America or in European countries, arising from a new regulatory framework for the treatment of air transportation GHG emissions, are expected to have an indirect but pronounced effect on air traffic volumes into the Caribbean (figure 7.1). Foreign visitors to the Caribbean region generally come from a few source markets in North America and Europe. Intraregional flows form a relatively minor share of the extraregional air passenger traffic arriving into Caribbean airports. By comparison, both EU and United States have sizeable domestic markets and a wider range of international source markets.

3. Infrastructure

Port facilities, generally located in the coastal zone, may be affected by sea-level rise, weather-related delays and periodic interruption of shipping services. Jetties or breakwaters protecting the port will be less efficient as peak tides rise, and may need raising and strengthening. The alternative is for the port to accept an increased risk of overtopping during storm surge and therefore a higher risk of damage. An increasing sea level will also result in a larger tidal prism (volume of tidal water entering/leaving the harbour), resulting in increased scour of foundations of marine structures. Changes due to increased sea-level rise could require some retrofitting of facilities. Warming temperatures and possible increases in temperature extremes will affect the ground facilities at airports - runways in particular - in much the same way that they will affect roads. More heat extremes could cause heat buckling of runways and may affect aircraft lift (hotter air is less dense, reducing mass flowing over the wing to create lift).[76] Thus, increases in extreme heat are likely to result in payload restrictions, flight cancellations, and service disruptions, and could require runway length extensions.

Figure 7.1: Significance of trading partners for Barbados (2007, percentage)



Source: Barbados Statistical Office

[75] Laurel Pentelow and Daniel J. Scott (2011) used a tourism arrivals model to examine the implications of currently proposed climate policies for the Caribbean. Their results indicate that, under current proposals for both mitigation and adaptation focused climate policy, reductions in tourist arrivals from the major markets of Europe and North America would be negligible versus business as usual growth projections, and that only under the most stringent mitigation policy scenario is a significant decrease in tourist arrivals predicted.

[76] If runways are not sufficiently long for large aircraft to build up enough speed to generate lift, aircraft weight must be reduced or some flights cancelled altogether.

Over 43% of the merchandise exports of Barbados are shipped within CARICOM. Most of this intraregional export trade is to Trinidad and Tobago (11.8 %), Saint Lucia (6.8 %), and Jamaica (4.8 %). Outside of the Caribbean subregion, the United Kingdom accounts for 11.3% of Barbados' total merchandise exports.

Total tonnage handled at the Bridgetown port terminal typically relates to import, export and trans-shipment cargo (containerized and breakbulk) for both the Deep Water Harbour and the Shallow Draught. According to the 2007 Annual Report of the Barbados Port, the Port handled a total of 1,314,716 tonnes in 2007, up slightly by 0.5 % from 2006. Containerized cargo comprised 88% of the total tonnage, the remainder being breakbulk cargo. The majority of the cargo was inbound-related, due to the high import requirements of the island. Cargo handled at the Shallow Draught Harbour, reflecting inter-island activity, continues to be low and represented only 2% of the total cargo handled at the Port in 2007. The total number of empty containers discharged from vessels was more than half of total imported containers.

4. Extreme events

Climate scientists believe that the expected increase in intensity of tropical storms may be related to climate change. Precipitation, wind speed, and wind-induced storm surge as a result of tropical storms are relevant to transportation. Strong storms tend to produce intense precipitation of longer duration; wind speed increases damage; and wind-induced storm surge and wave action can have devastating effects.

(a). Approach to estimating the economic impacts

Since emissions from the Caribbean subregion are deemed to be relatively low on the global scale, the approach focused on estimating the impacts of climate change on transportation networks, rather than considering the effects of emissions from the sector.

Transportation networks exist to facilitate the movement of people and goods and the need for these networks, or transportation demand, therefore, is defined by demographic and economic considerations – connecting population centres, providing access to economic resources, and facilitating integration. The demand for transportation is driven by economic growth, higher disposable incomes and increased leisure time on the demand side, coupled with technical change and low cost of travel on the supply side (Michalski, 1996).

A demand model for air and sea transportation was constructed as a function of per capita income, the average economic growth rate of the major trading partner countries (in general for the Caribbean these are the United States if America, Canada, the United Kingdom and Germany), crude oil prices, the change in annual mean temperature, and the change in annual mean precipitation. Oil prices are used to proxy travel costs.[77] A priori, it is expected that the income variables would be positively

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[77] The general specification of the demand models were:

$$AT = f(BPCI, \Delta\, G\text{-}4GDP, OIL, \Delta T, \Delta P) \quad (1)$$

$$ST = f(M, BGROWTH, OIL, \Delta T, \Delta P) \quad (2)$$

Where,

AT = Air Transportation
ST = Sea transportation
G-4GDP = growth rate of the major trading partner countries (US, Canada, UK and Germany)
BPCI = Barbados Per Capita Income
BGROWTH = economic growth in Barbados
M = Total imports in Barbados (M)
OIL = crude oil prices

associated with international transportation demand and that oil prices and the two climate variables would have a negative relationship with international transportation demand. The air and sea transportation demand models are used to generate forecasts of air and sea transportation expenditure until 2050. The forecast expenditure data are used to cost the effects of climate change (temperature and precipitation) on the international transportation sector under the A2 and B2 climate scenarios until 2050.[78] Results are estimated for Montserrat and Barbados and the impact of climate change on the transportation sector is estimated as the cumulative cost due to temperature and rainfall changes'

To this estimate, two additional impacts are added: impacts of climate change policies on international travel mobility; and impacts due to sea-level rise (SLR) on the international transport infrastructure.

D. RESULTS

1. Impact of temperature and precipitation changes

The demand for transportation (measured here as expenditure on transportation) falls as climate change intensifies, representing declines in trade and tourism. Thus, when compared to the BAU case, the A2 scenario is expected to be the worst case scenario, resulting in more losses in transportation demand than the B2 scenario. The study finds that the overall impact of climate change on air transportation is a fall-off in demand, with consequent decline in contributions of the sector to the national economies

The climate variables (rainfall and temperature) and crude oil prices each have a negative relationship with air and sea transport demand expenditure, while increases in per capita income and economic growth lead to increases in international transport expenditure. Table 7.4 presents the projected cumulative impact of temperature and precipitation on international transportation for Barbados and Montserrat under BAU and for the A2 and B2 scenarios at decadal intervals.

(a) Air transportation

For Barbados, cumulative air transportation expenditures (in 2008 dollars) in the A2 scenario are projected at US$ 13.3 billion by 2050, an implied loss of some US$ 5.7 billion relative to the BAU case over the forty year period; under B2 scenario losses to travel demand result in a cumulative loss of US$ 3.8 billion relative to the BAU scenario over the forecast period.

ΔT = the change in annual mean temperature

ΔP = the change in annual mean precipitation

Equations (1) and (2) were transformed into a double-logarithmic specification, one of the more popular specifications. Thus the equations to be actually estimated are:

$$\ln AT = \alpha_0 + \alpha_1 \ln BPCI + \alpha_2 \ln G\text{-}4GDP + \alpha_3 \ln OIL + \alpha_4 \ln\Delta T + \alpha_5 \ln\Delta P + u_1 \quad (3)$$

$$\ln ST = \beta_0 + \beta_1 \ln M + \beta_2 \ln BGROWTH + \beta_3 \ln OIL + \beta_4 \ln\Delta T + \beta_5 \ln\Delta P + u_2 \quad (4)$$

[78] Forecasts for the two climate variables were received from the INSMET in Cuba. The predictions from INSMET were obtained from the European Centre Hamburg Model (ECHAM), an atmospheric general circulation model developed at the Max Planck Institute for Meteorology. The annual costs of climate change impacts to 2050 are expressed in US$ using 2008 as the base year even though climate change impacts may not be fully experienced for some decades. This is standard practice in the literature (World Bank, 2002).

For Montserrat, cumulative air transportation expenditures (in 2008 dollars) in A2 are projected to reach up to US$ 1.1 billion by 2050, an implied loss of some US$ 452 million relative to the BAU scenario over the forty year period. Air transportation expenditures under B2, which is the lightest impact scenario, reach a cumulative US$ 1.2 billion by 2050, an implied loss of US$ 302 million relative to the BAU scenario over the forecast period.

Table 7.4: Impact of temperature and precipitation on transport expenditure, A2 and B2 (2008 US$ million)

Barbados		Air transportation			Maritime transportation			Total international transportation		
	Year	BAU	A2	B2	BAU	A2	B2	BAU	A2	B2
	2020	2 371	1 660	1 897	356	249	285	2 727	1 909	2 182
	2030	5 730	4 011	4 584	860	602	688	6 590	4 613	5 272
	2040	10 796	7 557	8 636	1 619	1 134	1 295	12 415	8 691	9 931
	2050	18 946	13 262	15 157	2 842	1 989	2 274	21 788	15 251	17 431
Montserrat		Air transportation			Maritime transportation			Total international transportation		
	Year	BAU	A2	B2	BAU	A2	B2	BAU	A2	B2
	2020	65	45	52	38	27	31	103	72	83
	2030	226	158	181	79	55	63	305	213	244
	2040	614	430	491	127	89	101	741	519	592
	2050	1 507	1 055	1 205	192	134	153	1 699	1 189	1 358

Sources: ECLAC (2011): ECLAC (2011a)

(b) Maritime transportation

Barbados: Sea transportation expenditures in the A2 scenario are projected to suffer a loss of US$ 853 million when compared to the BAU scenario of US$ 3.4 billion over the forty year period; losses under the B2 scenario are estimated at US$ 568 million over the forecast period.

Montserrat: Sea transportation expenditures in A2 are projected to reach a cumulative US$ 134 million by 2050, an implied loss of US$ 58 million when compared to the BAU scenario of US$ 192 million over the forty year period. Sea transportation expenditures under B2 reach a cumulative US$ 153 million by 2050, generating an implied loss of US$ 39 million.

(c) Total international transport

Relative to the BAU scenario, the implied cost to the international transportation sector in Barbados under the A2 scenario amount to US$ 6.5 billion by 2050, while that for the B2 scenario amount to US$ 4.4 billion by 2050. In the case of Montserrat, losses relative to BAU are US$ 510 million under the A2 scenario and US$ 341 million under the B2 scenario, by 2050.

These impacts, which relate to the effects of changing temperature and precipitation, are just one aspect of the total impacts of global climate change on the international transportation sector. Three other core impacts must be assessed: the impact of climate change policies on international travel mobility; the impact of sea-level rise (SLR) on the international transport infrastructure; and the impact of an eruption of the Soufriere Hills Volcano (an example of an extreme event), in the case of Montserrat.

2. Impact of climate change policy

Barbados: The cumulative loss in international transport expenditure in Barbados due to the impact of climate change policies in developed countries on international travel mobility is summarized in table X. The potential cumulative economic loss for air transportation under the A2 scenario is US$ 3,342 million and under the B2 scenario is US$ 3,820 million. Losses for the BAU scenario are equal to zero since the assumption is made that there are no impacts of climate change and therefore no losses. The potential cumulative economic cost for maritime transportation under the A2 scenario is US$ 501 million and under the B2 scenario is US$ 573 million. The cumulative economic loss for the international transport sector in Barbados arising from climate change policies in developed countries is US$ 3,843 million by 2050 under the A2 scenario and US$ 4,393 million under the B2 scenario over the forecast period.

Table 7.5: Impact of climate change policies in developed countries on international travel mobility in Barbados under A2 & B2 scenarios (2008 US$ million)

Barbados	**Air transportation**		**Maritime transportation**		**International transportation**	
Year	**A2**	**B2**	**A2**	**B2**	**A2**	**B2**
2020	105	120	16	18	121	138
2030	441	504	66	43	507	547
2040	1 511	1 727	227	259	1 738	1 986
2050	3 342	3 820	501	573	3 843	4 393

Sources: ECLAC (2011): ECLAC (2011a)

Montserrat: Simpson (2010) estimates that the imposition of the aviation passenger duty is likely, on a intermediate scenario basis, to reduce tourist arrivals to Montserrat by 6.3% in 2020 and by as much as 25.2% by 2050. Based on these estimates, table 14 gives the cumulative loss in international transport expenditure in Montserrat due to the impact of climate change policies in developed countries on international travel mobility. The potential cumulative economic loss for air transportation under the A2 scenario is US$ 266 million and under the B2 scenario is US$ 316 million. Losses for the BAU scenario are equal to zero since the assumption is made that there are no impacts of climate change and therefore no losses. The potential cumulative economic cost for maritime transportation under the A2 scenario is US$ 34 million, and under the B2 scenario is US$ 39 million. The cumulative economic loss for the international transport sector in Montserrat arising from the climate change policies in advanced countries is US$ 300 million by 2050 under the A2 scenario and US$ 355 million under the B2 scenario over the forecast period.

Table 7.6: Impact of climate change policies in advanced countries on international travel mobility in Montserrat under A2 & B2 scenarios (2008 US$ million)

	Air transportation		**Maritime transportation**		**International transportation**	
Year	**A2**	**B2**	**A2**	**B2**	**A2**	**B2**
2020	3	3	2	2	5	5
2030	17	20	6	7	23	27
2040	88	98	18	20	106	118
2050	266	316	34	39	300	355

Sources: ECLAC (2011): ECLAC (2011a)

3. Impact of sea-level rise on infrastructure

The other layer added to the analysis and methodology is the impact of sea-level rise (SLR) on the international transport infrastructure. SLR and the resulting erosion impacts are considered to be among the most serious long-term threats of global climate change. SLR will have a threefold impact: land loss, international travel expenditure loss and rebuilding cost. Simpson and McSharry (2010), in analysing the impact of SLR on the tourism sector in Barbados, make the assumption that beach loss would have a similar impact as rising temperature, and use a median figure of a 17.5% reduction in tourist arrivals. In this vein, a similar assumption would be that the contribution of international transport expenditure to

GDP is likely to decline by 17.5% for the proportion of air- and sea port areas lost. The annual loss of international travel expenditure due to sea-level rise is therefore estimated to amount to US$ 3,050 million (SRES B2 scenario) and US$ 2,669 million (SRES A2 scenario) by 2050.

The total rebuilding cost for Barbados resulting from damage due to SLR is conservatively assumed as follows. The cost of the upgrade and expansion programme at the Grantley Adams International Airport – US$ 100 million – is projected over the period 2010 to 2050 using an annual inflation rate of 5%. A similar method is used to project the rebuilding costs of the Bridgetown Port terminal which is valued at US$ 50 million. In line with compatible assumptions across the RECCC project, we assume about 80% of this value for the A2 scenario and 40% for the B2 scenario as the losses that will be generated by 2050. The total loss facing the international transportation network in Barbados due to sea-level rise amounts to an estimated US$ 4,507 million by 2050 under the A2 scenario and to an estimated US$ 3,969 million by 2050 under the B2 scenario. Again, the loss due to sea-level rise is zero for the BAU scenario because this is use as the benchmark scenario against which losses are estimated (table 7.7).

Table 7.7: Impact of sea-level rise on international transport infrastructure in Barbados under A2 and B2 climate change scenarios by 2050 (2008 US$ million)

	Air transportation		Maritime transportation		International transportation	
	A2	B2	A2	B2	A2	B2
Total land area, km^2	144	144	286	286	430	430
Land loss, km^2	2.8	1.4	5.8	2.9	8.6	4.3
2050 value of land loss	280	140	580	290	860	430
2050 Value of international transport loss	2 321	2 652	348	398	2 669	3 050
2050 Value of rebuilding costs	652	326	326	163	978	489
Total loss due to sea- level rise	**3 253**	**3 118**	**1 252**	**851**	**4 507**	**3 969**

Sources: ECLAC (2011): ECLAC (2011a)

Montserrat:

Sea levels are expected to continue to rise for many decades or centuries in response to warmer atmosphere and oceans (Simpson and others, 2010). SLR and the resulting erosion impacts are considered to be among the most serious long-term threats of global climate change. SLR will have a threefold impact: land loss, international travel expenditure loss and rebuilding cost.

Estimates of potential SLR from regional climate simulations range from 0.1m (B2 scenario) to 0.3m (A2 scenario). Following Nicholls and Toll (2006), the potential land loss ranges from 1% (B2 scenario) to 2% (A2 scenario). The value of the land is assumed to be US$ 100 million/km^2 and apportioned fully to the sea port infrastructure, since the airport is located on a mountain top and is unlikely to be subjected to SLR. Table 20 gives the details of the calculations for land loss in Montserrat.

Annual international travel expenditure loss is estimated by assuming a loss of amenity factor where SLR causes beach and transport infrastructure loss and hence reduced attractiveness of the country to tourism and travel. Haites (2002) found that a rise of 2 degrees Celsius in temperature would make the Caribbean less attractive to visitors in the range of 15%-20 %. Simpson and McSharry (2010) in analysing the impact of SLR on the tourism sector in Montserrat, make the assumption that beach loss would have a similar impact as rising temperature, and use a median figure of a 17.5 % reduction in tourist arrivals. In this vein, the present study makes a similar assumption that the contribution of international transport expenditure to GDP is likely to decline by 17.5 % for the proportion of sea port areas lost. The annual loss of international travel expenditure due to sea-level rise is therefore estimated to amount to US$ 62 million (B2 scenario) and US$ 53 million (A2 scenario) by 2050.

The total rebuilding cost for Montserrat resulting from damage due to SLR is conservatively assumed as follows. The cost of the upgrade and expansion programme at Little Bay Port – US$ 9 million – is projected over the period 2010 to 2050 using an annual inflation rate of 5%. About 80% of this value is assumed as the losses that will be generated by 2050 for the A2 scenario and 40% for the B2 scenario respectively.

Table 7.8: Impact of sea-level rise on international transport infrastructure in Montserrat under A2 and B2 climate change scenarios by 2050 (2008 US$ million)

	Air transportation		Maritime transportation		International transportation	
	A2	**B2**	**A2**	**B2**	**A2**	**B2**
Total land area, km^2	34	34	68	68	68	68
Land loss, km^2	0	0	1.4	0.7	1.4	0.7
2050 value of land loss	0	0	140	70	140	70
2050 value of international transport loss	0	0	6	7	6	7
2050 value of rebuilding costs	0	0	61	30	61	30
Total loss due to sea-level rise	**0**	**0**	**207**	**107**	**207**	**107**

Sources: ECLAC (2011): ECLAC (2011a)

In summary, the total loss facing the international transportation network in Montserrat due to sea-level rise amounts to an estimated US$ 207 million by 2050 under the A2 scenario and US$ 107 million by 2050 under the B2 scenario. Again, the loss due to sea-level rise is zero for the BAU scenario because this is used as the benchmark scenario against which losses are estimated.

4. Impact of the eruption of Soufriere Hills Volcano on international transportation

Montserrat is a volcanic island, the evidence suggesting that there have been at least five major volcanic eruptions in the last 30,000 years. Prior to the recent activity, the Soufriere Hills volcano had been dormant for approximately 400 years, although there was evidence to suggest a 30-year life cycle of activity. In mid- 2001, the Montserrat Volcano Observatory (MVO) reported that dome growth on the volcano was ongoing and that volcanic activity was expected to continue for at least two more years and possibly for several decades (Norton, 2001).

Since the Soufriere Hills volcanic eruption has had a severe and long-lasting impact on Montserrat, the modelling process should incorporate some jump effect to accommodate the possibility of volcanic eruptions, its impact on the island's long term growth trend, and the reorganization of international transportation services. Future eruptions will alter the population distribution of Montserrat and the location of important international transportation assets, and will impose considerable costs due to the necessity of building new transportation infrastructure.

Estimating the economic costs associated with volcanic eruptions is very difficult, because there are numerous distinct but interconnected hazards, each of which is threatening to different aspects of human activity. For any one volcano, not all of these hazards may be significant, and individual eruptions also differ in the extent and importance of each type of hazard. The next eruption at any volcano may be quite unlike those of the past. Indeed, 12 of the 16 biggest eruptions of the past 200 years have occurred at volcanoes which have not erupted in recorded history (McGuire, 2003). Thus, in assessing the potential risks associated with an eruption of the Soufriere Hills volcano, a well-informed scientific opinion is needed and a precautionary approach should be adopted.

In this regard, the assessment adopted a conservative approach and assumed a catastrophic eruption of the Soufriere Hills volcano at the end of the forecast period in 2050, with the economic costs similar to that of the eruption in 1997. The projected 1997 cost was US$ 10 million using an annual inflation rate of 5 % over the forecast period and assuming about 80% of this value for the A2 scenario and 40% for the B2 scenario, as the losses that will be generated by 2050. Table 7.9 shows that the impact of an eruption of the Soufriere Hills volcano on international transportation in Montserrat amounts to US$ 72 million under the A2 scenario and US$ 36 million under the B2 scenario by 2050.

Table 7.9: Impact of eruption of Soufriere Hills Volcano on international transportation in Montserrat under A2 & B2 scenarios by 2050 (2008 US$ million)

	Air transportation		Maritime transportation		International transportation	
Year	**A2**	**B2**	**A2**	**B2**	**A2**	**B2**
2050	24	12	48	24	72	36

Source: ECLAC (2011)

5. Total impact

The total cost of climate change on international transportation was calculated by combining the impacts of changes in temperature and precipitation, new climate policies and sea-level rise.

(a) Barbados

Table 7.10 gives the breakdown of these costs and shows that the impact for air transportation could range from US$ 10,727 million (B2 scenario) to US$ 12,279 million (A2 scenario) and for maritime transportation impact estimates range from US$ 1,992 million (B2 scenario) to US$ 2,606 million (A2 scenario). For international transportation as a whole, the impact of climate change varies from US$ 12,719 million under the B2 scenario to US$ 14,885 million under the A2 scenario

Table 7.10: Total impact of climate change on international transport expenditure in Barbados under A2 and B2 scenarios to 2050 (2008 US$ million)

	Air transportation (2008 US$ million)		**Maritime transportation** (2008 US$ million)		**International transportation** (2008 US$ million)	
	A2	**B2**	**A2**	**B2**	**A2**	**B2**
Changes in temperature and precipitation	5 684	3 789	853	568	6 537	4 357
International transport mobility	3 342	3 820	501	573	3 843	4 393
Sea-level rise	3 253	3 118	1 252	851	4 505	3 969
Total impact	**12 279**	**10 727**	**2 606**	**1 992**	**14 885**	**12 719**

Sources: ECLAC (2011): ECLAC (2011a)

Table 7.11 presents the net present value of the total impact of climate change (in 2008 dollars) on the air and sea transportation industry in Barbados for 2050. The net present value of the total impact under the A2 scenario ranges from US$ 6,064 million (4% discount rate) to US$ 10,759 million (1% discount rate). The net present value under the B2 scenario varies from US$ 5,300 using a 4% discount rate to US$ 9,405 million under a 1% discount rate.

Table 7.11: Net present value of total impact of climate change on international transportation In Barbados to 2050 under scenarios A2 and B2 (2008 US$ million)

Discount Rate (%)	Air transportation (2008 US$ million)		Maritime transportation (2008 US$ million)		International transportation (2008 US$ million)	
	A2	B2	A2	B2	A2	B2
1	8 969	7 985	1 790	1 420	10 759	9 405
2	7 670	6 828	1 531	1 214	9 201	8 042
4	5 055	4 500	1 009	800	6 064	5 300

Sources: ECLAC (2011): ECLAC (2011a)

(a) Montserrat

The total cost of climate change on international transportation in Montserrat was calculated by combining the impacts of changes in temperature and precipitation, new climate change policies in advanced countries, sea-level rise and an eruption of the Soufriere Hills volcano.

Table 7.12 gives the breakdown of these costs and shows that the impact on air transport could range from US$ 630 million (B2 scenario) to US$ 742 million (A2 scenario). Climate change impact estimates on maritime transport range from US$ 209 million (B2 scenario) to US$ 347 million (A2 scenario). For international transport as a whole, the impact of climate change varies from US$ 839 million under the B2 scenario to US$ 1,089 million under the A2 scenario.

Table 7.12: Total impact of climate change on international transport expenditure in Montserrat under A2 and B2 scenarios to 2050 (2008 US$ million)

Losses due to	Air transportation		Maritime transportation		International transportation	
	A2	2	A2	2	2	B2
Changes in temperature and precipitation	452	02	58	9	10	341
International transport mobility	266	16	34	9	00	355
Sea-level rise	0	0	207	07	07	107
Eruption of Soufriere Hills Volcano	24	2	48	4	2	36
Total Impact	**742**	**30**	**347**	**09**	**089**	**839**

Sources: ECLAC (2011): ECLAC (2011a)

Table 7.13 presents the net present value of the total impact of climate change (in 2008 dollars) on the air and sea transportation industry in Montserrat for 2050. The net present value of the total impact under the A2 scenario amount ranges from US$ 570 million (4% discount rate) to US$ 1,013 million (1% discount rate). The net present value under the B2 scenario varies from US$ 428 million using a 4% discount rate to US$ 758 million under a 1% discount rate.

Table 7.13: Net present value of total impact of climate change on international transportation in Montserrat to 2050 under scenarios A2 and B2 (2008 US$ millions)

Discount rate (%)	Air transportation		Maritime transportation		International transportation	
	A2	B2	A2	B2	A2	B2
1	748	599	265	159	1 013	758
2	639	512	226	136	865	648
4	421	338	149	90	570	428

Sources: ECLAC (2011): ECLAC (2011a)

E. MITIGATION STRATEGIES

The technological and operational potential for mitigating international and domestic GHG emissions from aircraft and sea vessels is considerable. The most promising strategies are improvements in operational efficiency over the short to medium term. In the aviation sector, improvements to communications navigation and surveillance (CNS) and air traffic management (ATM) systems, rather than changes to the aircraft itself, have the potential to reduce GHG emissions below BAU projections by about 5% by 2025. In marine transportation, immediate reductions in GHG emissions are possible simply by reducing ship speed, optimizing routing, and improving port time. Slower marine vessel speeds have the potential to reduce GHG emissions from marine shipping below BAU projections by up to 27% to 2025.

Over the longer term, technological options such as more efficient propulsion systems (engines), advanced lightweight materials, and improved aerodynamics (winglets and increased wingspans) could further reduce aviation CO_2 emissions by up to 35% below BAU projections by 2050. Larger ships, new combined cycle or diesel-electric engines, and optimized hull and propeller designs could provide an additional 17% reduction in maritime transportation emissions below BAU projections by 2050.

Switching to lower-carbon fuels such as biofuels, natural gas or hydrogen is another potential route to reducing the carbon intensity of energy used in the aviation and marine transportation sectors. While numerous technical challenges exist, the main challenge to aircraft and marine vessels shifting to low-carbon fuels will depend on the ability of aviation and shipping to compete with other modes and sectors for the limited supply of alternative fuels. This could be an issue for the marine shipping industry which currently consumes residual fuel oil, the lowest-cost fuel available. The marine transportation sector could also switch to lower-carbon, conventional fossil fuels (e.g. liquefied natural gas and marine diesel oil) or to other renewable energy sources, such as wind or solar power. These alternative fuel and power sources, however, appear to be more uncertain, long-term options.

Beyond technical measures, reducing the demand for aviation and shipping could help mitigate GHG emissions to some extent, although the potential impacts are probably limited. The challenge is that there are few suitable alternatives for the services provided by aviation and marine shipping. High speed rail could replace some passenger air travel, but is not a substitute for long-distance or transoceanic flights. Currently, there are few alternatives to marine shipping, which is already the most efficient, lowest-cost form of transportation, aside from pipelines, which compete with shipping in just a few markets. Finally, while advanced telecommunications and teleconferencing technologies have also been discussed as a possible substitute for air travel, the extent to which they can substitute on a global scale is unknown.

Combining the various abatement options, the potential exists to reduce annual emissions from global aviation by more than 50% below BAU in 2050. Reductions of more than 60% are possible from the global marine sector. For these reductions to be realized, however, policy intervention is required. Mitigation strategies to deal with GHG emissions from international aviation and shipping are especially challenging, because these emissions are produced along routes where no single nation has regulatory authority. Unlike other sources of GHG emissions, the 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) specifically excludes international emissions from air and sea transportation from developed countries' national targets.

F. ADAPTATION STRATEGIES

Even a dramatic reduction in global GHG emissions in the coming years is unable to prevent the consequences of a warmer world, which will experience more intense rainfall, more frequent and intense drought, sea-level rise, shrinkage of the glaciers and snow-pack which supply water to many river basins, and increases in other extreme weather events. Insufficient progress on adaptation strategies could even reverse or threaten development, however, as with mitigation, there are sizeable costs associated with adaptation.

In addition to building adaptive capacity, adaptation strategies must be mainstreamed, adopted and implemented before it is too late. Tables 7.14 and 7.15 show select potential climate changes and their impact on air and sea transportation together with relevant adaptation options. A successful adaptation strategy would entail combining these various measures with the specific climate change impacts being experienced. The most immediate and rapid adaptation response to the impact of climate change is likely to result from changes in transportation operating and maintenance practices. However, the response to tropical storms or even hurricanes remains the major focus of transportation operations in the Caribbean.

Mainstreaming such responses will require expanding the scope of the ministry responsible for transport to in

clude emergency management as a separate functional responsibility. Operational responses are geared to addressing short/near-term impacts of climate change. To make decisions today about rehabilitating or retrofitting air and sea transportation terminals, which are generally designed for a 40-50 year service life, transportation planners and engineers must consider how climate changes will affect these facilities in the future.

Adapting to climate change will also require re-evaluation, development, and regular updating of design standards that guide infrastructure design. For example, adapting to increases in temperature will require the development of new, heat resistant runway paving materials. The design standards provide engineers with guidance on how to construct infrastructure for safe and reliable performance but they also embody a trade-off against cost. A critical issue is whether current design standards are adequate to accommodate future climate changes. Climate extremes such as increased storm surges and greater wave heights are likely to place the greatest demands on air and sea infrastructure because they are likely to push the limits of the performance range for which these facilities were designed.

Finally, adapting to climate change will require new partnerships and organizational arrangements that better align with climate impacts than the current framework, and around which decision making in the international transportation sector could be structured.

Table 7.14: Adaptation options for air transportation

Potential climate change	**Impacts on air transportation**		**Adaptation options**	
	Operations and interruptions	Infrastructure	Operations	Infrastructure design and materials
Temperature: Increases in very hot days and heat waves	Delays due to excessive heat Impact on Jon A. Osborne Airport with insufficient runway lengths	Heat related weathering and buckling of pavements and concrete facilities Challenge to service reliability	Increase in payload restrictions on aircraft Increase in flight cancellations Continuous inspection, repair and maintenance of aircraft Monitoring of infrastructure temperatures	Development of new heat resistant runway paving materials Extension of runway lengths, if feasible
Precipitation: Increase in intense precipitation events	Increases in delays due to convective weather Storm water run-off exceeds capacity of collection system, causing flooding, delays and closings Implications for emergency evacuation planning, facility maintenance and safety management	Impacts on structural integrity of facilities Destruction or disabling of navigation aid instruments Runway and other infrastructure damage due to flooding Inadequate or damaged drainage systems	More disruption and delays in air service More airport closures	Increases in drainage capacity at and improvement of drainage systems supporting runways and other paved surfaces
Storms More frequent strong hurricanes (Cat. 4-5)	More frequent interruptions in air service	Damage to facilities (terminals, navigation aids, fencing around perimeters, signs)		Hardening of terminals and other facilities

Source: Adapted from United States Department of Transportation (2010)

Table 7.15: Adaptation options for sea transportation

Potential climate change	**Impacts on sea transportation**		**Adaptation options**		
	Operations & interruptions	Infrastructure	Operations	Infrastructure design & materials	Other
Temperature: Increases in very hot days and heat waves	Impacts on shipping due to warmer water in oceans		Improvement in operating conditions due to longer ocean transportation season		
Precipitation: Increase in intense precipitation events	Increases in delays due to convective weather Implications for emergency evacuation planning, facility maintenance and safety management	Impacts on harbour infrastructure from wave damage and storm surge Changes in underwater surface and silt and debris build up affect channel depth		Strengthening of harbour infrastructure to protect it from storm surge and wave damage	More dredging on some shipping channels
Rising sea levels Erosion of coastal areas Storm surges	More severe storm surges, requiring evacuation	Changes in harbour and port facilities to accommodate higher tides and storm surges Impacts on navigability of channels		Raising of dock and wharf levels and retrofitting of other facilities t to provide adequate clearance Protection of terminal and warehouse entrances	More dredging of some channels Raising or construction of new jetties and seawalls to protect harbour
Storms More frequent strong hurricanes (Cat. 4-5)	More frequent interruptions in shipping service Implications for emergency evacuation planning, facility maintenance and safety management	Damage to harbour infrastructure from waves and storm surges Damages to cranes, other docks and terminal facilities	Emergency evacuation procedures that become more routine	Hardening of docks, wharves, and terminals to withstand storm surge and wave action	

Source: Adapted from United States Department of Transportation (2010)

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CHAPTER VIII.
THE ECONOMIC IMPACT OF CLIMATE CHANGE ON FRESHWATER RESOURCES

A. CLIMATE CHANGE IMPACT ON FRESHWATER RESOURCES

The Fourth Assessment Report of the IPCC (IPCC, 2007a), identified the water sector, along with the agricultural sector, as being among those most sensitive to climate change-induced impacts, with wide-ranging consequences for human societies and ecosystems. Climate change directly and indirectly affects the hydrological cycle, changing precipitation patterns and increasing the frequency and intensity of extreme weather events. Higher water temperatures and extremes (such as floods and droughts) are expected to lead to deterioration in the quantity and quality of water available to meet human and environmental demands and changing patterns of consumption (United Nations World Water Assessment, 2009). Additionally, climate change affects the functioning and operation of existing water infrastructure, such as those supporting hydropower, structural flood defences, drainage and irrigation systems as well as water management practices (IPCC, 2008). Changes in water quantity and quality due to changes in climate are also expected to lead to decreased food security and increased vulnerability of farmers.

Bates and others (2008) confirmed, inter alia, that: (1) higher water temperatures are likely to affect water quality and exacerbate water pollution; (2) increased precipitation variability is likely to increase the risks of flooding and drought; (3) several gaps exist in knowledge related to climate change and water; and (4) current water management practices may not be able to cope with the impact of climate change. Table 8.1 summarizes the main anticipated changes in the water sector due to climate change.

B. IMPLICATIONS FOR THE CARIBBEAN

Many Caribbean countries face severe challenges in respect of water quantity and quality, mainly because of their small size, geology, topography, climate and the patterns of their socio-economic development. The volumes of precipitation they receive are as diverse as the countries themselves and, though the subregion generally receives high levels of precipitation, several of the smaller islands (e.g. Aruba) are water scarce because of their limestone topography. The varying geology, topography and size of the countries also influence the availability of freshwater and patterns of water resource development (United Nations Environment Programme (UNEP), 2010).

In the Caribbean, water is obtained primarily from surface water sources (rivers, springs and ponds) and ground water sources. For many countries, however, groundwater supplies are already limited. Rainwater harvesting, previously not regarded as a practical option, is now a viable alternative only in some smaller, drier islands and in locations not linked to public water distribution systems. This is despite the fact that, in some of these countries, there is a legal requirement for dwellings to build facilities to store water, and despite recent efforts to promote rainwater harvesting technologies as a sustainable water collection practice. Desalination technologies are increasingly being applied to meet an ever-growing water demand.

Table 8.1: Climate change impacts on the water sector

Climate change variable	Response	Impact on water sector		
		Quantity and quality	**Infrastructure**	**Resources**
Increasing length of the dry season	Low flows	Low volume Pollutants	Broken mains ;low storage, inactive pumps, pipelines. barge, trucks	Loss vegetation on slopes, fires,
Increased frequency of high intensity rainfall events	Rapid runoff, rapid flood-peak Increased erosion, high sediment loads. Landslides and floods.	Increased quantity high turbidity	Washout mains, pumps, siltation of intakes	Slope failure Debris slides Loss of soil Siltation of channels - reduced capacity
The likely increase in climatic variability	Flood-drought cycles - impact on agriculture	Variability in flow - high & low flows; High turbidity with high flows. Contaminants with low flows	Flood impacts Low flows Irrigation Trucking, barge	Slope failure Debris slides Loss of soil
Sea-level rise	Coastal flooding Saline intrusion	Brackish water	Corroded equipment - loss of use	Habitat alteration
Temperature increases	Increased evaporation ocean temperatures, extreme events	Flood impacts	Wash out	Accelerated erosion. Siltation of channels - reduced capacity

Source: United Nations Water, 2009. Climate Change and Water - An Overview from the World Water Development Report 3: Water in a Changing World: A United Nations World Water Assessment Programme Special Report. Online at: http://unesdoc.unesco.org/images/0018/001863/186318e.pdf.

In the Caribbean, water is obtained primarily from surface water sources (rivers, springs and ponds) and ground water sources. For many countries, however, groundwater supplies are already limited. Rainwater harvesting, previously not regarded as a practical option, is now a viable alternative only in some smaller, drier islands and in locations not linked to public water distribution systems. This is despite the fact that, in some of these countries, there is a legal requirement for dwellings to build facilities to store water, and despite recent efforts to promote rainwater harvesting technologies as a sustainable water collection practice. Desalination technologies are increasingly being applied to meet an ever-growing water demand.

The Caribbean water sector consists primarily of drinking water and wastewater assets. The water supply systems (production, treatment and distribution) are generally publicly owned, with a few exceptions (for example, Turks and Caicos Islands, and Saint Lucia) where water is produced by private sector entities and distribution remains the responsibility of the State. In most cases, the water supply subsector is more developed, while the wastewater subsector remains underdeveloped and inadequate, with responsibility for collection, treatment and disposal services belonging to State agencies (for example, Trinidad and Tobago) or provided by the private sector.

The responsibility for the regulation and management of water resources remains defined in most countries, with only larger States, such as Cuba, Jamaica, Trinidad and Tobago and Barbados, having functioning water resources agencies. In Trinidad and Tobago, this agency forms part of the public utility entity, which weakens its regulatory function. Table 8.2 provides estimates of water production volumes for selected Caribbean countries.

Water security is determined not only by the availability of water resources, but also by the quality of water, the ability to store surplus from precipitation and runoff, and having access to supply.

For Caribbean countries, providing adequate supplies of freshwater poses a considerable challenge to Governments, and this is further compounded by limited water resources management for surface water and groundwater supplies. These constraints are likely to be further compounded by climate change. Small island countries like British Virgin Islands, Curacao, Aruba, Cayman Islands and, to some extent, Barbados, have limited freshwater resources. The groundwater resources in small islands, such as Barbados, Antigua and Barbuda, and the Bahamas, are either being exhausted and/or contaminated by pollutants or saltwater. For most of these countries, desalination has become the main source of potable water.

Larger islands, such as Jamaica, Cuba, Hispaniola and Trinidad and Tobago, experience saltwater intrusion in some coastal areas as underground supplies are overdrawn to meet an increasing and competing demand for water. Moreover, polluted surface water and groundwater are major causes of degradation of coastal and nearshore marine ecosystems, including critical salt ponds, mangroves, estuaries, sea grass and coral reef systems. Due to insufficient investment in the sector, in particular investment in maintenance of infrastructure, most water utilities in the subregion are unable to account for up to 50% to 60% of total volume of water produced. Additionally, increasing rates of deforestation are believed to be contributing to severe drought-and-flood cycles in most of the insular Caribbean during the annual dry and wet seasons. Deforestation is also responsible for land erosion and siltation and sedimentation of surface reservoirs (for example, in Saint Lucia).

Growing populations and increased economic activities have caused an increase in the demand for freshwater resources, sometimes to the detriment to environmental activities (IPCC, 2008). Residential users and the tourism industry are often major users of water, with many resorts consuming up to five times more water than other residential areas. Irrigated agriculture is said to be one of the fastest expanding uses of freshwater. Water withdrawals for irrigation range from 56% of total withdrawals in the Caribbean (UNEP Latin America and the Caribbean Portal, 2010). Agriculture is also one of major polluters, especially in limestone terrains (such as Jamaica and the Dominican Republic), where coastal groundwater systems are composed of highly transmissive karstic limestone. Widespread use of agrochemicals is another area of concern with respect to water quality, human health and loss of biodiversity. Water recycling (such as the commercial use of grey water for irrigation) is an uncommon and unexplored asset. Urbanization and migration of rural populations to urban centres have made coastal groundwater aquifers unsuitable for domestic use, due to the lack of centralized sewage systems (for example, Kingston and its Liguanea aquifer).

Although the Caribbean subregion reports widespread access to water and sanitation facilities, and good progress toward meeting Target 7C of the Millennium Development Goals, which targets halving, by 2015, of the proportion of people without sustainable access to safe drinking water and basic sanitation, there is an apparent disconnect between access and use, and little consideration of the seasonality and variability which also affects quantity and quality of water resources. According to a report by the Caribbean Environmental Health Institute (CEHI), the Caribbean subregion has the least water available per capita compared to other SIDS regions (CEHI, 2007). For example, data compiled from the World Resources Institute 1998-99 database showed that, between 1970 and 1998, freshwater resources for the Caribbean subregion on average were 2,574 cubic metres per capita per year, compared with 19,333 m^3 per capita in the Indian Ocean and 149,505 cubic metres per capita in the South Pacific.[79] For the low-lying, coral based islands, where precipitation is lower, and there are limited surface water and groundwater supplies (for example, British Virgin Islands, Netherlands Antilles, Cayman Islands and, to some extent, Barbados), the annual volume per capita freshwater availability falls below the 1,000

[79] Data quoted by Jasminko Karanjac based on data compiled from World Resources 1998-1999 database: Departement Hydrogeologie, Orléans, France; Institute of Geography, National Academy of Sciences, Russia, 1997.

cubic metre level, placing them in the category of water-scarce countries.[80] Barbados, for example, is among the ten most arid countries of the world (Government of Barbados, 2008).

Many Caribbean States are increasingly vulnerable to the dual challenges of increasing demand for water and climatic variability, where even a slight reduction in rainfall would have serious consequences (IPCC, 2007a).[81] Climate modelling for the Caribbean subregion under a range of scenarios suggests a continuation of warming in average temperatures, a lengthening of seasonal dry periods, and an increase in the frequency of occurrence of drought conditions. In addition, major emerging concerns for the subregion include: a limited capacity to adapt, flooding, saltwater intrusion of underground aquifers, and limited storage capacity, all of which contribute to increased water scarcity (Arnell, 2004).

Table 8.2: Water production estimates for selected Caribbean countries

	Water production (m^3/day)	**Main supply**
Antigua and Barbuda	18 640 – 20 460 (2004)	Desalination
Barbados	159 909 (2005)	Groundwater sources (79% of total freshwater resources)
British Virgin Islands	11 365	Desalination (65% of demand)
Dominica	45 460	Surface water
Grenada (mainland)	27 300-31 800	Surface water
Jamaica	940 MCM (2008)	Surface water (16%) Groundwater (84%)
Trinidad and Tobago		Surface water (16%) Groundwater (84%)

Source: InterAmerican Development Bank (2008). Water Forum of the Americas Report of the Caribbean Subregion. Prepared by Vasantha Chase.

C. APPROACH TO ESTIMATING THE ECONOMIC IMPACT OF CLIMATE CHANGE

Water is a complex resource that enters almost every economic and ecological good and process. It is typically not priced in the market, often being subsidized, and its estimated values are unstable, sometimes due to seasonal or spatial variations (Asian Development Bank (ADB), 2010). The true economic value of water is, therefore, not easy to assess (Rodgers 2010). This may compromises the reliability and validity of the projections for climate-change-associated costs and benefits, the future status of the resource and its price (as determined by the interaction of demand and supply functions), a position that is solidified by Turner and others (2004).

Researchers have however agreed around two key points:

- Climate risks exacerbate the existing stresses on water resources due to rapid economic development, demographic changes, and associated increases in water demand (Bakker and van Schaik, 2010; Cashman and others, 2010; Rodgers, 2010; UNECLAC 2010).

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[80] Water requirements criteria set by the World Bank state that the minimum water availability required to sustain human life is approximately 1,000 m^3 per capita per annum.

[81] The IPCC Fourth Assessment Report projects a bleak future for water resource availability in regions such as the Caribbean. The report suggests that decreases in mean annual precipitation (in some cases by as much as 20%) are likely in the regions of the subtropics.

- The sustainability of water, irrigation and farming systems is dependent on climate variability and this is threatened by climate change (Diaz and Morehouse, 2003; Yano and others, 2007; Chakanda and others, 2008; ECLAC, 2010).

In general, the reports attempted to construct demand and supply models for freshwater and to value, in economic terms, the impact of changes in selected climate variables.[82] Water supply is synonymous with availability in these reports, thereby assuming perfect access, while water demand is taken as the sum of water demanded by the residential, tourism and agricultural sectors.

1. Estimating water availability

In general, since the main source of water in the Caribbean is rainfall, the availability of water was estimated from predictions of monthly rainfall during the period 2011 to 2050, which were determined using the RCM PRECIS and are presented as a percentage difference between the baseline average (for the control period 1961-1990) and the forecast year.

The models suggest the changes in temperature and precipitation for the countries under study as indicated in table 8.3: For Turks and Caicos Islands, the results for the A2 scenario (in 2050) reflect an increase of the average daily temperature of about 1.76° C and a decrease of the annual precipitation of 14%; and, for the B2 scenario (in 2050) the temperature will increase by 1.61° C, while the annual precipitation will be reduced by 10%. For all countries, temperature appears to be increasing consistently until 2090, though at varying rates, depending on scenario and country (see figure 8.1).

Table 8.3: Mean annual temperature change (compared to base period) (Degrees Celsius)

Country	2030		2040		2050		2060		2070		2080		2090	
Scenario	A2	B2	A2	B2	A2	B2	A2	B2	A2	B2	A2	B2	A2	B2
Grenada	1.11	1.15	1.53	1.49	1.76	1.72	2.15	1.94	2.78	2.21	3.07	2.24	3.48	2.08
Saint Vincent and the Grenadines	1.03	1.07	1.40	1.37	1.61	1.58	1.97	1.83	2.54	2.05	2.77	2.05	3.18	2.04
Turks and Caicos Islands	0.96	1.15	1.37	1.61	1.52	1.61	1.98	1.79	2.36	2.07	2.78	2.10	3.12	2.21
Caribbean Subregion	**1.18**	**1.26**	**1.59**	**1.55**	**1.78**	**1.84**	**2.27**	**2.07**	**2.78**	**2.28**	**3.12**	**2.30**	**3.55**	**2.40**

Source: INSMET –mean of projections from PRECIS - ECHAM4 and HadCM3 models

Although there is a clear trend towards decreasing rainfall on average, there are no discernible trends across the decades for the forecast rainfall patterns. Saint Vincent and the Grenadines is an interesting example of the ad hoc nature of rainfall patterns under the two scenarios. In the A2 scenario and by 2040, the country shows a mean temperature increase of 1.40° C on average and a decline in rainfall of 13% compared to the base period. However, 2050 is expected to be a relatively wet year with annual rainfall of just about 5% below average, while 2060 is predicted to have rainfall levels of about 20% less than average. Conversely, in the B2 scenario, Saint Vincent and the Grenadines is set to experience an increase in rainfall over the three decades (see table 8.4).

Table 8.4: Caribbean annual mean precipitation change (compared to base period) (%)

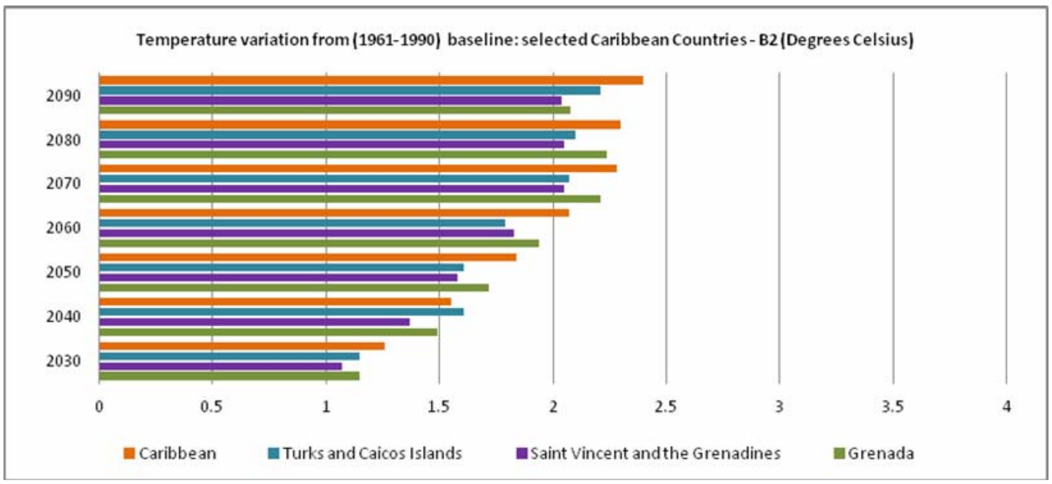
[82] The RECC reports deal only with freshwater. Sea-level rise is dealt with only insofar as it can lead to impacts on freshwater in the coastal zone for example, salinization of groundwater, coastal inundation and coastal ecosystem impacts. Such impacts are discussed in the text but are not estimated in economic terms.

Country	2030		2040		2050	
	A2	B2	A2	B2	A2	B2
Grenada	-5.14	-10.77	-11.26	-19.56	-3.77	-23.71
Saint Vincent and the Grenadines	-2.98	12.82	-13.21	14.06	-5.26	13.17
Turks and Caicos Islands	-8.06	-1.12	-5.33	-3.4	-14.3	-10.26
Caribbean Subregion	**-3.05**	**-3.69**	**-5.1**	**-9.82**	**-4.03**	**-11.51**

Source: INSMET – mean of projections from PRECIS - ECHAM4 and HadCM3 models

This situation of increasing temperatures coupled with declining rainfall is a complex one for the water sector in the Caribbean. In general, the available water is a function of both evaporation and precipitation (See Box 1 for explanation of water balance equation).

Figure 8.1: Mean annual temperature change (compared to base period) A2 and B2 compared (Degrees Celsius)



Source: INSMET, Cuba

Box 1

Water Balance

In the case of Turks and Caicos, a climate/ water balance was developed using the universal equation of balance and was calculated for the period 1961 to 1990. This method does not result in the exact quantity of available fresh water, but gives a god estimate of the "potential" available water from precipitation:

Turks and Caicos Water balance for 1961-1990
(base period average)

T	Ro	B	P	Eo	E	Q
28,0	102,2	1,27	1361	1732	1105	255

Where, T: temperature (℃); Ro: annual radiation balance (Kcal/cm2 – year); B: Index of aridity; P: precipitation (mm); Eo: potential evaporation (mm); E: evaporation (mm), Q: runoff (mm); and

2. Estimating water demand

In this assessment, water demand is taken as the sum of water demanded by the residential, tourism and agricultural sectors.[83] Each sub-component is calculated as described in the following section and the cumulative sum is taken as total water demand.

(a) Residential water demand

Consumption by the domestic sector is the single largest category of water use. Population increase and the concomitant development of housing with changes in lifestyle and housing patterns have increased domestic demand for freshwater. Residential demand was modelled using per capita water consumption estimates. Future residential demand under the A2 and B2 scenarios are forecast based on this per capita water consumption estimate and the population projections relevant to each scenario.[84] For Turks and Caicos Islands, a sensitivity analysis using three (low, medium and high) different per capita consumption estimates was conducted based on published consumption estimates in the literature (see table 8.5 and table 8.6). For Grenada and Saint Vincent and the Grenadines, the published consumption estimate for Jamaica (approximately 226 litres per day) was used.

Table 8.5: Daily water consumption selected Caribbean countries (Published)

Selected countries	Year	Metre^3/person/year	Litres/person/day
Antigua and Barbuda	1990	75	205
Barbados	1996	312	855
Belize	1993	396	1 085
Dominica	1996	239	655
Jamaica	1993	348	953
Grenada	estimate	348	953
Saint Lucia	1997	89	244
Saint Vincent and the Grenadines	1995	88	241
Trinidad and Tobago	1997	221	605
Turks and Caicos Islands	estimate	82	225
United Nations World Health Organization[85]	2007	n.a.	50-100

Source: Falkland, A.C. and Brunel, J.P., 2009. *Review of Hydrology and Water Resources of Humid Tropical Islands*. Cambridge University Press.

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[83] In the case of Turks and Caicos Islands, projections of water demand only into take into account household and tourism consumption, since agricultural sector consumption is almost negligible.

[84] The calculations were based on the assumption that the ratio of the Grenada population to the global population under both A2 and B2 scenarios would remain the same throughout the period under study (2011 to 2050) and that the per capita residential water consumption rate remains constant. Global populations for A2 and B2 correspond to the IPCC estimates (see the IPCC webpage). For Turks and Caicos Islands, the projections on population growth were taken from the United Nations Statistical Division.

[85] According to the United Nations Human Rights Fact Sheet No 35 on the Right to Water, WHO indicates that between 50 and 100 litres of water per person per day are needed to ensure that most basic needs are met and few health concerns arise.

Table 8.6: Daily water consumption estimates for residents in Turks and Caicos (Litres daily)

Year	High variant	Medium variant	Low variant
2015-2050	300	225	150

Source: ECLAC (2011)

(b) Tourism water demand

The importance of tourism to Caribbean economies is well known and, as the tourism sector develops and expands, so too does the demand for high quality potable water. For example, the Report of the Water Forum for the Americas for the Caribbean subregion noted that, in the Bahamas, the average daily consumption of water by tourists is estimated at 400 to 1,000 litres per capita, compared to 150 to 200 litres per capita for residential consumption. Furthermore, in Saint Vincent and the Grenadines, the per capita demand for fresh water by the tourism sector was about four times the per capita demand of residential households (Inter-American Development Bank, 2008). This increase in demand is paralleled by an increase in liquid waste which, if not adequately managed, will often pollute waterways and coastal water bodies. In addition to increased demand for piped water supply, the growth of the tourism industry has wider implications for pollution control and the maintenance of water quality and quantity.

In the assessments of Saint Vincent and the Grenadines, Grenada and Turks and Caicos Islands, tourism demand was modelled using a two-step process. Firstly, the impact of climate change on tourist arrivals was estimated based on a tourism climate index, which estimates the impact of climate change on arrivals, under the two emissions scenarios.[86] Secondly, a per tourist water consumption estimate is applied to the coefficient representing the response of arrivals to climate change, to obtain water demand for the sector.

In the case of Saint Vincent and the Grenadines and Grenada, a per tourist measure of water consumption and the estimated variation in tourist arrivals due to climate change under the A2 and B2 scenarios was obtained from Moore (2011). Moore (2011) estimated a decrease in tourist arrivals based on a climate impact for Saint Lucia of 11.9% and 9.2% under the A2 and B2 scenarios, respectively, by 2050, with losses increasing by decade (see table 8.7). In the case of Turks and Caicos Islands, the tourism climate index was calculated for the country based on available data (Box 2).

Table 8.7: Percentage change in tourist arrivals under A2 and B2

Period	Saint Lucia estimate	
	% change A2	% change B2
2011-2020	-10.3	-7.7
2021-2030	-11.3	-8.5
2031-2040	-11.9	-9.2
2041-2050	-12.6	-9.9
Total (Average 2011-2050)	-11.9	-9.2

Source: ECLAC (2011) LC/CAR/L306.

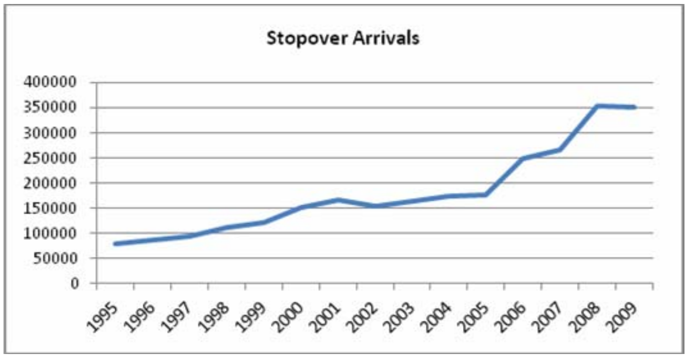
A water consumption estimate of 716 litres per day per tourist was used for Turks and Caicos Islands, while an estimate of 446 litres per day was used for the other two countries (based on an

[86] This methodology is also applied in the studies of climate change impact on tourism in the RECC project – See Chapter 6.

estimated average stay of 5 days per tourist and an annual total consumption of 2230 litres per annum per tourist). These values were used to forecast the tourism demand for water to 2050.

Tourist arrivals to Turks and Caicos Islands have grown at a mean annual rate of 11.3% over the last 15 years (see figure 8.2).

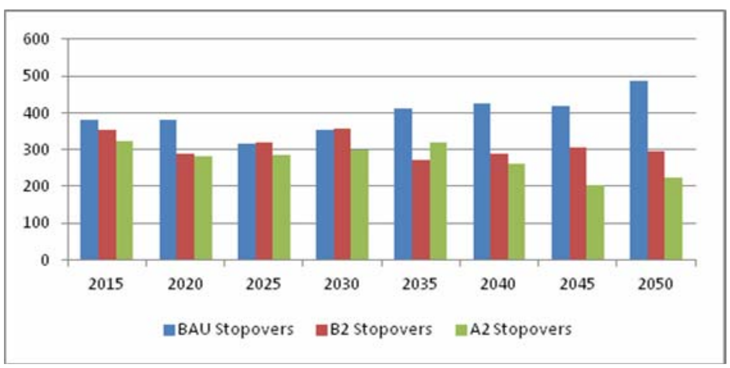
Figure 8.2 Stopover arrivals Turks and Caicos Islands (1995-2009)



Source: ECLAC, (2011)

Using a tourism climate index, which models the impact of changing climate variables on the tourism attractiveness of the country, it was determined that arrivals could fall by 29% under A2 and 20% under the B2 scenario. The main climate variables included in the model were maximum temperature, precipitation; relative humidity and wind speed (see also Chapter 6 on The Impacts of Climate Change on Tourism for a more complete description of this model).

Figure 8.3 Estimated changes in arrivals A2 and B2 compared to BAU



Source: ECLAC (2011)

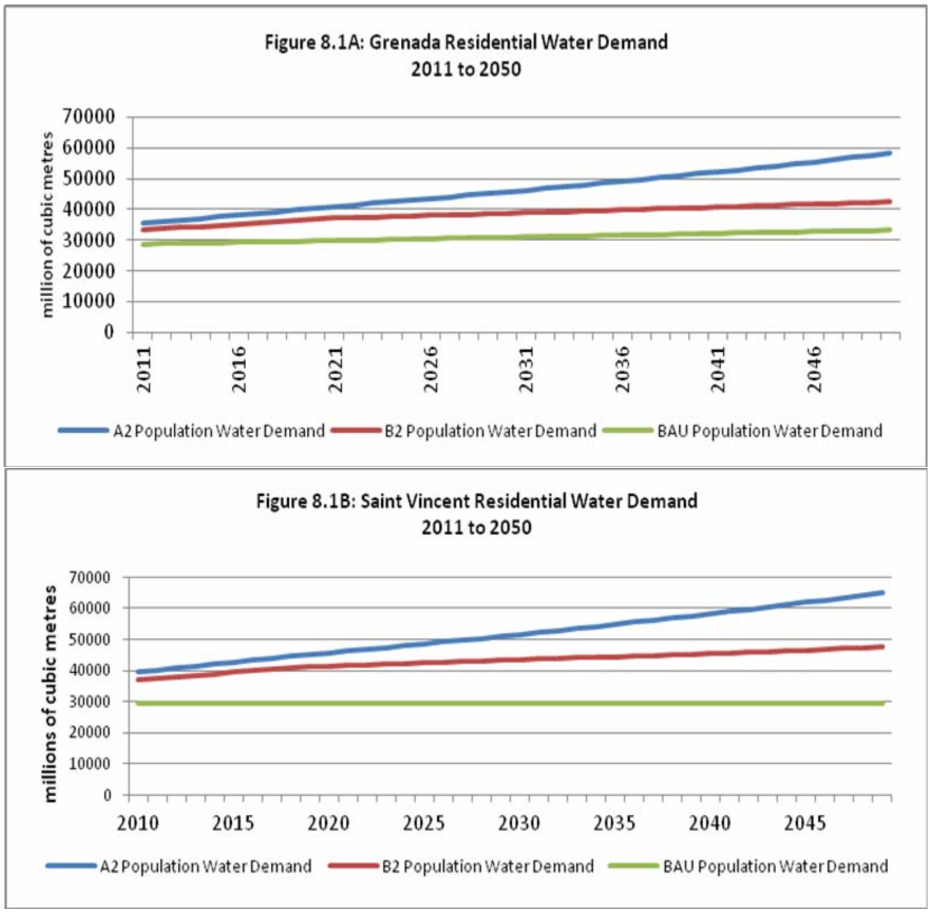
(c) Agricultural water demand

Agricultural water demand was estimated using proxy data found in IPCC publications in relation to anticipated global water demand for irrigation under the A2 (an additional 2% of water) and B2 (an additional 7%) scenarios, respectively. This is done on the assumption that Grenada will require at least as much irrigation water as is required for agriculture globally, which implies that the country has the same level of efficiency in the use of irrigation water as is generally observed globally. Firstly, the share of total water consumed by the agricultural sector in Grenada was estimated using a per acre estimate. This was then multiplied by total Grenada water demand during the period 1990 and 2009. Following the IPCC report, estimates based on Döll and Siebert (2002) and Döll and others (2003) found that net irrigation requirements could increase by up to 2% to 7 % under the A2 and B2 scenarios, respectively, by the 2070s (IPCC, 2007b).

D. RESULTS

The results indicate a reduction in water availability and thus suggest that there may be competition for the resource among sectors. Residential water demand increases under both the A2 and B2 scenarios, as a result of higher temperatures as well as increasing populations (under A2 population growth rate is assumed to be higher than under B2) (see figure 8.4).

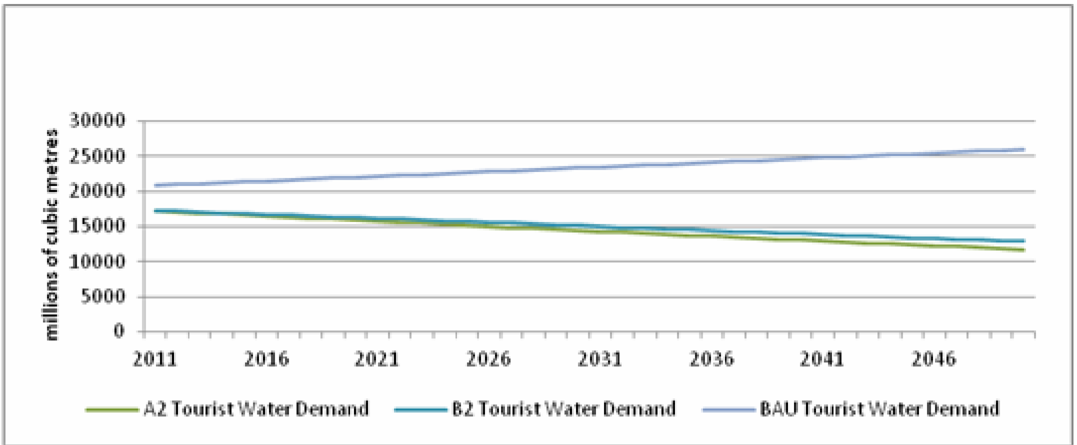
Figure 8.4: Residential water demand 2011 to 2050

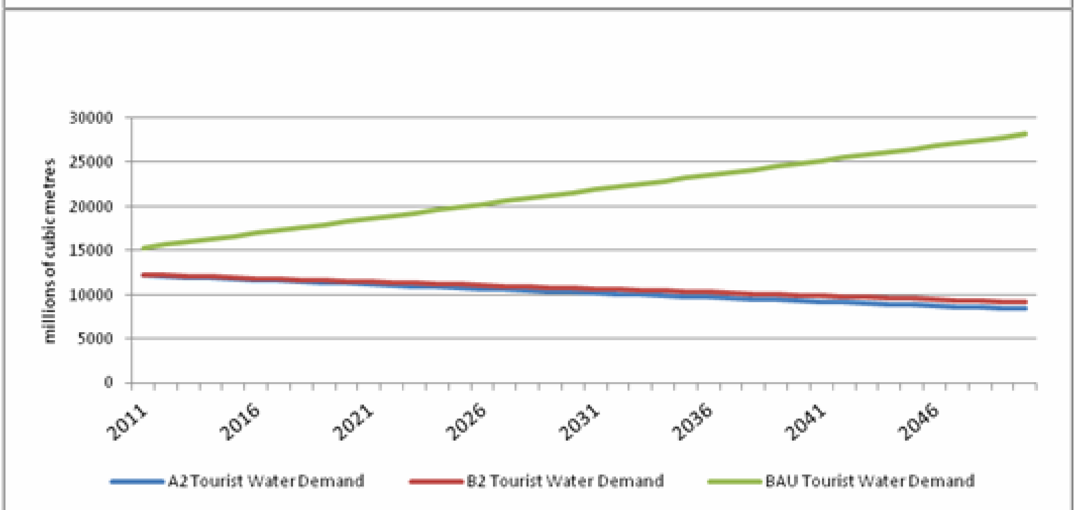


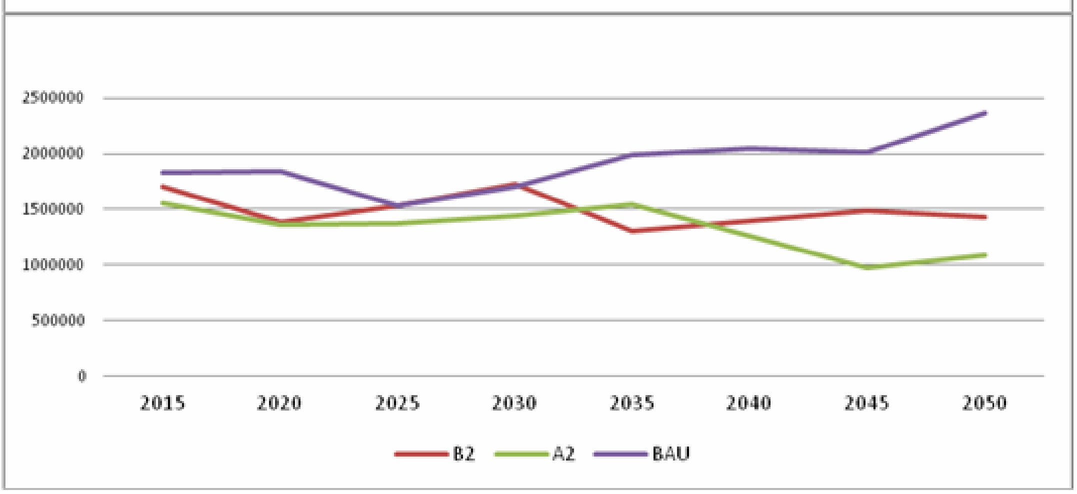
Sources: ECLAC (2011a): ECLAC (2011b)

Figure 8.5 shows the expected decline in the volume of water that is likely to be demanded by the tourism sector under the A2 and B2 scenarios. It reflects that, contrary to the BAU case which envisions a continuing increase in the number of tourist arrivals, under the A2 and B2 scenarios which predict increased climate volatility and intensity, the number of tourist arrivals is expected to decline. As a result, a proportional decline in the volume of water required by the sector is expected. This is consistent with the findings of the RECCC studies conducted for the tourism sector.

Figure 8.5: Tourism water demand 2011 to 2050







Sources: ECLAC (2011): ECLAC (2011a): ECLAC (2011b)

Agricultural sector water demand was estimated for Grenada and for Saint Vincent and the Grenadines only, given the importance of the sector to their economies. As anticipated, the results show a higher water demand under A2 and B2 than in the BAU case, due in large part to higher temperatures in the two scenarios.[87]

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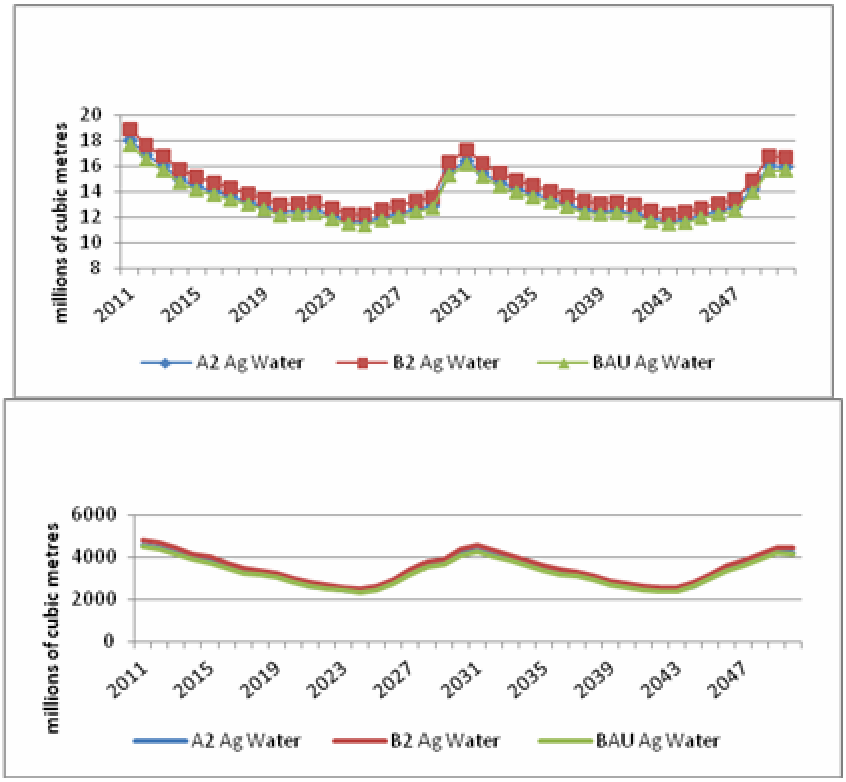
[87] Technology is assumed to be constant or at least to be changing proportionally across all scenarios.

Figure 8.6: Agricultural sector water demand



Sources: ECLAC (2011a): ECLAC (2011b)

1. Total water demand and availability

Seasonality and varying patterns of rainfall, factors that are of critical concern for water resources planning in the Caribbean, are masked in these models. It would appear that variability in the incidence of rainfall, as well as apparent declining totals, have influenced streamflow and water availability.

2. Water quality

Climate change is expected to affect water availability both in terms of quantity and quality. Changes in rainfall patterns and sea-level rise could mean increased water availability problems for countries where water demand continue to rise, unless adaptation measures that would curb demand and increase supplies are implemented. Low rainfall, in particular, can lead to reduced river flow and the amount of water harvested, thus resulting in a water deficit.

Sea-level rise is of particular concern for small island developing States that depend heavily on freshwater supplies and where aquifers and water infrastructure are located on the coastline. Substantial impacts are expected on the quality of available water resources, particularly during the forecast period. It will be increasingly important for planners to consider this aspect since salt-water intrusion due to sea-level rise and contamination associated with general economic development and debris from natural disasters (Arnell, 2004 and Terry, 2007) may require expensive and expansive water purification and treatment plants.

E. ADAPTATION STRATEGIES

Adaptation to climate change in the water sector requires the implementation of measures in a timely manner using an integrated approach which can significantly reduce risk to the sector. These measures may be categorized into four main groups:

Infrastructural: This encompasses erecting coastal and flood protection to guard against sea-level rise and flooding, and adopting technologies that improve water use efficiency, for example, switching to drip irrigation.
Behavioural: Altering habits and choices, such as changing irrigation practices to maximize efficiency; or using potable water only where treated water is required.
Managerial: Altering farm practices, including cultivation of drought-tolerant cultivars, implementation of demand management strategies through metering and pricing.
Government Policy: Modifying planning regulations, building codes, use of appropriate, renewable energy sources such as solar, wind, biofuels, landfill gas (methane).

The Global Water Partnership, in its policy brief, indicated that the best way for countries to build capacity to adapt to climate change would be to improve their ability to cope with today's climate variability (GWP, 2005). Further, it has been suggested that the portfolio of water sector actions for SIDS should include Integrated Water Resources Management (IWRM), demand management, water quality management, capacity-building, water governance and hydrological cycle observing systems (Overmars and Gottlieb, 2009).

According to the the Global Water Partnership (GWP, 2005) suggested measures to respond to projected changes in water resources in SIDS include:

- Incentives to encourage the use of water saving devices
- Selecting appropriate drought-tolerant vegetation
- Establishing river buffer zones to enhance the resilience of river and catchment areas
- Updating national water policies
- Improving water resource management
- Preparing water resource master plans for islands
- Revising building codes to increase opportunities for rainwater catchment and storage
- Assessing and improving the water supply system.

In an attempt to achieve water security in the Caribbean subregion, steps must be taken to manage water supplies by increasing and/or maintaining the water supply and improving the efficiency of water use. Key among these measures is the countries' ability to improve the storage of water from runoff when supplies are abundant, in order to maintain access to safe supplies of water at affordable prices. A number of water management initiatives are currently being employed by countries in the subregion and it is expected that these would assist the water sector to adapt to the impacts of climate change. These include:

- Increasing supplies of drinking water through (1) the implementation of improvement, rehabilitation and maintenance infrastructure projects; (2) utilization of desalination, particularly in countries where available freshwater is limited; (3) promotion of rainwater harvesting to augment supplies for domestic and agricultural use, and mainstreaming strategies that facilitate its adoption within wider water sector policies.
- Application of water pricing, metering and water user groups as policy options to manage water use and demand and for water conservation.
- Strengthening water resource management through the conduct of water resource management studies (which include assessment of water resources, economic assessment of the water

sector, water demand forecasting), institutional reform, capacity building, and the establishment water monitoring networks (to monitor water quality, precipitation, streamflow, flooding and drought).

- Development of water policies – with a focus on IWRM.
- Development of National Water Information Systems that would improve availability and accessibility of information on the sector.
- Development of sustainable land management projects geared at improving land use planning and development control, forest and watershed management and mainstreaming sustainable land management principles into development planning.

However, the cost of adaptation could be high relative to the size of the economies of Caribbean SIDS. For example, Bueno and others (2008) determined that the cost of inaction to climate change in Saint Vincent and the Grenadines would amount to 11.8% of GDP in 2025 (US $ 68.8 million in 2010 dollar terms) and the price of inaction could increase to 47.2% of 2010 GDP by 2100. More research is needed to better estimate the potential economic cost of adaptation strategies relative to the cost of inaction, given the integrated approaches that are required and the degree to which water is so intimately linked to so many other sectors of importance.

F. CONCLUSION

The waters sector is among those most vulnerable to climate change. The country assessments have shown that there will be a reduction in water availability in the long term, suggesting that competition for water among sectors is expected to increase. In the long term, residential water demand is expected to increase as a result of increased temperature and population under the A2 and B2 scenarios. Although tourism water demand is high in countries where the sector drives economic development, this will decline as tourism arrivals fall because of negative forecast impacts of climate change on the sector.

The Caribbean subregion is heavily dependent on surface water as a primary source of potable water supply, making rainwater reliance a major issue in the sector's vulnerability to climate change. Changing rainfall patterns may realise in reduced river flows coupled with increased flooding. Therefore, water resource management interventions should be applied to ensure human and ecological water needs are met. Critical among these are measures that would ensure continuous, safe water supply to the populations, at reasonable rates.

1. Policy recommendations

The following are suggested policy recommendations:

- **Mainstreaming adaptation in subregional water sector**

The provisioning of water remains a public enterprise and is developmental by nature. In most countries the population has good access to a safe water supply, and adaptation becomes critical to ensure that climate change does not undermine the progress made in water provisioning. Adaptation should be addressed at two levels – at the strategic, decision-making level, and at the operational level.

- **Balancing demand and supply**

Increasing demand and the need for improved water supplies have made many Governments focus attention on desalination technologies and on greater exploration and extraction of groundwater. The traditional practice of rainwater harvesting and storage is being promoted in recent times, but its use remains limited. This should be expanded and given greater prominence as a sustainable water source and in drainage management. There is also need to manage water demand and encourage water conservation through the application of economic incentives (metering and pricing), implementation of programmes to improve water use efficiency in agriculture and industry, establishment of national and community water recycling programmes, and the promotion of improved efficiency and wise water use by encouraging reduction, reuse and recycling of water.

- **Continued water-related climate change research**

Apart from the specific adaptation measures geared towards the water sector, many of the adaptation measures for other development sectors are water related, making water insecurity a major issue. Further research will be required to fully understand these links and the implications to the water sector. In addition, research needs to be conducted on the costs of adaptation. Furthermore, it would be important to develop appropriate indicators to monitor the performance of, and progress within, the sector in light of climate change. The information will provide a strong foundation for action and accountability.

- **Improving data collection, monitoring and analysis**

Management of water resources and assessment of the impact of climate change are dependent on the availability of data in a form that can be utilized for monitoring trends and identifying anomalies. Hydrological data collection are very limited and assessment of data for computation of water balance, therefore should be improved, given the need for sound knowledge to form the basis for decision making and for sustainable management of water resources.

- **Improved water resource management**

Responsibility for water resource management in most countries of the subregion is often ill defined, split across ministries or assigned to national public utility companies. Given the predicted adverse effect of climate change on water resources, it is important that sustainable water resource management become a priority for policymakers and for the populace of the subregion. Within recent times, some countries have adopted an IWRM approach, and this could be a useful in mainstreaming climate change considerations into water sector development and planning. However, there is need for wider acceptance of this approach reflected by the much-needed legislative, policy and institutional reforms and capacity building that would provide the prominence required to improve water resource management.

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CHAPTER IX.
THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE ENERGY SECTOR

INTRODUCTION

According to the Intergovernmental Panel on Climate Change (IPCC, 2007), if current trends in energy use continue, average global temperature could rise by as much as 6° C, posing serious threats to global energy, social, economic, and health security. Global atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial levels. Emissions of heat-trapping gases rose 70% between 1970 and 2004, with anthropogenic sources of CO_2 accounting for three-quarters of total emissions in 2004 (IPCC, 2007).[88] Global increases in CO_2 concentration are due primarily to the burning of fossil fuels and land use change, while increases in the levels of CH_4 and N_2O are mainly attributed to the agricultural sector (IPCC, 2007). These emissions will continue to grow over the next few decades if current policies and development practices are maintained.

Contreras-Lisperguer and de Cuba (2008), in their assessment of the potential impact of climate change on the energy sector, noted that the effects of climate change can be detrimental to both consumption and production of traditional and renewable energy systems such as hydropower, biofuels, wind farm, solar energy and geothermal energy production systems. Specifically, they highlighted the vulnerabilities of the sector to variations in temperature and precipitation on timing of peak electricity demand; weather-related energy supply disruption resulting from increased intensity and frequency of severe weather events; and increased incidence of power outages due to higher electricity demand for cooling induced by higher temperatures.

A. IMPLICATIONS FOR THE CARIBBEAN[89]

A case study was conducted to explore the implications of climate change on the energy sector in Trinidad and Tobago, which is one of the Caribbean's main producers of fossil fuel-based energy.[90]The energy sector plays an important role in Trinidad and Tobago's economy. In 2008, the energy sector's share in gross domestic product (GDP) amounted to approximately 48% while contributing 57% of the total Government revenue (Central Bank of Trinidad and Tobago, 2009).

As a major oil producer in the Caribbean subregion, Trinidad and Tobago plays an important role in supplying oil products to other Caribbean countries, mainly for use in transportation and power generation. Trinidad and Tobago accounts for more than 50% of the primary energy consumed in countries such as Barbados, Guyana, Jamaica and the Dominican Republic (South Trinidad Chamber of Industry and Commerce, 2009).

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[88] Fossil carbon dioxide emissions include those from the production, distribution and consumption of fossil fuels, and as a by-product from cement production. Annual fossil carbon dioxide emissions increased from an average of 6.4 GtC (23.5 $GtCO_2$) per year in the 1990s to 7.2 GtC (26.4 $GtCO_2$) per year in 2000–2005. An emission of 1 GtC corresponds to 3.67 $GtCO_2$.

[89] Anguilla, Antigua, Aruba, the Bahamas, Barbados, Belize, Cayman Islands, Cuba, Dominica, Dominican Republic, Grenada, Guadeloupe, Guyana, Haiti, Jamaica, Saint Kitts and Nevis, Saint Lucia, Martinique, Saint Vincent and the Grenadines, Suriname, and Trinidad and Tobago.

[90] As an energy-producing country, issues of priority concern to policymakers will be expected to differ from those of policymakers in energy-importing countries.

The sector plays a critical role in providing energy for commercial, industrial, transport, residential and public energy use purposes. However, the energy sector is a major source of anthropogenic GHG emissions in Trinidad and Tobago. With its hydrocarbon-based economy and small population, Trinidad and Tobago is ranked seventh in the world in terms of carbon dioxide (CO_2) emissions per capita with an estimated 40 million tons of CO_2 produced annually. In accordance with the requirements of Article 12.1 (a) of the United Nations Framework Convention on Climate Change (UNFCCC), Trinidad and Tobago conducted a National Inventory for Greenhouse Gases in 2008,[91] which estimated emissions sources and sinks of CO_2, CH_4, N_2O, oxides of nitrogen (NO_X), non-methane volatile organic compounds (NMVOC) and sulphur dioxide (SO_2). This inventory showed that CO_2 accounted for 95.4% of the global warming potential (GWP) of the country's emissions, and that almost 90% of these emissions are attributed directly to the energy sector through petrochemical production (56%), power generation (30%) and gas flaring (3%) (MEEA, 2011). Chemical industries produce ammonia, iron and steel and mineral products (such as cement) which accounted for 55%, 41%, and 4% of energy sector GHG emissions, respectively.[92]

The energy intensity (total primary energy consumption per dollar of GDP) of Trinidad and Tobago has been on an upward trend since the early 1980s, implying that increasing amounts of energy would be needed to generate a dollar of GDP in later years relative to earlier years (see figure 9.1). In absolute terms, energy consumption has been increasing steeply in the industrial and agricultural sectors since 1981, whereas total consumption in the residential, commercial, public and transportation sectors have been more or less stable over time (see figure 9.2). However, in the case of natural gas, which is a major source of domestic energy for electricity, the data show that final consumption has been increasing since 1981 (see figure 9.3).

While the United States of America remains the world's highest energy intensive country, it is currently pursuing a domestic energy policy that is expected to shift consumption away from fossil fuels and towards renewable energy sources. For instance, the Obama administration recently signified its commitment to reducing dependence on foreign oil by one third by 2025. If the United States of America and other emerging economies such as China and India adopt a climate change policy that emphasizes GHG emission mitigation and invest considerably in renewable energy, then a shift away from fossil fuel consumption is imminent. This will have significant implications for oil producing countries like Trinidad and Tobago whose economies rely heavily on export of fossil fuels for foreign exchange generation.

B. APPROACH TO ESTIMATING THE IMPACT OF CLIMATE CHANGE IN TRINIDAD AND TOBAGO

Focusing on the IPCC A2 and B2 climate scenarios, the report addressed two main lines of impact:

1. The impact on energy demand measured by the impact of climate change on domestic demand for electricity.

2. The impact of energy supply measured as the impact on the export of liquefied natural gas (LNG) and crude oil to the United States of America.

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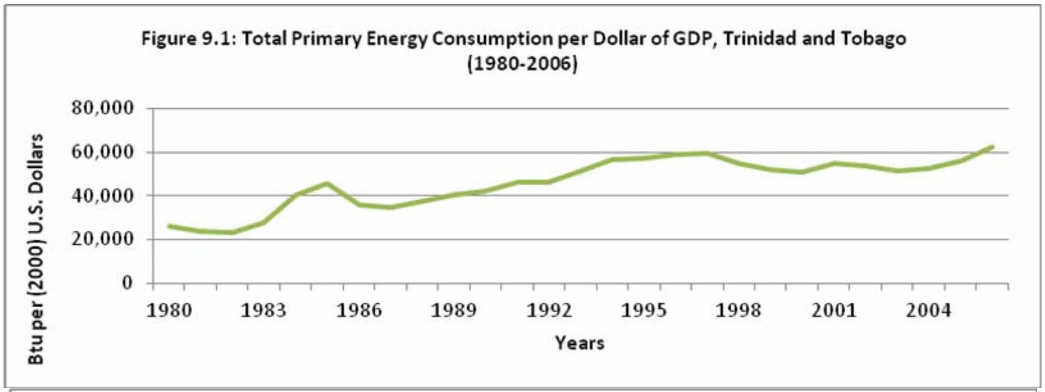
91 Boodlal, Donnie, Furlonge, Haydn I. and Williams, Rachael. (2008) *Trinidad and Tobago's CO_2 Inventory and Techno-economic Evaluation of Carbon Capture Options for Emission Mitigation.* Lowlands, Tobago: s.n.

92 It should be noted, however, that much of the CO_2 emitted during ammonia production is recovered, and later used as feedstock in the manufacture of methanol (The Republic of Trinidad and Tobago, 2001).

Figure 9.1: Total Primary Energy Consumption per Dollar of GDP, Trinidad and Tobago (1980-2006)



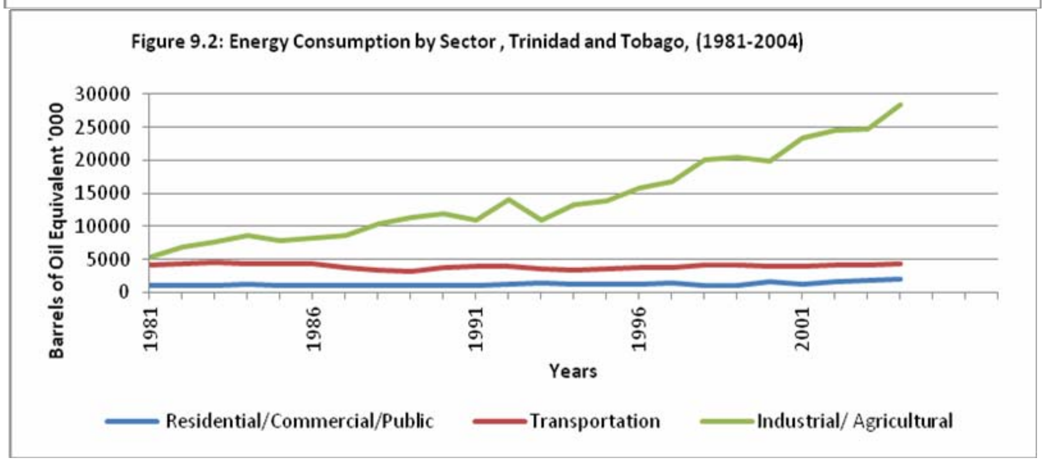
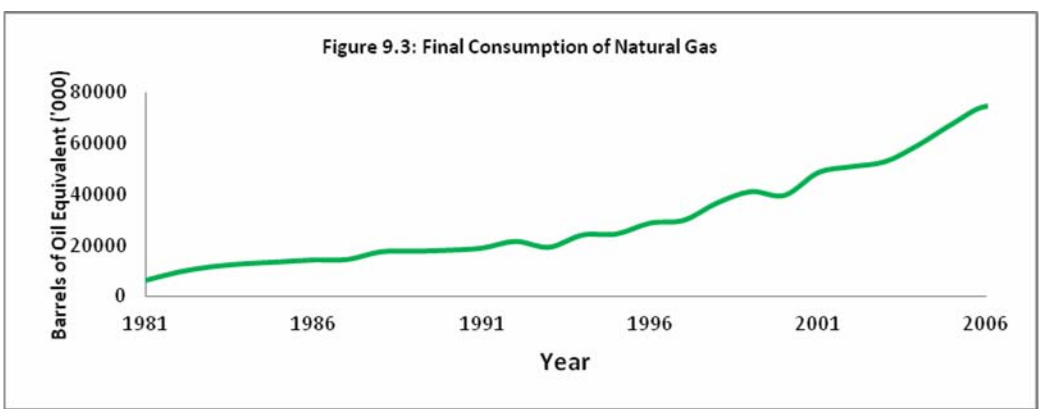


Figure 9.2 Energy Consumption by Sector, Trinidad and Tobago (1981-2004)

Figure 9.3: Final consumption of natural gas, Trinidad and Tobago (1981-2006)



Source: Ministry of Energy and Energy Affairs (2011). Energy Balance.

The impact of climate change on electricity demand was determined by examining variations in temperature under the A2 and B2 scenarios and the way these differ from electricity consumption under the baseline scenario of no climate change. Data limitations restricted the estimation of energy demand to demand for electricity only. Additionally, demand for electricity could not be estimated at the sectoral level, hence, only an aggregate demand function for electricity was estimated.

On the supply side, the key consideration was the impact on the world energy market of climate change adaptation and mitigation strategies pursued by major energy-consuming nations. Given the importance of the energy sector to the Trinidad and Tobago economy, and with the United States of America serving as a major export market for its liquefied natural gas (LNG) exports, domestic energy policy in the United States of America, as well as global trends on the world oil market, are expected to impact on the country’s energy sector export earnings. The impact of climate change on energy production and export of Trinidad and Tobago is therefore analysed in light of the energy policies, inclusive of renewable sources, of major energy-consuming nations.

Other important supply-side factors include short-run supply limitation due to refinery capacity restrictions, long-run supply limitations constrained by energy reserves, and disruption in supply due to sea-level rise and extreme weather events. Lack of engineering data on the extent to which rise in sea level and extreme weather events could impact oil production and/or transportation at the Petroleum Company of Trinidad and Tobago (PETROTRIN) and other oil company facilities imply that no reliable estimate could be made for direct impact of climate change on energy production. Thus, only the impact on domestic LNG production for export could be assessed.

Trinidad and Tobago is a ratified signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol.[93] However, as a non-Annex 1 country, the country is not mandated to reduce its GHG emissions. As such, the focus in the present study was on providing alternative adaptation options for the energy sectors based on the Synthesis Report of the IPCC Fourth Assessment Report (AR4; IPCC, 2007) and the draft Climate Change and Energy Policies of the Republic of Trinidad and Tobago. These measures are intended to provide policymakers with objective means of assessing alternative adaptation options by focusing on the economic benefits or the return on investment from implementing a particular option. The potential for mitigating GHG emissions is also estimated and valued.

C. RESULTS

1. Impact on demand

The baseline case assumes that growth in electricity consumption per capita observed in the past 27 years for Trinidad and Tobago will persist for the next 40 years. This conforms to the methodological approach of ECLAC (2009a) for projecting economic scenarios. Figure 9.4 shows actual and projected per capita consumption of electricity for the baseline scenario resulting from this approach.

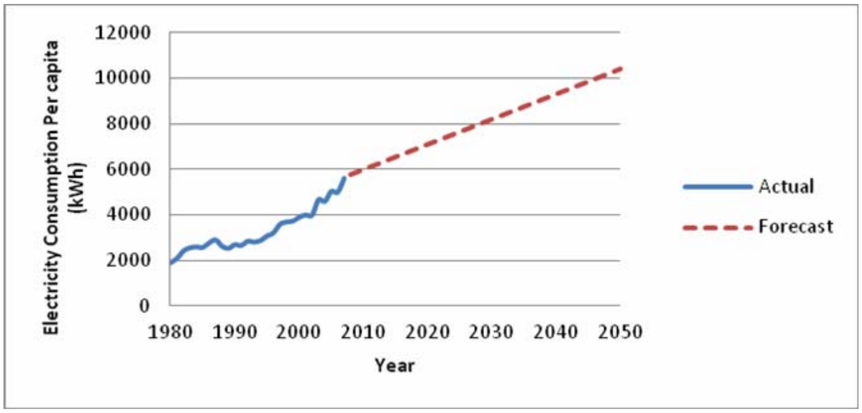
The results showed that electricity consumption per capita shares long-run relationships with both GDP per capita and temperature. Specifically, the elasticity estimate for GDP per capita (a proxy for the income elasticity of electricity consumption) was 0.524, confirming that electricity is a normal good. Similarly, the elasticity estimate of 9.302 for the temperature variable implies that a 1° C increase in average annual temperature will result in a 9.3% increase in electricity consumption per capita.

Using the estimated temperature elasticity of electricity consumption and the temperature projections for Trinidad and Tobago under the A2 and B2 scenarios, forecasts of future changes in per capita electricity consumption resulting from year-to-year variation in temperature were generated and compared to that of the baseline case (Figure 9.5). These projections of future consumption of electricity

[93] The current term of the Kyoto Protocol will end in 2012.

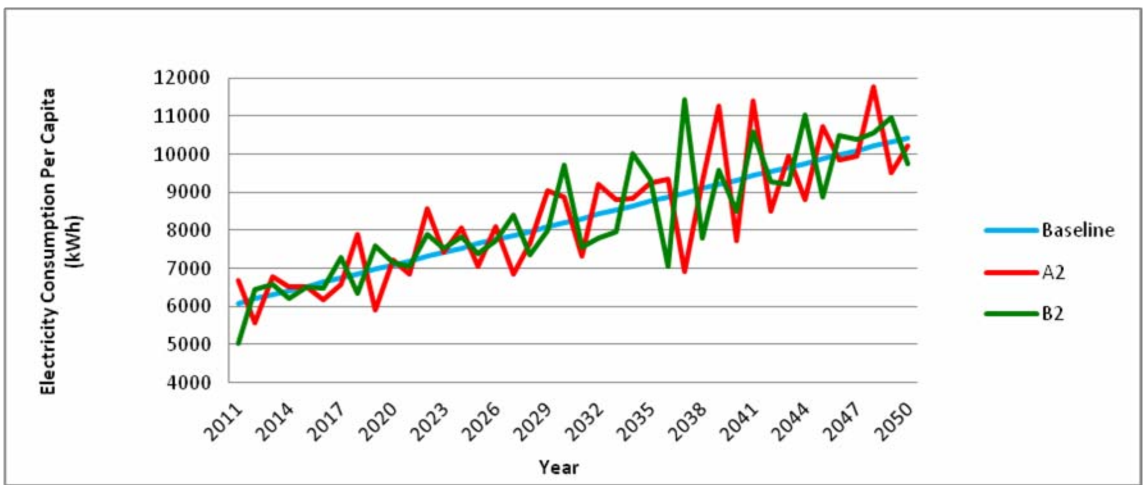
on a per capita basis are influenced by the pattern of temperature change, and show higher volatility in later decades than in earlier ones.

Figure 9.4: Historical and projected electricity consumption per capita for Trinidad and Tobago



Source: ECLAC, 2011.

Figure 9.5: Forecast of electricity consumption for Trinidad and Tobago under the A2 and B2 scenarios (kWh per capita per annum)



Source: ECLAC, 2011

Over the 40-year period, on average, electricity consumption is expected to increase for both scenarios. During 2021-2030, electricity consumption per capita will increase by an average of 143.76 kWh annually under the A2 scenario and by an average of 185.66 kWh annually under the B2 scenario. During 2031-2040, electricity consumption per capita will decrease by an average of 20.66 kWh annually under the A2 scenario and by an average of 107.72 kWh annually under the B2 scenario. In the final decade under study (2041-2050), electricity consumption per capita is expected to increase by an average of 134.28 kWh annually under the A2 scenario and by an average of 184.03 kWh annually under the B2 scenario. Over the entire period of 2011-2050, electricity consumption per capita is projected to increase by an average of 65.13 kWh annually under the A2 scenario and by an average of 61.46 kWh annually under the B2 scenario (see table 9.1). Therefore, the A2 scenario will lead to higher consumption of electricity than the B2 scenario over the entire forecast period, although electricity consumption under the B2 scenario will be more varied from year to year and from decade to decade.

Overall, the projected average annual change in electricity consumption per capita for the A2 scenario represents an annual increase of 1.07 % over the 2011 baseline value of electricity consumption per capita while that for the B2 scenario represents an annual increase of 1.01 % over the 2011 baseline value of electricity consumption per capita.

Table 9.1: Change in electricity consumption per capita (kWh) in Trinidad and Tobago relative to the baseline scenario (2011-2050)

Period	Climate scenario	
	A2	**B2**
2011-2020	3.15	-16.12
2021-2030	143.76	185.66
2031-2040	-20.66	-107.72
2041-2050	134.28	184.03
2011-2050	**65.13**	**61.46**

Source: ECLAC, 2011.

The total cost of meeting the additional demand for electricity during years of temperature increase, and the savings in cost of electricity during years of temperature decrease, were estimated for the entire population using the current electricity tariff of US$ 0.04 per kWh for residential customers, assuming prices will remain constant for the 40-year forecast period (see table 9.2). The economic impact estimates indicate that the B2 scenario will result in electricity cost savings during the 2011-2020 and 2031-2040 periods. The A2 scenario, in contrast, only results in cost savings during 2031-2040 period.

Table 9.2: Economic impact of climate change on electricity consumption in Trinidad and Tobago 2011-2050)

Period	Economic impact at different discount rates (US$ million*) (Percentage of 2009 GDP)							
	A2				**B2**			
	0%	**1%**	**2%**	**4%**	**0%**	**1%**	**2%**	**4%**
2011-2020	1.727 (0.009)	3.195 (0.016)	4.538 (0.023)	6.895 (0.036)	-8.841 (0.046)	-11.204 (0.058)	-13.377 (0.069)	-17.217 (0.089)
2021-2030	78.841 (0.407)	67.987 (0.351)	58.829 (0.303)	44.485 (0.230)	101.82 (0.525)	86.451 (0.446)	73.616 (0.380)	53.839 (0.278)
2031-2040	-11.331 (0.058)	-8.167 (0.042)	-5.923 (0.031)	-3.190 (0.016)	-59.077 (0.305)	-47.143 (0.243)	-37.817 (0.195)	-24.689 (0.127)
2041-2050	73.643 (0.380)	54.262 (0.0280)	40.111 (0.207)	22.129 (0.114)	100.93 (0.520)	73.154 (0.377)	53.215 (0.274)	28.464 (0.147)
2011-2050	**142.88 (0.737)**	**117.28 (0.605)**	**97.55 (0.503)**	**70.32 (0.363)**	**134.83 (0.695)**	**101.26 (0.522)**	**75.64 (0.390)**	**40.40 (0.208)**

Note: The values in parenthesis below the figures represent the corresponding proportion of cost to 2009 GDP. Source: ECLAC, 2011.

The economic impact estimates indicate that the B2 scenario will result in electricity cost savings during the 2011-2020 and 2031-2040 periods. The A2 scenario results in cost savings only during the period 2031-2040. The economic impact under the A2 scenario ranges from US$ 1.727 million when no discounting is applied to US$ 6.895 million with a 4% discount rate for the first decade. For the second and last decadal periods under the A2 scenario, impact ranges from US$ 44.485 million with a 4% discount rate to US$ 78.841 million with no discounting and from US$ 22.13 million with a 4% discounting to US$ 73.643 million when no discounting is applied, respectively. During the period 2031-

2040, however, the A2 scenario will result in cost savings that range between US$ 3.19 million with 4% discounting and US$ 11.331 million without discounting.

In the case of the B2 scenario, cost savings range from US$ 8.841 million with no discounting to US$ 17.217 million at a 4% discount rate for 2011-2020, and from US$ 24.689 million at a 4% discount rate to US$ 59.077 million without discounting for the 2031-2040 period. Conversely, for the 2021-2030 and 2041-2050 periods, the B2 scenario results in additional costs. The costs range from US$ 53.839 million at a 4% discount rate to US$ 101.82 million without discounting, for the period 2021-2030, and from US$ 28.464 million at a 4% discount rate to US$ 100.93 million without discounting, for the period 2041-2050.

For the entire 40-year period, economic impact of climate change results in cost to the economy for both the A2 and B2 scenarios and for all discount rates. The economic impact ranges from US$ 70.32 million under the A2 scenario with a 4% discount rate to US$ 142.88 million under the A2 scenario when no discounting is applied. In the case of the B2 scenario, economic impact ranges from US$ 40.40 million with a 4% discount rate to US$ 134.83 million when no discounting is applied. As a proportion of GDP, these economic impact estimates represent 0.737% of 2009 GDP for the case of no discounting and 0.363% of 2009 GDP for the case of a 4% discount rate under A2. Similarly for the B2 scenario, the economic impact estimates represent 0.695% of 2009 GDP for the case of no discounting and 0.208% when a 4% discount rate is applied. When economic impact estimates under the A2 and B2 scenarios are compared, A2 results in higher cost over the entire period of 2011-2050 and for all discount rates considered.

Given that electricity is heavily subsidized in Trinidad and Tobago and the fact that there has been a steady increase in the purchasing power of consumers as a result of economic growth, the results suggest that electricity consumers have been using electricity irrespective of changes in temperature in the immediate term. It is only in the long run that electricity consumption will be responsive to temperature change. Consequently, future climate change-induced alterations in electricity demand are predicted to have minimal economic impact, equivalent to losing 0.737% of 2009 GDP for the entire 40-year period from 2011 to 2050 under the A2 scenario, or 0.695% of 2009 GDP for the same period under the B2 scenario.

2. Impact on supply

In 2009, one third of Trinidad and Tobago liquid natural gas exports went to the United States of America, and another one third to Spain, United Kingdom and France combined. Less than 1% (0.41%) of Trinidad and Tobago LNG exports went to China and 3.4 % went to India. Trinidad and Tobago LNG exports to the United States of America accounted for more than half (52.19%) of United States LNG imports; and Trinidad and Tobago LNG exports to China and India accounted for 1.05% and 5.39% of LNG imports to each country, respectively (BP, 2010).

The Obama administration recently signalled its resolve to reduce the dependence of the United States of America on foreign oil by one third by 2025. Using 2009 figures and assuming that the policy results in an across-the-board reduction of 33% in all energy imports to the United States of America, then the value of Trinidad and Tobago LNG exports to the United States of America in 2009 would have declined by US$ 422 million. Such a reduction in export earnings from LNG is equivalent to a 2.2 % reduction in GDP for that year.

Should the United States Government policy of energy import substitution be predicated on an aggressive switch to renewable energy, then the decline in foreign oil dependence may be higher than the projected one third, or the target of one third reduction may be reached at a much earlier time than 2025 and this will impact their demand for energy from Trinidad and Tobago.

In an A2 scenario, economic growth continues on a rapid path and the use of cleaner energies gains more prominence. Under the B2 scenario, environmental sustainability becomes important and the Government, in addition to promoting use of cleaner energy, is encouraging and investing in renewable energy to substitute for coal and crude oil.

The situation is different with either the A2 or B2 scenario. Under the A2 scenario, China's consumption of natural gas will increase significantly. This has several implications for the Trinidad and Tobago energy sector. A substantial increase in LNG consumption in China could lead to a significant increase in Trinidad and Tobago LNG exports to that country, which is expected to more than compensate for the lost United States of America export market, given China's population. Another possibility is that the price of natural gas on the world market could increase, as China and India compete for available supplies. This will translate into higher export earnings from LNG exports from Trinidad and Tobago. Even more positively, an increase in exports at higher prices could result, when increased demand and competition among major consumers for available supplies coexist.

The A2 scenario provides the best situation for the Trinidad and Tobago energy sector. In contrast, the B2 scenario does not augur well for Trinidad and Tobago. Under the B2 scenario, China pursues a climate-change mitigation strategy that emphasizes renewable energy and devotes resources to developing renewable energy technology. This implies that growth in the use of natural gas will remain steady, at or below the growth level under the BAU scenario. Therefore, by placing emphasis on renewable energy, and marginal increase in the consumption of natural gas, China will not offer Trinidad and Tobago an alternative market to the lost United States of America export market. In addition, a shift to renewable energy has the potential to depress the price of natural gas on the world oil market. This implies that under B2, LNG export volume and unit price would fall. The consequence would be a decline in export revenues for Trinidad and Tobago.

D. ADAPTATION AND MITIGATION OPTIONS

Elements of the Energy Policy which is currently being drafted by the Ministry of Energy and Energy Affairs (MEEA) include strategies for carbon reduction and for the introduction of renewable energy. Plans for implementing mitigation and adaptation strategies to deal with the effects of climate change have been integrated into national planning, recognizing that climate change affects all sectors of the economy and, if not addressed, can retard steps towards future development (CCP, 2009). A 2007 study prepared by the International Energy Agency (IEA, 2007) proposed that the global energy sector could conservatively achieve potential energy efficiency savings of 13-16% or roughly 5-11 exajoules/year (EJ/yr). Another study, prepared by McKinsey (2009) showed that, with respect to the economy of the United States of America alone, the potential exists to achieve a 23% reduction in CO_2 emissions by the year 2020 (excluding transportation-sector energy-efficiency improvements). Such a reduction would eliminate approximately US$1.2 trillion in energy waste in that country and roughly 1.1 gigatons of GHGs. Similar assessments are needed for the Caribbean subregion to continuously assess the energy efficiency and renewable energy potential for the energy sector.

1. Adaptation strategies

The draft energy policy for Trinidad and Tobago indicates potential areas to promoted energy efficiency in the energy sector. These include introduction of energy efficient bulbs (CFL[94] and LED[95]), adoption of CNG as an alternative transport fuel, introduction of energy-efficient building codes, and adoption of twin-cycle technology in electricity generation. It also highlights solar, wind and biomass as viable renewable energy sources for the country. Table 9.3 provides a matrix of adaptation options that promote

[94] Compact fluorescent bulbs
[95] Light emitting diodes

energy efficiency and the feasibility of their implementation in Trinidad and Tobago. A cost-benefit analysis (CBA) to further inform development of the energy policy was performed on various strategies. The costs of and benefits to be derived from the adoption of CFL bulbs by residential electricity consumers, the introduction of solar water heater to replace electric water heater by residential consumers, the introduction of Variable Refrigerant Volume (VRV) air conditioners (ACs) to replace split ACs in the hospitality industry, and the introduction of CNG to replace gasoline as a transport fuel, were estimated and compared.

Table 9.3: Adaptation options for the energy sector in Trinidad and Tobago with energy efficiency potential

Adaptation Option	Sectors of impact	Implementation timeframe	Policy/tax incentive needed	Required technology	Cost of adaptation
Compact fluorescent light bulbs	Residential Public Industrial	Immediate	Little or none	Available locally	Low
Light emitting diodes	Industrial Public	Immediate	Little or none	Available locally	Low
Solar water heater	Residential Hospitality	Immediate to medium	Medium	Available locally or regionally	Medium
VRV air conditioner	Hospitality Public	Immediate to Medium	Medium	Available internationally	Medium
Compressed natural gas	Transport	Medium to Long	High	Available locally	High
Electric vehicle	Transport	Medium to Long	High	Available internationally	High
Building codes	Housing	Long	High	Available locally	Medium
Retrofitting building with smart electrical switches	Housing Public	Immediate	Little to none	Available locally	Low

Source: ECLAC, (2011)

(a) Compact fluorescent light (CFL) bulbs.[96]

This adaptation option is expected to result in a net capital (instalment) cost of US$ 85.71 per household or a total capital cost of US$ 32.38 million for all households in the first year, yet at the same time may result in cost savings of US$ 28.32 per household for the first year of electricity cost. In order to project future costs of electricity, the real unit price of electricity was assumed to be constant at a value of US$ 0.04 and a population growth rate of 0.82 % per annum was assumed.

This yielded a NPV of US$ 345.20 million for the adaptation option and a payback period of less than 3 years for the initial capital outlay, to be recovered in terms of savings in the cost of electricity. As a proportion of 2009 GDP, the NPV represents savings over a 40-year period equivalent to 1.78% of 2009 GDP. This corresponds to a benefit-cost ratio (BCR) of 1.83, implying that every dollar invested in switching from insulation contact (IC) to CFL bulbs will be cost effective and yield a return of 83 cents. When discounting is applied to the yearly net cost of switching, the BCR ranged between 1.80 for 1% discount rate to 1.77 for a 4% discount rate. The NPV similarly ranged between US$ 277.51 million for a 1% discount rate to US$ 157.01 million for a 4% discount rate.

[96] Assuming a total of 376,084 residential consumers (TTEC, actual data for 2010), and a current average of ten 60-Watt incandescent (IC) bulbs per household in use for four hours every day of the year, this option considered the benefit to replacement of these 60-Watts IC bulbs with 13-Watt CFL bulbs (for all households). An IC bulb is estimated to have a useful life of 1,500 hours while a CFL bulb has a lifespan of 10,000 hours. The price of a 60-Watt IC bulb was estimated to be TT$ 3.99 and that of a CFL bulb to be TT$ 57.99.

In addition to saving households future electricity expenditure, the adaptation option of switching to CFL bulbs also contributes to GHG emission abatement. Reduction in electricity consumption translates to a reduction in the amount of natural gas used for generating electricity. The amount of CO_2 that will be abated as a result of implementing the adaptation option was estimated to be 7.74 Mt over the 40-year period. If Trinidad and Tobago were to adequately position itself to participate in the Clean Development Mechanism[97] (CDM) of the Kyoto Protocol, and using a carbon price of US$ 15 per credit, it was estimated that the country could receive a total payment of US$ 116.03 million from carbon trading. If this indirect benefit is accounted for in the total benefits derived from switching to CFL bulbs, then the NPV will increase to US$ 461.23 million before discounting.

(b) Solar water heaters (SWHs)[98]

A single element electric water heater was estimated to consume 630 kWh of electricity per month, amounting to a total operating cost of US$ 311.90 per year in electricity charges; this figure represents a potential annual saving in electricity costs that a household would realize by using a SWH instead of an electric water heater. When the population of customers with an electric water heater is considered, then switching from an electric water heater to a SWH will result in a total net installation cost of US$ 26.75 million for 26,538 residential customers and a total saving of US$ 8.34 million in electricity costs in the first year of switching to SWH. This resulted in a NPV of TT$2.20 billion and a BCR of 4.66. Switching from electric water heater to SWH will save residential consumers electricity costs over the forty year period equivalent to 1.77 % of the GDP in 2009. When the stream of costs are discounted, the NPV ranged from US$ 283.54 million for 1$ discount rate to US$ 153.50 million for a 4% discount rate. The BCR also ranged from 4.2 for 1% discount rate to 3.4 for a 4% discount rate.

Additionally, switching from electric water heater to SWH will reduce CO_2 emissions as reduction in electricity consumption will lead to reduction in the utilization of natural gas for electricity production by power plants. It is estimated that over the forty-year period of implementing this adaptation option, a total of 6.01 mt of CO_2 will be abated worth US$ 92.91 in carbon credit payments to Trinidad and Tobago. When this indirect benefit from implementing the adaptation option is factored into the total benefit, the NPV will increase to US$ 442.86 million.

(c) Variable refrigerant volume (VRV) air conditioners

Replacement of mini split air conditioners with VRV air conditioners is mainly considered as a strategy for the tourism industry in Trinidad and Tobago.[99] Based on the reported verified room stock of hotels and guest houses in Trinidad and Tobago for 2004 and the occupancy rate (Ministry of Tourism, 2004), the total net capital cost of implementing the adaptation option amounts to US$ 0.90 million. At a unit price of TT$ 0.10 per KWh of electricity for commercial customers, the net saving in operating cost (electricity charges) per room in the first year of adaptation is US$ 35.34. When aggregated for the total room stock, the net savings in electricity cost for the first year equals US$ 0.11 million. The NPV of implementing the adaptation option for the 40-year period is US$ 1.60 million and the BCR is 1.06. As a proportion of the 2009 GDP, the net savings from implementing the VRV option is negligible at 0.01%. When the stream of costs are discounted, the NPV ranges between US$ 1.01 million for a 1% discount rate and US$ 0.11 million for a 4% discount rate, while the BCR ranges between 1.04 for a 1% discount rate and 0.99 for a 4% discount rate.

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97 http://unfccc.int/kyoto_protocol/items/2830.php

98 Based on a previous study conducted by the Engineering Institute at the University of the West Indies, St. Augustine Campus, 26,538 residential electricity consumers were reported to each have an electric heater (MEEA, 2011).

99 A total of 3,000 hotel and guest house rooms are assumed to operate an air conditioner for eight hours on average every year.

These figures imply that the adaptation option of replacing split AC with VRV is only marginally cost-effective at discount rates below 4%. If future costs and benefits are discounted at a 4% discount rate, the option changes from being a cost-saving to a cost-generating alternative. However, when the indirect benefit of CO_2 abatement that results from the use of the more energy-efficient VRV system is considered, the adaptation option would be regarded as being cost-effective. This is because 170.09 kt of CO_2 valued at US$ 2.55 million will be abated by switching to VRV ACs, resulting in an increase of the NPV to US$ 4.15 million. In fact, the indirect benefit of CO_2 abatement surpasses the direct benefit of savings in electricity costs in implementing this adaptation option.

(d) Compressed natural gas (CNG)[100]

The results of the CBA performed on CNG as an alternative to petrol as a transport fuel is the conversion of 5,000 vehicles to CNG in 2010 and a projected annual growth in the population of CNG-converted cars by 3.5% based on the CNG fuel growth rate. At current prices (the annual fuel cost of operating a car on super grade petrol is estimated to be US$ 416.57 and that of operating a car on CNG is US$ 171.20), a motorist switching from petrol to CNG would incur a one-time installation or capital cost of US$ 1,587 and save US$ 245.38 in fuel costs in the first year of using CNG. At the aggregate level, the cost of converting 5,175 cars to CNG in 2011 would be US$ 8.21 million and the total savings in fuel costs from operating these CNG-converted cars in the first year of conversion would be US$ 1.27 million. Over the 40-year period of implementation, the NPV of converting petrol cars to CNG would amount to US$ 99.15 million and the BCR equals 1.98. The net savings from implementing the CNG adaptation option is equivalent to 0.50% of 2009 GDP.

The replacement of cars running on petrol with those running on CNG will result in reducing CO_2 emission by 131.264 kT[101] over the implementation period. This has the potential yield of US$ 2.1 million to Trinidad and Tobago in carbon credits.

The conversion of the motor fleet to CNG is a cost-effective adaptation option for the transport sector, although it has a high initial cost of implementation and the highest cost per capita among the four adaptation options evaluated in the study. However, there are tax incentives already in place to encourage motorists to convert to CNG.

2. Mitigation options

A major share of the potential for climate change mitigation lies in the energy sector, which is consequently expected to realize the most far-reaching changes. Climate change mitigation strategies under consideration include increased usage of alternative fuels and renewable energy, adoption of cleaner production technologies, conservation of natural carbon sinks, and implementation of energy efficiency measures.

(a) Reducing heat-trapping emissions

In addition to avoiding the most severe effects of climate change over the long term, reducing emissions can result in lower energy use, thereby resulting in savings to consumers and industries. These economic gains can offset a substantial portion of the expenditure made to reduce emissions. Many emissions

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100 The conversion of vehicles to CNG requires an installation of CNG kit at a cost of TT$ 10,000. It is assumed that a vehicle will be driven for an average of 12,000 km annually. A car running on gasoline is estimated to use 972 litres of petrol annually while a car running on CNG is estimated to consume 1,008 litres annually, based on United States of America Environmental Protection Agency (EPA) vehicle efficiency rating of a 2010 Honda Civic car. In Trinidad and Tobago, a litre of super petrol costs TT$ 2.7 whereas a litre of CNG costs $TT 1.78.

101 kT is the product of the Boltzmann constant, k, and the temperature

reduction strategies also provide benefits in air quality, energy security, public health, agricultural production, balance of trade, employment, income generation, wealth creation, and poverty alleviation. For example, lower emissions result in reduced air pollution from power plants and factories, with consequent health benefits.

(b) Emission reduction strategies

A combination of well-designed policies can be strategically used by Governments to overcome economic, technological, informational, and behavioural barriers. Policymakers play crucial roles in creating institutional, policy, legal, and regulatory frameworks that enable significant climate change emission reductions. Many policy-related mitigation strategies are at their disposal, including integrated polices, regulatory standards, taxes and fees, financial incentives, tradable permits and voluntary agreements.[102]

E. CONCLUSION

Findings emanating from the present report on the impact of climate change on the energy sector in Trinidad and Tobago indicate that economic growth, patterns of electricity use, and temperature, affect electricity consumption. However, on an aggregate level, changes in electricity consumption in response to climate change are not expected to have a significant economic impact. This suggests that, regardless of variations in temperature, electricity consumption will continue to increase into the immediate future. This phenomenon makes energy efficiency an important policy instrument for addressing growth in electricity consumption and for reducing the associated GHG emissions.

Findings from the study suggest that change in temperature has no statistically significant impact on electricity consumption in the short-term, since the main driver of electricity use is economic growth. However, over the long-term, electricity demand will be sensitive to changes in temperature. Specifically, a 1% increase in annual average temperature will result in a 9.302% increase in electricity consumption per capita. When the trajectory of future temperature under the A2 and B2 scenarios is considered, electricity consumption per capita will increase by an annual average of 65.13 kWh for the A2 scenario and by an annual average of 61.46 kWh for the B2 scenario during 2011-2050. This represents an annual increase in electricity consumption per capita of 1.07% and 1.01% over the baseline values for 2011 for the A2 and B2 scenarios, respectively.

On the supply side, analyses indicate that the Trinidad and Tobago energy sector will be susceptible to climate change policies of major energy-importing countries, and especially to their renewable energy strategies. Implementation of a foreign oil substitution policy by the United States of America will result in a decline in Trinidad and Tobago LNG exports unless an alternative market is secured for the lost United States of America market. The magnitude of the fall in export earnings is estimated to be equivalent to a 2.2% reduction in 2009 GDP.

China, with its rapid economic growth and the highest population in the world, may offer a potential replacement market for Trinidad and Tobago LNG exports. Using storylines that align with the IPCC climate scenarios, it is estimated that the A2 scenario will offer the best option for the Trinidad and Tobago energy sector. Under this scenario, China is expected to pursue a clean energy strategy of substituting coal with cleaner energy sources such as natural gas and hydroelectricity. This will bolster demand for LNG and/or improve the price of LNG on the world market.

[102] http://www.ucsusa.org/global_warming/science_and_impacts/science/findings-of-the-ipcc-fourth-1.html

Informed by the draft energy policy of Trinidad and Tobago, cost-benefit analyses were performed on some climate-change adaptation options that the Government is contemplating. The results revealed that the adaptation option by residential electricity consumers of converting incandescent light bulbs to CFL bulbs is the most cost-effective in terms of the NPV of electricity cost savings over a 40-year period. However, when adaptation options are assessed using BCR, the option of replacing electric water heaters with SWH was the most cost-effective strategy. This implies that, on an individual level, the use of SWH is most effective but, on an aggregate level, the use of CFL bulbs is more effective, reflecting the mass of households that can implement the CFL adaptation option relative to the few that can implement the SWH option. The adaptation option of replacing mini split air conditioners in hotels and guest houses with VRV air conditioners is only marginally cost-effective when the discount rate is below 4%.

It is also apparent, from the conduct of the present study, that quality data are crucial to assessing the full impact of climate change on the energy sector. Economic data are generally available but not usually at the desirable level of disaggregation. Engineering data relating to energy audits are difficult to access and, in most cases, are not collected. Resources need to be devoted to the conduct of energy audits to facilitate proper valuation of energy consumption in the various sectors.

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CHAPTER X.
CONCLUSIONS AND POLICY RECOMMENDATIONS

The present report has reviewed the potential impact of climate change on key economic and non-economic sectors and, where possible, has provided estimates of the fiscal implications of those impacts for Caribbean economies. Overall, the results show that some countries appear to be more vulnerable to climate change than others, as their specific socio-economic structure and geographical characteristics make them more sensitive to the predicted impacts and limit their adaptive capacity.[103] In general, these assessments have shown that all countries are likely to experience losses under both climate change scenarios, relative to a situation of no climate change. Vulnerability to climate change is unevenly spread among the countries under study.

The main conclusions of the assessments are as follows:

a. By 2050, the mean annual temperature for the Caribbean subregion is projected to reach an estimated 1.78° C to 1.84° C higher than the baseline average (1961-1990) under the SRES A2 and B2 scenarios, respectively, based on a average of the predictions from the ECHAM4 and HadCM3 models. By 2090, these figures could be as high as 2.40° C (under the B2 scenario) to 3.55° C (under the A2 scenario) above the baseline average. Similarly, changes in maximum temperature will range somewhere between 2.77° C to 3.72° C, depending on the scenario.

b. Predictions for mean monthly and annual precipitation for individual countries in the Caribbean vary widely depending on the choice of model (ECHAM4 or HadCM3), making it extremely difficult to properly identify long-term trends under the individual scenarios. However, the subregion is expected to experience progressive overall declines in total annual rainfall, with the A2 scenario predicting more precipitous declines than the B2 scenario.

c. The agricultural sector accounts for 30% of employment in the Caribbean, with the subregion largely dependent on small subsistence farmers using traditional rain-fed systems. The impact of climate change on the agricultural sector as a whole was found to be mixed, since different crops require different optimal conditions at various stages of growth. Overall, the largest impact of climate change on agriculture was expected to be derived from increases in the incidence of extreme weather events, including high-intensity hurricanes and consequent flooding.

d. In Guyana, the sugarcane subsector is expected to realize early gains of US$ 48 million by 2020 under B2, but by 2050, the subsector is expected to experience cumulative losses of US$ 300 million under A2, and of about US$ 150 million under the B2 scenario. In Jamaica, forecasts show that sugarcane yield under both the A2 and B2 scenarios decline at first (during the decade of the 2020s), then increase steadily through to 2050. The difference in the direction of yield projections for the two countries can be explained by the difference in rainfall and temperature predicted under the two scenarios for the two countries, based on their geospatial differences.

[103] Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. It is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, the sensitivity and adaptive capacity of that system.

e. Losses due to ecosystem services related to sea surface temperature rise are estimated to be even higher By 2050 losses due to SST rise are estimate at between US$19.4 billion and US$30.9 billion for the British Virgin Islands and between US$8.1 billion and US$12.9 billion for Saint Kitts and Nevis.

f. In Barbados where approximately 70 percent of the population lives on the coast and where much infrastructure including most of the tourism industry's assets are located on the coastline, there is a high degree of vulnerability of human settlements and infrastructure to sea level rise and high intensity extreme weather events. Under the A2 scenario, the value of exposed assets is estimated at US$4.7 billion in 2020 and can be expected to reach US$44 billion by 2100. Assuming SLR of 1m by 2050, the estimated loss due to coastal erosion alone is expected to be approximately US$14.5 billion.

g. Banana production is therefore doubly affected by projected declines in rainfall over time alongside projected increases in temperatures in the next four decades. By 2050, the value of cumulative yield losses (2008 dollars) for bananas is expected to be about US$ 61 million regardless of the scenario.

h. Root crops are likely to be worse off overall from the expected fall-off in rainfall and the rising temperature. For Saint Lucia, by 2050, root crop losses are estimated at between US$ 22.73 million and US$ 21.50 million under the A2 and B2 scenarios, respectively (in 2008 dollars). For Trinidad and Tobago, the value of yield cumulative losses (2008$) for root crops is expected to be approximately US$ 248.8 million under the A2 scenario and approximately US$ 239.4 million under the B2 scenario (by 2050).

i. Forecast losses in fisheries revenue for Trinidad and Tobago under the A2 and B2 scenarios could be US$ 160.2 million and US$ 80.1 million, respectively, at a 1 % discount rate. Similarly, for Saint Lucia, by 2050 under the A2 and B2 scenarios, losses in real terms were estimated to be US$ 23.18 million and US$ 11.81 million, respectively, at a 1 % discount rate.

j. For British Virgin Islands, cumulative losses to coastal lands due to sea-level rise and coral reef decline is estimated to be at least 11 % of 2008 GDP (about US$ 0.14 billion) by 2050, but could be as high as US$ 51 billion. Similarly, cumulative losses for Saint Kitts and Nevis are estimated to be at least 28 % of 2008 GDP (about US$ 0.16 billion), and could reach as high as US$ 0.68 billion, depending on the scenario and discount rate applied.

k. In Guyana, the current (2010) estimated value of exposed assets is US$ 3.2 billion, mainly on account of the large proportion of the population that lives within the low elevation costal zone (LECZ). The value of exposed assets is expected to increase over the period, consistent with projected trends in population density and GDP per capita.

l. On average, disease incidence is expected to be higher under either the A2 or B2 scenario compared to the baseline average (BAU) across the subregion. Consistent with the literature, dengue fever was found to be positively correlated with rainfall, while gastroenteritis was found to be more closely related to temperature levels. Case studies for leptospirosis (in Trinidad and Tobago) and malaria (in Guyana) confirm significant relationships between temperature and rainfall variations and disease incidence in these countries.

m. Overall, countries could expect to experience increases in disease burdens and related treatment costs. Controlling for sanitation and economic development, the incidence of malaria in Guyana is projected to increase by between 35% and 47 % over the next four decades, costing the country at the minimum an additional US$ 125,000 above the baseline for anti-malaria treatment (chloroquine) alone over the period. Similarly, in Guyana, treatment costs for dengue fever are expected to increase by about US$ 13 million on average for both scenarios, while in Jamaica the extra treatment costs range from US$ 25 to US$ 26 million.

n. Trinidad and Tobago can be expected to spend US$ 36 million on average in treatment costs related to dengue fever, gastroenteritis and leptospirosis over the period 2011-2050, while these same diseases can be expected to cost Jamaica an average of US$ 285 million over the same period. Guyana can be expected to face a burden of approximately US$ 300 million due to direct costs related to dengue fever, gastroenteritis and malaria.

o. The Caribbean tourism sector is expected to be adversely affected by an overall deterioration in climate attractiveness of Caribbean destinations due to climate change, which is expected to result in a fall-off in arrivals. Additional land loss due to sea-level rise, and deterioration of the tourism product due to coral reef loss are expected. Estimated losses range from US$ 111.5 million in Montserrat (5.2 times 2009 GDP) to US$ 19 billion in the Bahamas (2.8 times 2008 GDP). For Barbados, when tourist mobility impacts of mitigation strategies are taken into account, total losses are estimated at approximately US$ 7.4 billion over the period.

p. The total impact of sea-level rise, and long term variations in temperature and precipitation trends on international transportation infrastructure in the Caribbean, is estimated to lie somewhere between US$ 8.0 billion and US$ 9.2 billion for Barbados, and between US$ 428 million and US$ 570 million for Montserrat.

q. Temperature change has no statistically significant impact on electricity consumption in the short-term. However, in the long-term, electricity demand will be sensitive to changes in temperature; specifically, a 1% increase in annual average temperature will result in a 9.3% increase in electricity consumption per capita.

r. Energy exports from Trinidad and Tobago can be expected to be susceptible to climate change policies of major energy-importing countries, and especially to their renewable energy strategies. For example, implementation of a foreign oil substitution policy by the United States of America will result in a decline in Trinidad and Tobago liquid natural gas exports unless an alternative market is secured for the lost United States of America market.

A. KEY ADAPTATION AND MITIGATION RESPONSES

Faced with the enormity of the threats and challenges posed by climate change, three options remain open to policymakers: mitigation, adaptation or "no response". Adaptation was initially thought to play a minor role in the response to climate change, but as the understanding of its implications has grown over time, appreciation of adaptation as a response strategy has increased, as more research into the potential impact has been conducted in various parts of the world. Thus, although the absolute response to climate change requires rapid and significant reductions in global GHG emissions, concerted efforts at adaptation are essential, particularly for SIDS. Societies, as a matter of course, have a long record of adapting to the impacts of weather and climate through a range of practices that include land-use planning and control of development, crop diversification, irrigation, water management, disaster risk management, and insurance. However, climate change poses novel risks often outside the range of experience, such as impacts related to sea-level rise, increased frequency of droughts, heat waves, accelerated glacial retreat, and hurricane intensity.

With its share of global greenhouse gas emissions estimated at less than 0.1%, adaptation to climate change has been put forward as the only option for small island developing States, such as the SIDS of the Caribbean, and this urgency has been echoed by IPCC in their Third Assessment Report. The socio-economic vulnerability of the Caribbean to climate change is directly linked to patterns of development and structural ills, such as poverty and unemployment, which already challenge the subregion. Their environmental vulnerability stems from geophysical phenomena and the small size of the countries under study – factors that cannot be changed. Several studies have indicated that climate change poses a risk to advances made in recent decades towards the reduction of poverty and inequality in these countries.

Several initiatives aimed at strengthening the capacity of Caribbean countries to adapt to climate change have been implemented over the years. These include the Caribbean Planning for Adaptation to Climate Change (CPACC), the Adaptation to Climate Change in the Caribbean (ACCC), the Mainstreaming Approach to Climate Change (MACC), and the Special Pilot Adaptation to Climate Change (SPACC).[104] The present economic assessments complement those projects by focusing on the estimation of the cost of adapting to and mitigating against the projected impacts of climate change in key sectors of the economy.

In the final analysis, a country's ability to adapt to climate change will depend on the availability of local resources, the ability to spread and manage risk, public awareness, local attitudes towards the problem, the degree to which a climate-change agenda is interwoven into other national and regional sectoral policies, and political will. In addition, sound strategic planning and programme development cannot occur in the absence of reliable, accessible data suitable for making accurate and valid projections with which to aid decision-making.

B. POLICY RECOMMENDATIONS

The environment is an integral part of the long-term social and economic well being of the people of the Caribbean subregion and, as such, in addition to being an environmental issue, climate change must equally be seen as a developmental issue. In general, this requires an internal shift towards efficient energy use, better development planning and control, improved management of resources, proactive fiscal policy and financing mechanisms that support sustainable adaptive actions. This approach recognizes the need for integrating mitigation efforts and promoting low carbon economies, while focusing on the design and implementation of adaptation policies and strategies.

1. Mainstreaming sustainable adaptive strategies into national and subregional policies

For Caribbean countries, mainstreaming climate change into national policies and sectoral plans may be considered a pillar of any response. Additionally, some existing national policies will need to be reviewed to incorporate the different aspects of climate change. Based on the proximity of the countries that make up this group and their inherent interdependencies, there is need to adopt a subregional adaptation response and to strengthen the institutional frameworks for responding to climate change. This approach may also have scale effects that may prove to be beneficial to individual countries, whose small size and limited resources may prevent them from achieving substantive results on their own. In this regard, the following are recommended:

- The development of a strategy geared towards transborder and multinational conservation of biodiversity across the subregion.
- The sharing of information, especially best practices, among SIDS in the areas of renewable energy and energy efficiency.
- Mainstreaming of coastal zone management policies with other relevant policies, such as water resource management, which is a key response to food security and agricultural production in the face of climate change.
- Mainstreaming climate change and disaster risk reduction in development planning.
- Incorporation of climate change analysis into national agricultural strategies, and harmonization with sectoral polices in reducing deforestation, improving the efficiency of water use and protecting biodiversity

[104] http://caribbeanclimate.bz/

2. Monitoring the socio-economic impacts of climate change in the short- and long-term

The challenges associated with climate change are accelerating now, at a time when the economic models that have worked for a long time (at least in the developed countries) are becoming less relevant. This represents an opportunity for the major contributors to global GHG emissions to respond to the global crisis, while at the same time pursuing more sustainable modes of production. For the Caribbean subregion, these challenges highlight the importance of monitoring and evaluating the progress being made with respect to socio-economic indicators. The following are suggested:

- There is need to develop quantitative and qualitative methods of evaluating the costs of the impact of climate change, as well as adaptive capacity.
- All efforts at formal and informal education should be accelerated, given the importance of the educational component in successfully transitioning to low-carbon economies, through adoption of an approach to development that consciously protects the environment.
- Investment in activities that directly protect the productive sectors, including: the building of sea walls and other sea defence mechanisms; the relocation of agricultural production to less sensitive locations; the development of salt-tolerant crop varieties and the adoption of more integrated and intensive livestock farming; the establishment of systems of food storage; the improvement of irrigation and agricultural drainage systems; and the establishment of early warning systems.

3. Reduce the impact of extreme events

Many of the assessments show that extreme events have catastrophic consequences for major economic sectors and this is more so for the agriculture and tourism sectors. While the research is as yet undecided about the relationship between extreme events such as hurricanes and climate change, the decision by national Governments to address the uncertainty and risk involved by being proactive is of paramount importance, given the large-scale losses that have been manifested in the recent past. In particular, the following are the recommended actions for the subregion:

- Increase the environmental security requirements for basic infrastructure, including roads, bridges, airports, and sea ports.
- Locate emergency and disaster facilities away from high risk zones. In particular, consideration should be given to their removal from the LECZ.
- Integrate disaster preparedness and response into poverty reduction strategies.
- Raise public awareness of the potential risks involved and sensitize populations about the role that they can play in reducing the impact of extreme events, including relocation of communities, local response plans and other responses of a self-help nature.

4. Potential fiscal policies to address climate change

Concerted efforts should be made to promote economic behaviour that supports the move towards more carbon-neutral type economies, including efforts that demonstrate leading by example. The following strategies are recommended:

- Development finance should focus on activities that increase capital formation, raise the quality, diversity and quantity of exports, and raise the technical capacity and knowledge of the workforce.
- Reward private mitigation activities that reduce CO_2 emissions.
- Provide incentives for the design and renovation of settlements and homes that conform to building codes (some of which need to be revised) which will make them more resistant to extreme

events, or which will serve to improve the efficiency of water use and support the use of renewable energy technologies.

- Resist policies that suggest reducing social spending, since impoverished households and families already struggling to cope with structural unemployment and its consequences are, by definition, more vulnerable to the impacts of climate change. Reduction in Government assistance will only serve to limit resilience and adaptive capacity.

5. Consistent methodological approach and collection of relevant data

A high degree of uncertainty exists with respect to projections for climate variability, especially of precipitation, but also in terms of the relationships among the non-climate variables under consideration and their interaction with macroeconomic indicators. As a result, the costs presented in these assessments are only indicative. As a first step, there needs to be a streamlined approach to arriving at these estimates so that they are comparable across the subregion, and to start collecting data that are relevant if such data do not already exist. However, as more research is conducted over time and the relationships become clearer, it would be necessary to streamline the methodological approaches that produce the most consistent and accurate results which could assist respective Governments in decision making. Additionally, new studies need to be conducted in the subregion to examine the cost and economic impacts of adaptation.