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AN ASSESSMENT OF THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE TRANSPORTATION SECTOR IN BARBADOS

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BRIDGETOWN
The Crane
Grantley Adams
International Airport
Caribbean
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Executive Summary

Barbados is at great risk from the economic impact of climate change on its international transportation sector, which brings nearly all of its visitors (mainly tourists) from the main markets in North America and Western Europe and moves virtually all of its merchandise trade.

The total cost of climate change on international transportation in Barbados combined the impacts of changes in temperature and precipitation, new climate policies and sea level rise. The impact for air transportation ranges from US$10,727 million (SRES B2 scenario) to US$12,279 million (SRES A2 scenario), and for maritime transportation impact estimates range from US$1,992 million (SRES B2 scenario) to US$2,606 million (SRES A2 scenario). For international transportation as a whole, the impact of climate change varies from US$12,719 million under the SRES B2 scenario to US$14,885 million under the SRES A2 scenario.

While further study is needed to examine in more detail the potential impacts of climate change on the two key international transportation assets - the Grantley Adams International Airport and the Port of Bridgetown - the findings of this preliminary assessment are so important that transportation decision makers should begin immediately to assess them in the development of transportation investment strategies in Barbados.

Mitigation strategies to deal with greenhouse gas (GHG) emissions from international aviation and shipping are especially challenging because the 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) specifically excludes these from developed countries' national targets. Instead, countries are expected to work through the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO), but so far neither organization has reached agreement on binding actions, and many key issues remain unresolved.

Barbados has the institutions set up to implement the adaptive strategies to strengthen the resilience of the existing international transportation system to climate change impacts. Air and sea terminals and facilities can be hardened, raised, or even relocated as need be and, where critical, to safety and mobility; expanded redundant systems may be considered. What adaptive strategies may be employed, the associated costs, and the relative effectiveness of those strategies will have to be determined on a case-by-case basis, based on studies of individual facilities and system-wide considerations.

I. INTRODUCTION

A. CLIMATE CHANGE AND INTERNATIONAL TRANSPORTATION

The Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (IPCC, 2007) provided compelling scientific evidence that human activity in the form of (GHG) emissions is responsible for many observed climate changes, but noted that use of this knowledge to support decision making, manage risks and engage stakeholders is inadequate. The international transport sector is a relevant case in point. Several studies have examined the contribution of both air and sea transport to climate change through the burning of fossil fuels [Environmental Protection Agency, 2006; International Energy Agency, 2008; and (IMO), 2008]. Far less attention, however, has been paid to the consequences of potential climate changes for planning, designing, constructing, retrofitting, and operating the international transportation infrastructure. This inaction partly stems from the difficulty of defending the case for substantial investments in transportation infrastructure on the basis of climatic changes that may or may not occur years or even generations into the future.

Nevertheless, there are many reasons for transportation professionals and decision makers to consider climate change impacts and adaptation requirements as a matter of priority. First, climate change is not just a problem for the future. IPCC (2007) identified five climate changes of particular importance to 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. 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 et. al., 2009). Even if drastic actions were taken today to stabilize or even eliminate GHG emissions, the impact of climate change on international transport networks would continue to be felt far into the future, forcing transportation professionals to adapt to their consequences.

Second, climate change could lead to potentially sudden or dramatic changes far outside historical experience (e.g. record rainfall and record heat waves). Transportation infrastructure is designed for typical weather patterns, incorporating assumptions about reasonable changes in temperature and precipitation. But what if the 100-year tropical storm were to become the 50- or 30-year storm, or design thresholds were frequently to be exceeded, or evacuation routes themselves were to 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. Improving adaptive capacity must, therefore, be an urgent priority.

Third, decisions taken today by transport professionals about 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. Focusing on the problems now should help avoid costly investments and disruptions to operations in the future.

Fourth, international transportation is crucial for the sustainable development of trade and tourism in developing countries, which are likely to be hardest hit by climate change (Dasgupta et. al., 2009). Air transportation supports 8% of global economic activity, carries 40% of the value of freight with speed and efficiency, and acts as an economic catalyst by opening up new market opportunities. Sea transportation facilitates more than 90% of world trade and contributes directly to a country's international competitiveness (ICTSD, 2010). The vulnerability of both air and sea transport infrastructure to climate change carries tremendous implications for Caribbean Small Island Developing States (SIDS). They 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. Caribbean SIDS, constrained by shrinking budgetary space and rising public debt can least afford to allocate a large proportion of their annual budgets to rehabilitate damaged infrastructure due to climate change. They must now consider preventative measures such as a better design methodology and a more sustainable maintenance effort to minimize the impact of climate change.

Finally, international transportation is the fastest growing source of GHG emissions and there is now a growing consensus that future targets for emissions reductions in the post 2012 Climate Policy Framework must now include air and sea transportation. Global emissions from international aviation doubled between 1990 and 2005 and are projected to almost quintuple to 2050 (IPCC, 2007). Emissions from the international maritime industry also doubled between 1994 and 2007, and are projected to possibly even triple by 2050 (Lee et. al., 2009). Even though air and sea transportation combined are responsible for just 3% of GHG emissions, policy proposals to mitigate emissions from international transportation could increase economic costs for Caribbean SIDS.

B. OBJECTIVES OF THE STUDY

The main objective of this study is to establish an approach to analyzing the economic impact of climate change (temperature, precipitation, extreme events, sea level rise, and ocean acidification) on the international transportation sector in Barbados so as to inform national strategies for mitigation and adaptation. Its specific objectives are:

- To collect relevant data on the air and sea transportation sectors in Barbados in order to estimate the costs of identified and anticipated impacts associated with climate change over the next 40 years in comparison to a Business As Usual (BAU) scenario and a scenario with adaptation measures;

- To forecast losses in the air and sea transportation sectors in Barbados until 2050 derived from climate change using an appropriate discount rate; and

- To prepare a list of possible adaptation and mitigation strategies that can be undertaken by the air and sea transportation sectors in Barbados to address the observed and projected impacts of climate change.

C. LIMITATIONS OF STUDY

Perhaps one of the main limitations to undertaking any climate change study is uncertainty (Stern, 2006). Predicting the economic impacts of climate change along the lines outlined above requires predicting the future trajectory of the Barbadian economy 40 years into the future, and doing so for a series of different scenarios. The long-term nature of climate change compounds the difficulty in determining the types of adaptation required and when they will be required. Climate is not the only variable that is changing; non-climatic variables are also changing, both positively and negatively (O’Brien, 2004).

Secondly, any attempt to estimate the economic impacts of climate change must take into account that many of the physical impacts of climate change are expected to appear only with considerable time lags. This means that comparing the counterfactual “no climate change” scenario with the counterfactual “climate change but no adaptation” scenario and with the actual “climate change and adaptation” scenario is a challenge (IIED, 2010). Moreover, the economic impacts of climate change on Montserrat will depend crucially on the impacts and policies of other countries.

This raises the moral argument that many of the impacts of climate change will be felt by people who have not contributed to the problem.

Finally, little consensus exists on the choice of an appropriate social discount rate for the cost-benefit analysis of the economics of climate change. At best, there appears to be general agreement that the Social Rate of Time Preference should be used in discounting climate change projects whose effects span more than one generation (more than 30-40 years) or even hundreds of years (Zuhang et. al., 2007). However, there is a wide variation in the actual choice of social discount rates for climate change studies. Stern (2006) uses an interest rate of 1.4%; the United Kingdom Treasury's Green Book recommends 3.5% and Dasgupta et. al., (2009) suggests a range of 2%-4%. In addition, there are significant variations in public discount policies with developing countries using much higher interest rates ranging between 8%-15%. This study uses three social discount rates – 1%, 2%, and 4% – to better gauge the sensitivity of the economic impact estimates of climate change on the international transportation sector, but recognizes the need to regularly review the appropriateness of this range of interest rates in light of changing economic and capital market circumstances, both domestic and international.

D. CLIMATE SCENARIOS

Regarding climate scenarios, this study uses a BAU scenario as a baseline for comparisons. This scenario includes climate change as a historic trend inside the economic model. The other two scenarios used in this study are based on the Special Report Emissions Scenarios (SRES) storylines. Table 1 describes the SRES A2 and B2 storylines used for calculating future GHG and other emissions.

Table 1: SRES storylines and a Business As Usual (BAU) Scenario used for calculating future greenhouse gas and other pollutant emissions

Storyline	Description
A2	A world of independently operating, self-reliant nations; preservation of local identities; high population growth; high energy use; low resource availability; slower and more fragmented technological changes; and regionally-oriented economic growth.
B2	Emphasis on local rather than global solutions to economic, social and environmental sustainability; population growth at a lower rate than in A2; intermediate levels of economic development; medium energy use; less rapid technological change than in other storylines.
BAU	Continuing trends in population, economy, technology and human behavior.

Source: Nakicenovic, N. et. al., *(*2000)

The A2 scenario is of a more divided world. It envisages that by the year 2100 the population would have reached 15 billion, with generally slow economic and technological development. It predicts slightly higher GHG emissions than other scenarios. The B2 scenario is of a world more divided but more ecologically friendly. It forecasts a slower population growth of 10.4 billion by 2100, with a rapidly developing economy and greater stress on environmental protection, thereby generating lower emissions.

E. STRUCTURE OF STUDY

The rest of this paper is structured as follows. Section 2 undertakes a brief review of the literature regarding climate change impacts on international transport. Section 3 describes the economic setting in the Caribbean and Barbados while Section 4 discusses the role of the air and sea transportation sectors in the Caribbean and in Barbados. Section 5 discusses the vulnerability of the international transport system in Barbados to climate change. Section 6 defines the modelling framework for estimating the costs of climate change. It reviews the literature, explores the variables and statistical sources, and specifies the econometric model. Section 7 provides the forecasted costs of climate change under the BAU, A2 and B2 scenarios. Section 8 initiates the discussion on the approaches to mitigation and adaptation in the air and sea transportation sectors in Barbados. Section 9 concludes the study.

II. LITERATURE REVIEW REGARDING CLIMATE CHANGE IMPACTS ON INTERNATIONAL TRANSPORTATION

Studies on the impacts of climate change on transportation are either standalone assessments of transportation impacts or a broader examination of climate impacts. Many of these studies have been conducted primarily from the perspective of transportation's contribution to global warming through the burning of fossil fuels. Far less research has examined the economic consequences of climate change for transportation infrastructure and operations. Moreover, there is a dearth of literature on climate change impacts on the international transport sector, particularly in developing economies. It is interesting to note that IPCC multivolume assessment reports (IPCC, 1996; IPCC, 2001) dealt with the issue of transportation in a limited fashion. The 2006 report noted the vulnerability of transportation infrastructure in coastal zones and permafrost regions to climate impacts, while the 2001 report discussed Europe-specific concerns such as impacts on aviation operations and river navigation.

The 2010 U.S. DOT report, *The Potential Impacts of Climate Change on Transportation,* is perhaps the most comprehensive examination of the potential impacts of climate change of greatest relevance for United States transportation, and suggests appropriate adaptation strategies and organizational responses. The study found that climate change would affect United States transportation infrastructure primarily through increases in several types of weather and climate extremes, such as very hot days; intense precipitation events; intense hurricanes; drought; and rising sea levels, coupled with storm surges and land subsidence. The impacts would vary by mode of transportation and region of the country, but they would be widespread and costly in both human and economic terms, requiring significant changes in the planning, design, construction, operation, and maintenance of transportation systems.

U.S.DOT (2010) found that more than half of the United States population now lives in counties with coastal regions, many among the most densely populated in the nation. As retirement magnets and tourism destinations, coastal communities would continue to experience development pressures from extreme weather events. The Atlantic and Gulf Coasts are particularly vulnerable because they have already experienced high levels of erosion, land subsidence, and loss of wetlands. Seven of the 10 largest U.S ports (by tons of traffic), as well as significant oil and gas production facilities, are located on the Gulf Coast, an area whose vulnerability to disruption and damage was amply demonstrated during the 2005 tropical storm season. Sea level rise and coastal flooding also pose risks for the East Coast, as well as the Pacific Northwest and parts of the California Coast.

The vulnerability of United States transportation infrastructure to climate change extends beyond coastal areas. The study found that watersheds supplying water to the St. Lawrence Seaway and the Great Lakes as well as the Upper Midwest river system are likely to experience drier conditions. This could result in lower water levels and reduced shipping capacity. Thawing permafrost in Alaska is already creating settlement and land subsidence problems for roads, rail lines, runways, and pipelines. Higher temperature extremes (mainly heat waves) in some United States regions could lead to more frequent buckling of pavements and misalignment of rail lines. More severe weather events with intense precipitation could see repeats of storms that plagued the Midwest during the 1993 flooding of the Mississippi and Missouri River system, the Chicago area in 1996, and the Houston region during Tropical Storm Allison in 2001.

Extreme weather events, such as intense storms, could disrupt services, including at United States ports, as well as challenge sailing conditions and potentially pose hazards to navigation, ship, cargo, crew and the environment. Difficult sailing conditions could also lead to a modal shift – when technically feasible and economically viable – if other modes are deemed less vulnerable to weather. This may entail further implications for infrastructure investments, fuel consumption and GHG emissions, as well as transportation efficiency and trade facilitation.

The 2010 U.S. DOT report makes the point that not all climate change impacts would be negative. The United States marine transportation sector, for example, could benefit from more open seas in the Arctic, creating new and shorter shipping routes and reducing transportation time and costs. In cold regions, expected temperature rises could mean reduced costs of snow and ice control for departments of transportation and safer travel conditions for passenger vehicles and freight.

The United Kingdom Climate Impacts Programme, an initiative similar to the United States National Assessment, specifically included impacts on the transportation sector in the overall assessment and in each of the regional reports. The Governments of Canada and Australia also have commissioned studies to examine transportation impacts of special interest to them – Canada has concerns with permafrost and interest in the opening of the Northwest Passage; Australia with dry land salinity impacts due to its unusual soil and climatic conditions (Andrey and Mills, 2003; Norwell, 2004).

Nicholls et. al., (2007) assessed the exposure of 136 of the world’s largest port cities to coastal flooding. The top 10 cities in terms of exposed population were Mumbai (India), Guangzhou and Shanghai (China), Miami (United States of America), Ho Chi Minh City (Viet Nam), Kolkata (India), New York (United States of America), Osaka-Kobe (Japan), Alexandria (Egypt) and New Orleans (United States of America). In terms of asset exposure, the most vulnerable cities were Miami, New Orleans (United States of America), Osaka-Kobe, Tokyo (Japan), Amsterdam, Rotterdam (Netherlands), Nagoya (Japan), Tampa–St. Petersburg and Virginia Beach (United States of America).

In a study commissioned by Allianz and World Wide Fund for Nature, Lenton et. al., (2009) estimated that assuming a sea level rise of 0.5 m by 2050, the value of exposed assets in the 136 port megacities will be as high as US$ 28 trillion. This potentially significant risk exposure and the related adaptation costs - which for developing economies would be devastating – are matched by important knowledge gaps about vulnerabilities, impacts and adaptation strategies as well as insufficient levels of preparedness. Indeed, a survey carried out by the International Association of Ports and Harbors, American Association of Port Authorities, and Stanford University revealed that, while 81% of respondent ports consider that climatic changes may have serious implications for the port community, only 31% feel that they are sufficiently informed on the potential risks and costs concerning port operations.

A potentially positive impact of climate change relates to shipping routes, since rising temperature in the Arctic could open some new opportunities for shipping. Many experts expect the Arctic to be ice free before the date projected by the IPCC (i.e. mid-2070). Although current trade lanes are likely to continue serving the bulk of international trade, new trade may emerge with some existing trade being diverted towards northern routes. Currently, ships sail on the main shipping routes using the Panama Canal, South-east Asian straits or the Suez Canal. If the potential Arctic sea lanes were fully open for traffic, savings on distance, time and costs could be achieved. Such a route between Tokyo and New York that is 7,000 km shorter than the route through the Panama Canal, thus saving on time, fuel and transit fees. Taking into account canal fees, fuel costs and other relevant factors that determine freight rates, the new trade lanes could cut the cost of a single voyage by a large container ship by as much as 20%. The savings would be even greater for the megaships unable to fit through the Panama and Suez Canals, and currently sailing around the Cape of Good Hope and Cape Horn.

This would impact on seagoing trade, fuel consumption and GHG emissions, fuel costs and freight rates. It would also entail some implications for ship order books (i.e. ice-class ships), icebreaking services and associated fees. These potential shortcuts could foster greater competition with existing routes, including through a cut in transportation costs, thereby promoting trade and international economic integration. Changing transportation and trade patterns are likely to affect infrastructure investments. Ports and terminals in the Arctic need to be able to berth ice-class ships, equipment needs to be sturdy and adequate, and labor needs to be skilled and specialized.

Many studies also were identified in engineering and transportation journals, ranging from transportation-specific publications such as the National Academy of Science Transportation Research Board's *Transportation Research Review* to more general sources such as *Civil Engineering – ASCE* or the *Journal of Cold Regions Engineering,* and even some transportation trade journals (Barrett, 2004). These studies did not carry an economic perspective on the costs of climate change on transportation.

Finally, though many nongovernmental organizations (NGO) are engaged in research and policy advocacy related to climate change, few NGOs produce literature on climate impacts on transportation. Most noteworthy are the Union of Concerned Scientists and the Pew Center on Global Climate Change. Both NGOs published multiple reports on impacts and adaptation, yet transportation implications have received little direct attention in these reports.

III. ECONOMY OF THE CARIBBEAN SUBREGION AND BARBADOS

F. THE CARIBBEAN

Transportation networks exist to facilitate the movement of people and goods and are integral to the Caribbean's social and economic fabric. The need for these networks, or transportation demand, therefore, is defined by demographic and economic considerations – connecting population centers, providing access to economic resources, and facilitating integration. It is important, therefore, to understand the people and the economy that exist in the Caribbean subregion in order to assess the significance of climate impacts on its transportation systems.

Caribbean countries share many of the characteristics of small island developing States. With a combined nominal GDP of US$60 billion in 2007 and a population of 15.4 million persons, the 14 Caribbean countries in the Caribbean Community (CARICOM) present a relatively small economic size, 20 times smaller than the Brazilian economy. They are very open economies; trade averaged more than 110% of GDP for the region over the period 1998-2007. This economic openness and a limited export base (tourism, sugar, bananas, energy, and alumina) make small Caribbean economies vulnerable to external shocks such as volatility in global commodity prices or policy changes abroad.

Table 2 highlights the Caribbean's fairly respectable growth performance prior to the eruption of the global economic crisis even though the region was not well prepared to manage the multiple external shocks that occurred over 1998-2009. These shocks included reduced aid, dismantling of preferential trade arrangements for sugar and bananas, interventions related to anti-money laundering and combating the financing of terrorism, and the September 11 terrorist attacks. A rising frequency of natural disasters over the period also disrupted economic activity and imposed disproportionate costs. Growth performance has also varied widely across countries in the region and has been widely volatile (World Bank and OAS, 2009).

Table 2: Selected economic indicators for the Caribbean, 1998-2009

% of GDP	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Growth (%)	3.9	3.7	3.1	0.4	1.7	3.7	3.2	4.0	5.1	3.5	1.9	-1.8
Current Account Deficit	12.3	10.9	10.5	13.0	13.6	13.2	9.7	12.8	12.5	17.1	18.2	14.6
Fiscal Deficit	4.2	5.1	5.3	5.1	7.9	5.1	4.2	3.9	3.4	3.4	3.6	5.9
Public Debt	65	75	83	87	98	97	99	94	88	82	80	83

Sources: IMF World Economic Outlook (WEO) database; IMF Article IV Consultation Reports (various issues)

Despite these fairly strong growth rates, regional unemployment rates remain high, averaging more than 10% over 2002-2006. Countries such as Bahamas, Barbados, Belize, Jamaica and Suriname face near double digit unemployment rates. Trinidad and Tobago is the only exception where strong economic growth saw unemployment falling to historical lows of around 5%. In addition, the pace of poverty reduction in the region has been relatively slow and uneven with as much as one-third of the population living on less than US$1 per day.

Persistently large external current account and fiscal deficits as well as high public indebtedness hamper sustainable growth in the Caribbean. The region's external current account deficit averaged almost 13% of GDP in 1998-2007, partly reflecting the concentrated trade structure of Caribbean countries. Foreign direct investment (FDI), a historically stable source of external flows, has financed most of the region's current account deficits. Remittances, particularly from the United States, constitute another important source of external financing but are unable to fully mitigate pressures on the region's balance of payments. The Caribbean is the largest recipient of remittances in proportion to its GDP (Mishra, 2006).

The Caribbean has also been experiencing persistent fiscal deficits, which averaged nearly 5% of GDP over 1998-2007. A large public debt overhang has become a dominant feature of the Caribbean's macroeconomic landscape over the past few years. The region's gross public sector debt climbed rapidly from 65% of GDP in 1998 to a peak of nearly 99% of GDP in 2002, before falling to a still elevated 83% of GDP in 2009. Indeed in 2002, when regional public debt was at its most elevated level, 7 Caribbean countries were ranked among the top 10 most indebted emerging market economies in the world (Sahay, 2005).

The United States subprime mortgage collapse that started in the summer of 2007 morphed into a global economic and financial crisis by the autumn of 2008. World growth prospects deteriorated and in 2009 the global economy entered its deepest recession in 60 years. The global crisis hit the Caribbean economies hard, particularly through spillovers from the United States, the region's most important trading and investment partner. By far the most influence took place through tourism receipts, with trade in goods playing a much smaller role. Many Caribbean countries are also heavily dependent on Foreign Direct Investment (FDI), mainly to the tourism sector, and these financial flows were abruptly curtailed. The reduced flow of remittances from the large base of Caribbean migrants living abroad and financial market spillovers were other major channels of transmission.

The Economic Commission for Latin America and the Caribbean (ECLAC) (2010b), in its Economic Survey of Latin America and the Caribbean revealed a dire situation and bleak prospects for Caribbean countries in the aftermath of the global financial crisis. Other than Guyana and Suriname, all other Caribbean countries experienced negative growth in 2009, the worst performers being the eight countries of the Eastern Caribbean Currency Union, which contracted by almost 7.5%, on average. ECLAC estimated the cost of the global crisis to the Caribbean at a huge 10% of GDP in 2009. The report forecasts a slight recovery of less than 1% for the Caribbean in 2010 but six Caribbean countries are expected to experience further economic contraction, especially Haiti and Antigua and Barbuda.

G. ECONOMY OF BARBADOS

With a per capita income of US$17,700 (PPP, 2009), Barbados has one of the highest standards of living in the Caribbean. It has consistently ranked third in the Americas (after Canada and the United States) on the United Nations Development Programme Human Development Index. Low crime rates, a first-class educational system, a well-educated work force, reliable infrastructure and attractive natural setting are well established characteristics of the Barbados economy. The Global Competitiveness Report 2010-2011 released by the World Economic Forum ranked Barbados third in the region and forty-third out of 139 countries in the world on its competitiveness standing. Barbados has strong public institutions, well-entrenched parliamentary practices and enjoys high political stability (see table 3). A social partnership of government, private sector and unions, established in the early 1990s, facilitates consensus-building on national policies.

Table 3: Key economic, social and political indicators in Barbados [1/]

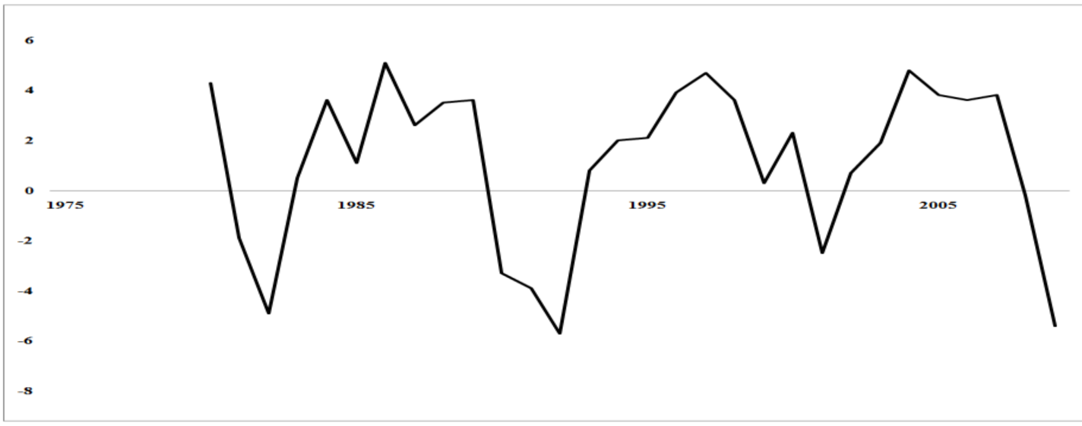
	Barbados	Jamaica	Trinidad and Tobago
Economic Indicators			
GDP per capita (PPP US$, 2009)	17,700	8,400	21,300
S&P Sovereign Rating (2010)	BBB	CCC+	A
Social Indicators			
Human Development Index (UNDP, 2009 rank)	37	100	64
Health & Primary Education Index (WEF, 2010 rank)	14	102	61
Business Climate			
Global Competitiveness Index (WEF, 2010 rank)	43	95	84
Business Sophistication Index (WEF, 2010 rank)	59	81	73
Regulatory Quality (WB, 2009%ile)	65.2	59.0	69.5
Political Indicators			
Corruption Perceptions Index (TI, 2009 rank)	20	99	79
Political Stability (WB ,percentile)	87.7	33.0	44.8

Sources: IMF World Economic Outlook; World Bank (WB) Governance Indicators; World Economic Forum (WEF) Indices; Transparency International (TI); and UNDP.1/ A low rank or high score indicates relative strength

Barbados has successfully moved away from a heavy reliance on the sugar industry towards being a leading destination for high-end tourism and a prime location for offshore financial services and informatics. Travel and tourism accounted for 48% of GDP in 2010, ranking Barbados sixth out of 181 countries in terms of its relative dependence on travel and tourism for driving overall economic activity (WTTC, 2010). Real GDP growth for the travel and tourism economy is projected to average 3.3% per annum over the coming decade. Within its tourism product, Barbados has moved into higher value-added niches for example, health and medical tourism, with significant local employment.

Barbados' trade openness and dependence on tourism and a few other services expose it to geopolitical tensions and cyclical swings. Chart 1 shows much volatility in output of the Barbados economy during 1980-2009, including a major crisis in the early 1990s and a recession after the September 11th attacks. Moreover, while the 33-year peg to the United States dollar enjoys strong support and credibility, vulnerabilities arise from high public debt and a sizeable current account deficit. Public debt rose from 74% of GDP in 2001 to 96% of GDP in 2009. In addition to this fragile debt position, the external situation has worsened significantly, with the current account deficit averaging close to 9% of GDP over the last seven years. These imbalances left Barbados highly exposed to spillover effects from the global financial crisis, which hit the island hard.

Chart 1: Economic growth in Barbados, 1980-2009 (percent)



Source: IMF World Economic Outlook (WEO) Database

According to an International Monetary Fund Public Information Notice issued in December 2010, the global crisis severely impacted the Barbados economy, especially its key sectors - tourism, financial services, and real estate. Real GDP contracted by nearly 5.5% in 2009, after expanding on average by about 3% during the previous five years. Despite a variety of policy measures to alleviate the impact of the crisis, the level of economic activity is expected to remain flat in 2010 and to rebound gradually, but downside risks persist mainly from the uncertain global economic environment. Tourism receipts remain constrained by weak consumption growth in the North America and United Kingdom markets, which are important drivers for the country's international transportation and related industries.

IV. THE INTERNATIONAL TRANSPORTATION SYSTEM IN THE CARIBBEAN AND IN BARBADOS

H. AIR TRANSPORTATION IN THE CARIBBEAN

Air transportation comprises airports and ground facilities, as well as the airplanes that carry both passengers and freight and the air traffic control system. 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 region 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 the region's travel needs, particularly in the tourism industry. The region's tourism industry attracted approximately 20 million visitors in 2009 (WTTC, 2010) showing a modest annual growth of around 1.5% over the past decade. In addition, the Caribbean accounted for between 13%-15% of total international arrivals to the Americas during 2000-2009.

Table 4: Socio-economic importance of travel and tourism in the Caribbean

Country	Travel & Tourism % of GDP (World Ranking, 2010)	GDP Per Capita (PPP, US$, 2009)	% Visitors Arriving by Air
Anguilla	61.0 (5)	12,200	84
Antigua & Barbuda	78.5 (1)	17,800	95
Bahamas	46.5 (8)	29,700	88
Barbados	48.1 (6)	17,700	92
Belize	28.2 (17)	8,300	85
Bermuda	11.2 (65)	69,900*	86
British Virgin Islands	43.7 (10)	38,500*	94
Cayman Islands	23.3 (24)	43,800*	67
Dominica	23.3 (23)	10,200	88
Grenada	24.4 (22)	10,300	96
Guyana	11.5 (63)	6,500	99
Haiti	7.0 (125)	1,300	N/A
Jamaica	25.4 (20)	8,400	92
Montserrat	N/A	3,400**	99
St. Kitts & Nevis	30.5 (16)	14,700	91
St. Lucia	35.1 (13)	10,900	90
St. Vincent & the Grenadines	23.6 (23)	10,200	98
Suriname	4.6 (164)	9,500	93
Trinidad and Tobago	10.9 (66)	21,300	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

Table 4 illustrates some striking facts about the socio-economic importance of air transportation in the Caribbean. First, 13of the 19 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 13 ranking in the top 25 most tourism dependent countries (WTTC, 2010). Second, there appears to be a wide variation in per capita income among the selected countries, from the Bahamas which is the third ranked in the Western Hemisphere to Haiti which is the poorest country in the Americas. Third, almost all the 19 countries listed depend on air transportation to bring in long-stay visitors, who generally contribute more to total foreign exchange earnings than short-stay cruise passengers.

Table 5: List of Caribbean airports and home based airlines

Country	Main Airport (s)	Airport Volumes (000, 2006)	Home Based Airlines
Anguilla	Wallblake (AXA)	131	None
Antigua & Barbuda	V.C. Bird (ANU)	920	LIAT (LI)
Bahamas	Nassau (NAS), Freeport (FPO), Marsh Harbour (MMH)	3,233	Bahamasair (UP), Southern Air Charter (PL)
Barbados	Grantley Adams (BGI)	2,365	None
Belize	Philip Goldson (BZE)	480	Maya Island Air (AW), Tropic Air (PM)
Bermuda	L.F. Wade (BDA)	898	None
British Virgin Islands	Tortola (EIS)	562	None
Cayman Islands	Owen Roberts (GCM), Cayman Brac (CYB)	960	Cayman Airways (KX)
Dominica	Melville Hall (DOM)	168	None
Grenada	Point Salines (GND)	421	None
Guyana	Cheddi Jagan (GEO)	426	None
Haiti	Port-au-Prince (PAP)	1,123	Tropical Airways (M7)
Jamaica	Sangster (MBJ), Norman Manley (KIN)	4,874	Air Jamaica (JM)
Montserrat	John A. Osborne (MNI)	22	None
St. Kitts & Nevis	Robert Bradshaw (SKB)	270	None
St. Lucia	Hewanorra (UVF), George F.I. Charles (SLU)	910	None
St. Vincent & Grenadines	E.T. Joshua (SVD)	580	None
Suriname	Johan Adolf Pengel (PBM)	480	Suriname Airways (PY)
Trinidad and Tobago	Piarco (POS), Crown Point (TAB)	3,172	Caribbean Airlines (CAL)
Turks & Caicos Islands	Providenciales (PLS)	786	Air Turks & Caicos (RU)

Source: Warnock-Smith (2008)

The region's air transportation sector 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 regional based carriers also make a notable contribution to the tourism sector as well as to the travel needs of local residents. Table 5 provides a full list of airports and airlines based in the Caribbean along with airport traffic flow data for 2006.

In the tourist dependent economies such as Antigua and Barbuda, 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. This is evident in the cases of Jamaica, Trinidad and Tobago, the Bahamas, Cayman Islands and Antigua and Barbuda although there are also exceptions to this general rule for example, Barbados – no airline, and Suriname - low activity with national airline.

Foreign visitors to the Caribbean subregion generally come from a few source markets in North America and Europe. Intra-regional flows form a relatively minor share of the extra-regional air passenger traffic arriving into the region's airports. By comparison, both European Union and United States markets have sizeable domestic markets and a wider range of international source markets. These two factors make it difficult for Caribbean countries to exercise any degree of control over developments in these traditional source markets. Socio-economic changes in the United States or in European countries arising from a new regulatory framework for the treatment of air transportation GHG emissions would undoubtedly have a pronounced effect on air traffic volumes into the Caribbean.

Local air carriers in the Caribbean have a track record of poor financial performance and have received several rounds of blanket subsidies by the region's stakeholder governments. Carriers such as Leeward Islands Air Transport (LIAT), Air Jamaica, Bahamasair and Caribbean Airlines have typically suffered from inefficiencies stemming from a lack of access to scale economies, weak capitalisation, preferential lease and fuel rates and relaxed labor markets. Frequent government interference in strategic, network and operational decision making has worsened the situation (Warnock-Smith, 2008).

In the absence of deep alliances or strategic cooperation between the region's carriers (or between regional and foreign carriers), the Caribbean has not been able to create a competitive airline hub. As a result, the two main hubs of CARICOM and the wider Caribbean currently lie outside the region (San Juan, Puerto Rico (SJU) and Miami (MIA)). Foreign carriers command the lion's share of capacity on United States- and United Kingdom-CARICOM routes, whereas local carriers provide the majority of intra-CARICOM services.

I. SEA TRANSPORTATION IN THE CARIBBEAN

Marine transportation infrastructure includes ports and harbors and supporting intermodal terminals and the ships and barges that use these facilities. 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.

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 countries very open economies. Merchandise trade to GDP ratios for the commodity-based economies in CARICOM averaged more than 100% over the past decade, while those for the services-based (mainly tourism) economies ranged between 60-75% over the same period.

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-United States of America average (see table 6). On average, 277 Twenty Foot Equivalent Units (TEU) containers were deployed per voyage on the Caribbean-Imports/USA trade in comparison to 584 TEU containers for the World-Imports/United States of America trade, for the period under review. Low cargo volumes in many small Caribbean islands can only reasonably support one public port.

Table 6: Deployed capacity per voyage for different trade lanes

(Imports to the U.S., 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

Low 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 transshipment services. Table 7 shows the number of inter-regional liner shipping services to the Caribbean. Four direct services from Europe and 13 direct services from North America call on countries with a larger trade volume, such as Jamaica and Trinidad and Tobago, whereas there is no single direct service from Europe and only a few services from North America for the smaller countries in the Caribbean.

Table 7: Inter-regional Liner shipping services in the Caribbean, June 2000

Country or Island	Number of Regular Liner Shipping Services	
	From/To Europe	From/To North America
Antigua & Barbuda	0	6
Anguilla	0	2
Aruba	1	3
Bahamas	0	2
Barbados	2	8
Belize	0	1
Bermuda	0	4
Bonaire	0	1
Cayenne	3	0
Cayman Islands	0	5
Colombia	13	14
Costa Rica	8	11
Cuba	2	0
Curacao	2	4
Dominica	0	3
Dominican Republic	6	18
El Salvador	0	1
Grenada	0	2
Guadeloupe	4	3
Guatemala	2	26
Guyana	3	4
Haiti	0	8
Honduras	2	22
Jamaica	4	20
Martinique	4	3
Montserrat	0	1
Nevis	0	2
Nicaragua	0	2
Panama	0	2
St. Barthelemy	0	2
St. Croix (Virgin Islands)	0	4
St. Eustatius	0	1
St. John (Virgin Islands)	0	2
St. Kitts	0	3
St. Lucia	0	6
St. Maarten	0	5
St. Thomas (Virgin Islands)	0	4
St. Vincent	0	4
Suriname	3	2
Tortola (Virgin Islands)	0	2
Trinidad and Tobago	4	13
Turks and Caicos	0	2
Venezuela	7	20
Virgin Gorda (Virgin Islands	0	2

Source: Sanchez (2009)

Insufficient sea transportation volumes lead to multiple port calls for a limited amount of cargo and result in higher ocean freight costs and port charges. In addition, smaller volumes force carriers to operate smaller vessels so the Caribbean region is unable to reap economies of scale in terms of lower transportation costs per unit. Apart from trade volumes, other factors such as the composition of trade, port dues and tariffs, and waiting times in ports impact on total transportation costs. The United Nations Conference on Trade and Development (UNCTAD) (2010b) stated that there is a relationship between maritime transportation, foreign trade and economic growth. In particular, inefficient sea transportation hampers trade and the development of non-maritime industries and services. Less expensive transportation then 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 schedules, otherwise known as "transshipment." In the Caribbean, the major transshipment 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 where cargo is distributed mainly to the southern Caribbean.

Almost all big shipping carriers that operate in the Caribbean are at these transshipment 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 be transshipped twice until it reaches its final destination, which raises overall transportation costs. More port calls also raise the level of GHG emissions. 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.

J. AIR TRANSPORTATION IN BARBADOS

Air transportation in Barbados is organized around catering to the demands of tourists, both extra and intraregional, and other visitors, numbering just under 520,000 arrivals in 2009 (see table 8). The United Kingdom is the largest market, accounting for over 35% of total market share in 2009. Increased airlift capacity out of the United Kingdom has facilitated increased arrivals from that country. There are eight carriers providing services out of the United Kingdom. The United States is the second largest market with nearly 25% of the total market. Four carriers service the United States route. There are also significant intra-Caribbean movements, almost 90,000 arrivals in 2009 or nearly 17% of all arrivals. Trinidad and Tobago commands the single largest share of the intra-Caribbean market, accounting for 5% of total arrivals in 2009. The non-UK European market, which has experienced a reduction of airlift and increased competition from cheaper tourist destinations, still managed to retain a market share ranging between 5%-6% over 2005-2009.

Barbados has one airport, Grantley Adams International, which lies 12.9 km from the centre of the capital city, Bridgetown, in an area officially known as Seawell. The terrain around the airport is relatively flat and quite suburban. The airport lies in the south-eastern portion of the parish of Christ Church, close to the southern tip of the island. The airport is provided with easy access to the ABC highway/Highway 7 heading towards the capital and locations to the north and west coast of the island. The Government of Barbados had recently completed a major US$100 million upgrade and expansion airport programme, which has doubled peak period capacity. The airport's current infrastructure is supposed to meet the needs of Barbados until at least 2015.

Table 8: Air passenger arrivals to Barbados by country of residence, 2005-2009

Country	2005	2006	2007	2008	2009	2009 Share (%)
United States	131,005	130,767	133,519	131,795	122,306	23.6
Canada	47,690	49,198	52,981	57,335	63,751	12.3
United Kingdom	202,765	211,523	223,575	219,953	190,632	36.8
Other Europe	26,852	29,400	27,198	31,825	30,072	5.8
Trinidad and Tobago	30,889	34,480	30,404	28,385	26,289	5.1
Other CARICOM	97,134	82,989	68,979	72,254	62,482	12.0
Rest of the World	11,199	24,201	36,281	26,120	23,032	4.4
Total	547,534	562,558	572,937	567,667	518,564	100.0

Sources: Caribbean Tourism Organization, Barbados Statistical Service

Barbados does not have its own national airline and does not have an “open skies” agreement with the United States. However, the United States has used its discretion in the past to allow regional carriers, such as Air Jamaica and Caribbean Airlines to provide services on routes granted under the Barbados/United States of America Bilateral Air Services Agreement (BASA). The Grantley Adams International Airport has direct service to destinations in Canada, Central America, South America and Europe and operates as a major gateway to the Eastern Caribbean (table 9). The airport is a second hub for (LIAT). As there is no direct commercial air service to the United States by carriers registered in Barbados, the United States Federal Aviation Administration has not assessed the Government of Barbados’ Civil Aviation Authority for compliance with (ICAO), aviation safety standards.

K. SEA TRANSPORTATION IN BARBADOS

In 2008, the total value of trade in goods in Barbados amounted to US$2.1 billion or 60.5% of GDP. Chart 2 shows the significance of different trading regions for Barbados, both in terms of imports and exports. In terms of imports, the United States is by far the most important trading partner for Barbados accounting for 36.5% of total merchandise imports. Trinidad and Tobago ranks second and accounts for 25.3% of total imported products. Other major trading partners are the United Kingdom (5.2%), Japan (3.6%), and Canada (3.5%). Outside of Trinidad and Tobago, Barbados has little merchandise import trade with other CARICOM countries.

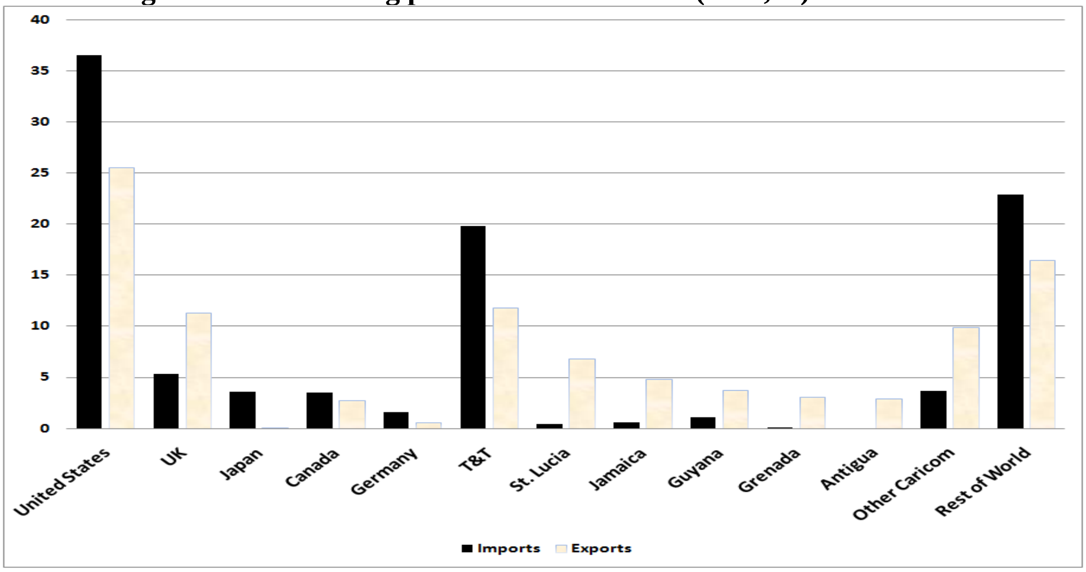
Table 9: Major airlines serving Barbados and other destinations

Airline	U.S.	Canada	U.K.	Other Europe	Caribbean
Air Canada		Montreal, Toronto - Pearson			
Air Jamaica	New York				Grenada, Jamaica
American Airlines	Miami, New York				
American Eagle					Puerto Rico
BMI			Manchester		
British Airways			London, Gatwick		Trinidad and Tobago
Caribbean Airlines					Antigua, Guyana, Port of Spain, St. Maarten, Jamaica, Tobago
Condor Airlines				Frankfurt, Germany	
Delta Air Lines	Atlanta				
First Choice Airways			London-Gatwick, Manchester		
LIAT					Antigua, Castries, Georgetown, Kingstown, Port of Spain, Tobago, St. George's, Martinique
Livingston Energy Flight				Milan-Malpensa	
Monarch Airlines			London-Gatwick, Manchester		
Mustique Airways					Bequia, Canouan, Kingstown, Mustique
Skyservice		Toronto-Pearson			
Sunwing Airlines		Toronto-Pearson			
SVG Air					Bequia, Kingstown, Mustique, Union Island
Thomsonfly			Birmingham, Manchester		
Thomas Cook Airlines			Belfast-International		
US Airways	Charlotte, Philadelphia				
Virgin Atlantic			London-Gatwick, Manchester		
WestJet		Toronto-Pearson			

Source: Grantley Adams International Airport

For exports, the situation is different, as Chart 2 illustrates. Over 43% of the merchandise exports of Barbados are shipped within CARICOM. Most of this intra-regional export trade is to Trinidad and Tobago (11.8%), Saint Lucia (6.8%), and Jamaica (4.8%). Outside of the Caribbean region, the United Kingdom accounts for 11.3% of Barbados' total merchandise exports.

Chart 2: Significance of trading partners for Barbados (2007,%)



Source: Barbados Statistical Office

Total tonnage handled at the Bridgetown Port terminal typically relates to import, export and transshipment 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 (table 10).

Table 10: Barbados port total containers discharged by Shipping Line

(TEUs, 2007)

Shipping Line	Local	Transshipment	Empty	Total	%
BERNUTH	5,754	283	56	6,093	12.2
CAT	4,182	28	14	4,224	8.5
CMA CGM	6,289	270	281	6,840	13.8
EWLU	871	65	18	954	1.9
GEEST	2,150	344	147	2,641	5.3
SBML	4,531	210	56	4,798	9.7
TROPICAL	9,116	6,326	1,782	17,224	34.7
ZIM	6,753	52	115	6,920	13.9
Total	39,646	7,578	2,475	49,699	

Source: Barbados Port Inc. Annual Report 2007

While tourism in Barbados is predominantly driven by higher spending air arrivals, the cruise market has been strong and growing. According to the Caribbean Tourism Organization (CTO), cruise ship passenger arrivals to Barbados amounted to almost 648,000 persons in 2007. More than 485 cruise ship calls were made in 2007. Barbados is seeking to develop its potential as a hub connecting air and cruise traffic. It has invested in upgrading facilities to accommodate cruise ships.

Table 11: Barbados cruise ship industry, 2005-2009

	2005	2006	2007	2008	2009
Cruise Passenger Arrivals	563,588	539,092	647,636	597,523	635,746
Cruise Ship Calls	395	440	486	425	261

Source: Caribbean Tourism Organization

V. VULNERABILITY OF INTERNATIONAL TRANSPORT SYSTEM IN BARBADOS TO CLIMATE CHANGE

Barbados is the most easterly of the islands of the Lesser Antilles with an area of 431 km^2. It is located in the Atlantic Ocean, at 13° 4' north latitude and 59° 37' west longitude. It is bordered by the Caribbean Sea on the west coast and the Atlantic Ocean on the east, with a coastline of 97 km, and an exclusive economic zone of about 167, 000 km^2. No comprehensive inventory exists of the vulnerability of Barbados' international transportation infrastructure to climate change impacts, the potential degree of exposure, and the potential damage costs. Nevertheless, some salient data can be pieced together to provide a reasonable enough perspective upon which transport professionals and decision makers can act.

L. ANTHROPOGENIC EFFECTS

Barbados relies on imported refined product to meet nearly all (about 95%) of its power and transportation fuel needs. This makes the country's air and sea transport infrastructure very vulnerable to disruptions in fuel supplies. Less than 15% of the refined product comes from domestic oil production. Domestically produced natural gas provides less than 5% of total energy needs. In the 1950s when 22 sugar factories were operating, Barbados generated half of its energy from renewable sources (ECLAC, 2010a).

Table 12 shows the carbon dioxide (CO_2) emissions for selected Caribbean countries in 2006. Barbados is ranked fifth out of 14 countries in the Caribbean and with emissions of 1.33 metric tons per capita is not considered a main emitter of CO_2 in the region. The annual average growth rate of CO_2 emissions in Barbados was the third smallest in Latin American and the Caribbean in 1990-2005. The per capita emission level in Barbados is almost evenly balanced between fossil fuel consumption and liquid fuel consumption.

Table 12: Carbon dioxide emissions for selected Caribbean countries (2006)

Country	Total Emissions by Activity (thousand metric tons)					
	Per capita Emissions (metric tons)	Fossil Fuel Consumption	Solid Fuel Consumption	Liquid Fuel consumption	Gas Fuel Consumption	Cement Production
Anguilla	1.00	14	-	14	-	-
Antigua and Barbuda	1.38	116	-	116	-	-
Aruba	6.12	630	-	630	-	-
Barbados	1.33	365	-	307	-	-
Dominica	0.47	32	-	32	-	-
Grenada	0.62	66	-	66	-	-
Guyana	0.54	411	-	411	-	-
Haiti	0.06	494	-	453	-	41
Jamaica	1.24	3,314	23	3,187	-	103
Netherland Antilles	6.21	1,176	-	1,176	-	-
St. Kitts and Nevis	0.86	37	-	37	-	-
St. Lucia	0.62	104	-	104	-	-
St. Vincent and the Grenadines	0.53	54	-	54	-	-
Trinidad and Tobago	6.90	9,164	-	1,365	7,679	120

Source: USAID 2009 Latin America and the Caribbean Selected Economic and Social Data

Barbados is seeking to expand the sources of renewable energy production, which can significantly contribute to reducing the overall vulnerability of its international transport infrastructure to climate change. 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, 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.

M. TEMPERATURE AND PRECIPITATION

Barbados experiences a tropical, oceanic climate. Inter-annual variability in the southern Caribbean climate is influenced strongly the El Niño Southern Oscillation. El Niño episodes bring warmer and drier than average conditions during the late wet-season and La Niña episodes bring colder and wetter conditions at this time.

The mean temperature in Barbados is around 27°C, dropping by only a degree or so in the cooler months of December to February. The highest temperatures (generally about 31°C) are experienced in the summer months of May to September. The observed mean annual temperature in Barbados has increased at an average rate of 0.14°C per decade over the period 1960-2006 (Simpson, 2010). According to projections from the PRECIS Regional Circulation Model at the Institute of Meteorology (INSMET) in Cuba, by 2030 the mean annual temperature in Barbados is projected to rise by 0.8°C relative to 1970-1999. Temperatures are expected to rise by 1.25°C by 2050. Moreover, locally, phenomena such as ocean acidification, which is likely to affect coastal lowlands in countries like Barbados, could even see mean changes in temperature of up to 3°C in some places (Martin, 2010).

Warming temperatures and possible increases in temperature extremes will affect the ground facilities at the Grantley Adams International Airport runways in particular - in much the same way that they will affect roads. More heat extremes could cause heat buckling of runways. Extreme heat can also affect aircraft lift; hotter air is less dense, reducing mass flowing over the wing to create lift. If runways at the Grantley Adams International Airport are not sufficiently long for large aircraft to build up enough speed to generate lift, aircraft weight must be reduced or some flights canceled altogether. Thus, increases in extreme heat are likely to result in payload restrictions, flight cancellations, and service disruptions, and could require the Grantley Adams International Airport to extend runway lengths, if feasible.

Barbados has a marked dry season from December to May (peaking in February-March), where mean rainfall is about 50 mm per month; and a wet season from June to November, when monthly rainfall can more than triple that of the dry season. Observed mean annual precipitations in Barbados indicate a slight positive change per decade over the period 1960-2006 (Simpson, 2010). According to projections from the PRECIS Regional Circulation Model at INSMET in Cuba, the mean annual precipitation in Barbados is expected to decrease over the next 40 years but displays a large variability that makes it difficult to properly identify any long-term trend.

N. EXTREME EVENTS

Climate scientists believe that more intense tropical storms are a likely effect of climate change. Three aspects of tropical storms are relevant to transportation: precipitation, winds, and wind-induced storm surge. Strong storms tend to have longer periods of intense precipitation; wind damage increases with wind speed; and wind-induced storm surge and wave action can have devastating effects. Barbados lies on the southern edge of the Atlantic hurricane belt and is rarely, but occasionally, affected by hurricanes which occur throughout August, September and October. Table 13 shows the top five natural disasters that have affected Barbados in 1990-2010. According to the Centre for Research on Epidemiology of Disasters, Barbados has spent upwards of US$107 million in economic damages due to natural disasters mainly tropical storms. On average, Barbados is hit by a tropical storm about every three years, and experiences a direct hit once every 27.8 years.

On 30 October 2010, Barbados was hit by Tropical Storm Tomas, which was later upgraded to a Category One hurricane. The event demonstrated the vulnerability of the island's transportation infrastructure. Excessive rainfall, flooding and high winds resulted in damage to the housing stock, agriculture sector, road infrastructure, downed power lines and disruption to the utilities sector. The Grantley Adams International Airport was closed for one day but subsequently re-opened to international flights. The level of impact to Barbados resulted in the Caribbean Catastrophe Risk Insurance Facility announcing an estimated payout of US$8.5 million.

Table 13: Top 5 natural disasters in Barbados, 1900-2010

Disaster	Date	Number Killed	Total Affected	Economic Damage (US$ mn)
Storm	1987	-	230	100
Storm	2004	1	880	5
Storm	1980	-	5,007	1.5
Flood	1970	3	210	0.5
Storm	2002	-	2,000	0.2

Source: EM-DAT, the OFDA/CRED International Disaster Database, Université Catholique de Louvain, Brussels, Belgium

O. SEA LEVEL RISE

With most of its population living along southern and western coasts of the island and over 90% of the country's hotel rooms built on the coast, transport infrastructure in the coastal zone of Barbados is an important connector to communities and the dominant tourism sector, and a vital lifeline to the country, as a whole. Current measurements at tidal gauging stations around the Caribbean indicate average sea level rises of around 1.5 to 3 mm per year (Simpson, 2010). Housing, hotel and coastal transport networks in many parts of Barbados are currently at risk from coastal flooding related to storm surge. Sea level rise will worsen the situation, with associated infrastructure damage and service interruptions. Roadways that presently serve as evacuation routes during hurricanes may be compromised in the future.

Facilities of both the Port of Bridgetown and the Bridgetown Cruise Terminal – important transport assets with long design lives – are located in the coastal zone and will be affected by increased sea level rise. Compared with current conditions, decking and wharves will be exposed more frequently to larger uplift forces, ships will ride higher at the wharf, and cargo handling facilities will have less access to all parts of a ship. Loading and unloading may have to be scheduled for low tide periods to allow greater access into the ship, or else mooring and cargo handling facilities will need to be elevated. At a minimum, they are likely to result in increased 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 harbor) resulting in increased scour of foundations of marine structures. Changes due to increased sea level rise could require some retrofitting of facilities. On the positive side, a rise in sea level will provide opportunities for the Port of Bridgetown to accommodate deeper draught vessels and undertake less dredging to maintain required channel depths.

However, even if the port's infrastructure and operations are not unduly affected by climate change, because the port authority is taking steps to adapt to such changes, its commercial wel-lbeing is critically dependent on secure transport links to other parts of Barbados. The port may be adversely affected by interruptions in passenger and freight traffic caused by transport delay following damage to road infrastructure. Thus, aside from the port itself, the vulnerability of its key road links also need to be considered in the context of climate change. In this regard, the Port of Bridgetown has a high transport link risk profile; it is a single mode connection (all freight arrives by road) with low-lying sections susceptible to inundation from future sea level rise.

P. PHYSICAL IMPACTS

The main physical impacts stem from loss of air and sea ports since these facilities are located close to the coastline. The Sir Grantley Adams International Airport lies close to the southern tip of Barbados. Any climate-related damage to the runway and other airport facilities, which were upgraded and expanded at about 3% of GDP at 2008 current prices, would not only have a serious negative impact on the island's tourism industry but also on much of the rest of the Eastern Caribbean, a region to which the airport serves as a major gateway.

Both the Port of Bridgetown and the Bridgetown Cruise Terminal are almost wholly dependent on coastal infrastructure. The port completed a US$50 million (1.5% of GDP) infrastructural upgrade project in 2007. The Cruise Terminal is the centre for all services relating to cruise passengers and crew members visiting Barbados. The offices of customs, immigration, port health, plant and animal quarantine, post office and the Barbados Tourism Authority are all located in this area (Simpson, 2010). Severe damages that require facilities of either the port or cruise terminal or both to be closed for an extended period would lead to costly structural repairs and loss of revenue.

The network character of the transportation system usually helps to mitigate the impact of a shock to the system, as shipments can be shifted to alternative ports to pick up the interrupted service. Unfortunately, since Barbados has only one air and sea port, this works to magnify the effects of a shock to the system, particularly when critical links are damaged or destroyed.

VI. MODELING FRAMEWORK

Q. LITERATURE REVIEW

Economic growth, higher disposable incomes and increased leisure time on the demand side, combined with falling real airline tariffs and technical change on the supply side, are important driving forces behind the long-term growth of international air transportation. Many statistical models exist for predicting the demand for air travel. Some of the models discussed in the literature include Box-Jenkins approach which is useful for modelling a time series with seasonal components (Anderson 1976); market-share model which is based on estimating a proportion of the regional or national level of activity assigned to the local level, usually assumed to be a regular predictable quantity. In this method, the existence of a data source minimizes the cost of forecasting but it neglects abnormal growth factors at the local level (Uddin et al., 1986). However, multiple regression is considered the most reliable method for forecasting air travel demand (Uddin et al. 1986). The model relates variations in air traffic to variables of different socio-economic factors of the residents and seeks to derive an equation for demand in terms of price and other relevant variables. Multiple regression methods are designed to account also for variables in non-price factors.

The most studied determinant of transportation cost is geography, particularly distance. The greater the distance between two markets, the higher the expected transportation costs. For air carriers, the cost variable most affected by distance is fuel cost, which represented between 12% and 15% of airlines' total operating costs during most of the 1990s (Doganis, 2001). The impact of distance on countries' volume of trade is significant. Estimates of the elasticity of trade volumes with respect to distance indicate that when distance increases by 10%, the volume of trade is reduced between 9% and 15% (Overman, Redding and Venables, 2003).

IMO (2008) estimates future fuel use and emissions from shipping activity between 2020 and 2050. The model is based on three driving variables (shipping transportation demand, transportation efficiency and embodied fuel energy) which, in turn, are related to a number of secondary variables e.g. population, global economic growth, ship design, vessel speed, cost and availability of fuels, and technical efficiency improvements). Macroeconomic, energy use and demographic variables are drawn from IPCC SRES family of scenarios and extrapolations of historic trends are adjusted according to specific factors such as pipeline construction, iron scrap demand and new sea routes that are likely to have an impact on maritime transportation demand. These adjustments reduce maritime transportation demand projections by up to half of what might otherwise have been expected by extrapolating past GDP-maritime transportation activity trends.

The literature on the demand for air and sea transportation indicates that international trade and travel flows between the destination and source countries can be explained using a demand function. Most studies use the number of air arrivals and the volume of sea-borne freight as the measures of air and sea transportation flows, respectively. In this study, however, expenditure on both air and sea transportation has been used as the dependent variable. This is because one of the main objectives of the study is to calculate the cost of climate change to the air and sea transportation industry. By directly employing the expenditure variable it means the process of calculating forecasted cost is not complicated by the transformation of the volume data to expenditure after the model is estimated.

R. INTERNATIONAL TRANSPORTATION DEMAND FORECASTING MODEL

From the literature review, the demand model for air transportation (AT) was constructed as a function of per capita income of Barbados (BPCI), the average economic growth rate of the major trading partner countries (United States, Canada, United Kingdom and Germany) (G-4GDP), crude oil prices (OIL), the change in annual mean temperature (ΔT), and the change in annual mean precipitation (ΔP).

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

Similarly, the demand model for sea transportation (ST) was constructed as a function of the following independent variables: total imports in Barbados (M), economic growth in Barbados (BGROWTH), crude oil prices (OIL), the change in annual mean temperature (ΔT), and the change in annual mean precipitation (ΔP).

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

In this study oil prices are used to proxy travel costs due to the unavailability of travel cost data over the sample period. It is expected that these two variables would be highly correlated. A priori, it is expected that the income variables would be positively associated with international transportation demand and that oil prices and the two climate variables would have a negative relationship with international transportation demand.

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:

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

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

Both air and sea transportation demand models used in this study are consistent with demand theory and are augmented by two climate variables. Air travel to the Caribbean has few close substitutes, as nearly all travel on the route is by air. Thus one can ignore another dimension of price which is relevant when several modes of transportation are available, the amount of time spent in travel. The general demand function is therefore relatively simple keeping in mind the concept of parsimony.

S. DATA COLLECTION AND ECONOMETRIC ANALYSIS

Several sources were used to collect the data used in the study over the sample period 1980-2009. Information on international transport expenditure, economic growth, per capita income and imports for Barbados were sourced from the statistics centre of the Central Bank of Barbados. The income variables for the trading partner countries and the oil price data were collected from the World Economic Outlook database of the International Monetary Fund. The two climate variables (mean temperature and mean precipitation) were obtained from the Center for Climatic Research, Department of Geography at the University of Delaware. Annual data were employed in this study for two main reasons. First, monthly data were not available in a consistent manner for most of the variables used in the air and sea transportation demand models. Second, the more advanced econometric models make better use of annual data and have superior forecasting performance over the more basic time series models (Song and Witt, 2000). Forecasting performance is also impacted by data frequency and modelling techniques.

Table 14: Variables used in the International Transportation model

Variable	Unit	Source	BAU	A2	B2
Foreign Exchange Earnings from Air Transportation	U.S. mn	Central Bank of Barbados (www.centralbank.org.bb)	X	X	X
Foreign Exchange Expenditure on Sea Transportation	U.S. mn		X	X	X
Per Capita Income of Barbados	US$		X	X	X
Economic Growth in Barbados	%		X	X	X
Total Imports in Barbados	US$ mn		X	X	X
GDP of Four Top Trading Partner Countries	US$ tr	International Monetary Fund (www.imf.org)	X	X	X
Crude Oil Prices	US$/bbl		X	X	X
Δ Mean Annual Temperature	º C	Precis Model at INSMET, Cuba (www.insmet.cu/precis)		X	X
Δ Mean Annual Precipitation	mm			X	X

Source: Data compiled by author

Equations (3) and (4) were estimated by applying a cointegration analysis according to the Johansen (1988) unified maximum likelihood framework. Tables 16 and 17 indicate that the results of the trace test indicate that there is at most one cointegrating relationship for both equations, in respect of the variables specified.

Table 15: Test for Cointegrating sectors – air transportation expenditure

Null hypothesis	Alternative	Eigenvalue trace	
		Statistic	95% critical value
r=0	r>=1	81.32*	68.52
r<=1	r>=2	43.65	47.21

Notes: r = number of cointegrating vector under the null hypothesis.

*Significant at the 5% level. Critical values are taken from Osterwald–Lenum (1992, Table 1).

Table 16: Test for Cointegrating Vectors – sea transportation expenditure

Null hypothesis	Alternative	Eigenvalue trace	
		Statistic	95% critical value
r=0	r>=1	78.49*	68.52
r<=1	r>=2	44.31	47.21

Notes: r = number of cointegrating vector under the null hypothesis.
*Significant at the 5% level. Critical values are taken from Osterwald–Lenum (1992, Table 1).

The results for the error correction models are provided in equations (5) and (6) below (with t-values in parentheses). All of the variables proved to be significant. The climate variables and crude oil prices have a negative relationship with air and sea transport expenditure while increases in per capita income and economic growth lead to increases in international transport expenditure. The model results suggest that temperature is expected to affect the international transport infrastructure in Barbados to a much greater degree than precipitation.

$$\ln AT = 6.32 + 0.72 \ln BPCI + 0.54 \ln G\text{-}4GDP - 0.055 \ln OIL - 3.10 \ln \Delta T - 0.67 \ln \Delta P$$

(5.321) (6.561) (2.389) (-3.721) (-4.215) (-2.824)

n=30; R^2 = 0.6238; Theil U statistic 0.035; MAPE 14.6% (5)

$$\ln ST = 3.38 + 2.57 \ln M + 4.79 \ln BGROWTH - 0.57 \ln OIL - 3.12 \ln \Delta T - 0.55 \ln \Delta P$$

(4.525) (6.515) (2.447) (-3.163) (-5.842) (-4.512)

n=30; R^2 = 0.6988; Theil U statistic 0.041; MAPE 15.9% (6)

The R^2 shows a relatively good fit. The air transportation model is able to predict 62% of the variation in air transport expenditure in Barbados, while the sea transportation can predict close to 70% of the change in sea transport expenditure in Barbados. The forecasting power of both models was evaluated by comparing the forecasts with the actual international transport expenditure demand functions over the ex-post forecasting period, that is, 2000-2009. The mean absolute percentage error (MAPE) and the Theil U statistic suggest that the forecasted variable tracks fairly closely the actual data. The models can therefore be used to generate forecasts of the cost of climate change to Barbados under the relevant scenarios.

VII. ECONOMIC IMPACT ANALYSIS OF CLIMATE CHANGE ON THE INTERNATIONAL TRANSPORT SECTOR

T. TEMPERATURE AND PRECIPITATION

The air and sea transportation demand models are used to generate forecasts of air and sea transportation expenditure for Barbados until 2050. The forecasted expenditure data is used to cost the effects of climate change (temperature and precipitation) on the international transportation sector in Barbados under the A2 and B2 climate scenarios until 2050. The Box-Jenkins approach to forecasting was used to project the economic variables. Forecasts for the two climate variables were received from (INSMET). The predictions from INSMET were obtained from the European Centre Hamburg Model, 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 United States dollars 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, 2010).

Table 18 shows the impact of temperature and precipitation on cumulative international transport expenditure for Barbados under the BAU, A2 and B2 climate change scenarios in respect of air and maritime transportation for four different points in the half-century period: 2020, 2030, 2040 and 2050.

Table 17: Impact of temperature and precipitation on cumulative International Transport Expenditure for Barbados under A2 and B2 Scenarios

(2008 US$ millions)

	Air Transportation			Maritime Transportation			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

In comparison to the BAU scenario, SRES A2 is expected to be the worst case scenario for emissions, and has a heavy impact on climate change and on international transport expenditure. Cumulative air transportation expenditures (in 2008 dollars) in SRES A2 are projected to reach up to US$13,262 million by 2050, an implied loss of some US$5,684 million relative to the BAU scenario over the 40 year period. Air transportation expenditures under SRES B2, which is the lightest impact scenario, reach a cumulative US$15,157 million by 2050, an implied loss of US$3,789 million relative to the BAU scenario over the forecast period.

A similar trend, albeit at a much lower expenditure level (in 2008 dollars), is observed for maritime transportation. Sea transportation expenditures in SRES A2 are projected to reach a cumulative US$1,989 million by 2050, an implied loss of US$853 million when compared to the BAU scenario of US$3,380 million over the 40 year period. Sea transportation expenditures under SRES B2 reach a cumulative US$2,274 million by 2050, generating an implied loss of US$568 million.

For the combined international transportation sector, the total cumulative expenditure (in 2008 dollars) amount to a considerable US$15,251 million under the SRES A2 scenario and US$17,431 million under the SRES B2 scenario. Relative to the BAU scenario, the implied costs to the international transportation sector under the SRES A2 scenario amount to US$6,537 million by 2050, while that for the SRES B2 scenario reach US$4,357 million by 2050.

Evaluating the changes relating to temperature and precipitation in Barbados is just one aspect of assessing the impacts of global climate change in the economics of the international transportation sector in the country. Two other core impacts must be considered. The first relates to the impact of climate change policies on international travel mobility and the second concerns the impact of sea level rise on the international transport infrastructure.

U. CLIMATE CHANGE POLICIES IN ADVANCED COUNTRIES AND INTERNATIONAL TRAVEL MOBILITY

The international community and various national governments are experimenting with carbon taxes and alternative mitigation policies to reduce emissions from air transportation that may impact the international transportation sector in Barbados. The European Union (EU) will become the first to include all flights in and out of its airports to account for emissions as part of the EU cap and trade programmes. The United States is considering similar cap and trade policies. The Aviation Passenger Duty (APD) has been doubled for travellers from the United Kingdom to destinations around the world and is expected to have a significant impact on travel to the Caribbean, including Barbados. Other policies that will affect international travel mobility are voluntary offsets to carbon emissions and the potential for taxation of aviation fuel.

Simpson (2010) estimates that the imposition of APD is likely, on a intermediate scenario basis, to reduce tourist arrivals to Barbados by 6.3% in 2020 and by as much as 25.2% by 2050. Based on these estimates, Table 19 gives the cumulative loss in international transport expenditure in Barbados due to the impact of climate change policies in advanced countries on international travel mobility. The potential cumulative economic loss for air transportation under the SRES A2 scenario is US$3,342 million and under the SRES 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 SRES A2 scenario is US$501 million and under the SRES B2 scenario is US$573 million. The cumulative economic loss for the international transport sector in Barbados arising from the climate change policies in advanced countries is US$3,843 million by 2050 under the SRES A2 scenario and US$4,393 million under the SRES B2 scenario over the forecast period.

Table 18: Impact of climate change policies in advanced countries on international travel mobility in Barbados under A2 & B2 Scenarios

(2008 US$ millions)

	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

V. SEA LEVEL RISE AND INTERNATIONAL TRANSPORT INFRASTRUCTURE

The other layer added to the analysis and methodology is the impact of sea level rise on the international transport infrastructure in Barbados. Sea levels are expected to continue to rise for many decades or centuries in response to warmer atmosphere and oceans (Simpson et. al. 2010). Sea level rise and the resulting erosion impacts are considered to be among the most serious long-term threats of global climate change. Sea level rise will have a three-fold impact: land loss, international travel expenditure loss and rebuilding cost.

Estimates of potential sea level rise 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 one-third to air transport infrastructure and two-thirds to the sea port infrastructure. Table 20 gives the details of the calculations for land loss in Barbados.

Annual international travel expenditure loss is estimated by assuming a loss of amenity factor, where sea level rise 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 ° Celsius in temperature would make the Caribbean less attractive to visitors in the range of 15%-20%. Simpson (2010), in analyzing 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 is made 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.

Table 19: Impact of sea level rise on international transport infrastructure in Barbados under A2 and B2 climate change scenarios by 2050

(2008 US$ millions)

	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**

Source: Data compiled by author

The total rebuilding cost for Barbados resulting from damage due to sea level rise 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 RECC project, we assume about 80% of this value for the SRES A2 scenario and 40% for the SRES B2 scenario as the losses that will be generated by 2050.

In summary, 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 SRES A2 scenario and some US$3,969 million by 2050 under the SRES 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.

W. TOTAL IMPACT OF CLIMATE CHANGE ON INTERNATIONAL TRANSPORTATION

The total cost of climate change on international transportation in Barbados was calculated by combining the impacts of changes in temperature and precipitation, new climate policies and sea level rise. Table 21 gives the breakdown of these costs and shows that the impact for air transportation could range from US$10,727 million (SRES B2 scenario) to US$12,279 million (SRES A2 scenario) and for maritime transportation impact estimates range from US$1,992 million (SRES B2 scenario) to US$2,606 million (SRES A2 scenario). For international transportation, as a whole, the impact of climate change varies from US$12,719 million under the SRES B2 scenario to US$14,885 million under the SRES A2 scenario.

Table 20: Total impact of climate change on international transport expenditure in Barbados under A2 and B2 scenarios to 2050

(2008 US$ millions)

	Air Transportation		**Maritime Transportation**		**International Transportation**	
	A2	**B2**	**A2**	**B2**	**A2**	**B2**
Changes in Temperature & 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**

Source: Data compiled by author

Table 22 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 SRES A2 scenario amount ranges from US$6,064 million (4% discount rate) to US$10,759 million (1% discount rate). The net present value under the SRES B2 scenario varies from US$5,300 using a 4% discount rate to US$9,405 million under a 1% discount rate.

Table 21: Net Present Value of Total Impact of Climate Change on International Transportation in Barbados to 2050 under Scenarios A2 and B2
(2008 US$ millions)

Discount Rate (percent)	Air Transportation		Maritime Transportation		International Transportation	
	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

VIII. APPROACHES TO MITIGATION AND ADAPTATION IN THE AIR AND SEA TRANSPORTATION SECTORS

X. MITIGATION STRATEGIES

The technological and operational potential for mitigating international and domestic GHG emissions from aircraft and sea vessels is considerable. Table 23 shows the range of mitigation options available over the short, medium, and long term to slow the growth of energy consumption and GHG emissions from international transportation. 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 and air traffic management 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 bio-fuels, 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 for example 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.

Table.22: International Transport - Summary of GHG reduction potentials in 2050 by mitigation option

Sector	Category	Measure	Reductions Under BAU Conditions (% in 2050)	Additional Reductions from BAU Emissions in 2050 (%)	Combined Reduction Potential (% in 2050)
Aviation	Operations	Advanced CNS/ATM systems (e.g. NextGen, SESAR)	0	5	5
	Airframe Design & Propulsion	More efficient turbofan (jet) engines, advanced lightweight materials, improved aerodynamics (e.g. winglets, increased wingspans)	30	0	30
		Unducted fan (open rotor) engines; Greater application of advanced lightweight materials; Improved aerodynamics (e.g. laminar flow control), New airframe designs (e.g. blended wing body)			
	Alternative Fuels	Medium term: Biofuels; Long term: Biofuels, Hydrogen	0	24	24
	Total reduction from BAU emissions in 2050		53		
Marine	Operations	Speed reduction, optimized routing, reduced port time	20	27	47
	Ship Design & Propulsion	Novel hull coatings, propellers, Fuel efficiency optimization, Combined cycle operation and Multiple engines	20	17	37
	Alternative Fuels & Power	Marine diesel oil (MDO); Liquefied Natural Gas (LNG); Wind power (sails)	2	38	40
	Total Reduction from BAU Emissions in 2050		62		

Source: Mc Collum (2009)

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 (UNFCCC) specifically excludes international emissions from air and sea transportation from developed countries' national targets.

Article 2.2 of the Kyoto Protocol states that:

"Parties included in Annex 1 (developed countries and economies in transition) shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively".

ICAO and IMO are specialized United Nations agencies. The primary purpose of the IMO is to develop and maintain a comprehensive regulatory framework for shipping and its mandate today includes safety, environmental concerns, legal matters, technical co-operation, maritime security and the efficiency of shipping. ICAO codifies the principles and techniques of international air navigation and fosters the planning and development of international air transportation to ensure safe and orderly growth.

In response to the mandate from the Kyoto Protocol, both organizations have initiated activities aimed at assigning international GHG emissions from their respective sectors to specific countries, but so far neither has reached agreement on binding actions, and many of the key issues remain unresolved (Mc Collum et. al., 2009). Much of the deadlock over tackling bunker emissions on a global scale has revolved around how to apply to aviation and shipping the differing guiding principles of the institutions that govern bunker emissions.

A key issue, is reconciling the IMO specific precept of No Favorable Treatment, that is, all ships are regulated equally regardless of where the ship is owned or registered, and the fundamental ICAO principle of non-discrimination, with the UNFCCC's principle of Common But Differentiated Responsibilities, in which different obligations are imposed on the Parties to the UNFCCC, depending on their level of development. This attempt at reconciliation has been challenging and has hampered discussions, leading to uncertainty about how international transportation emissions will be dealt with in any post-2012 agreement (ICTSD, 2010).

Y. B ADAPTATION STRATEGIES

Even a dramatic reduction in global GHG emissions in the coming years is unable to prevent the consequences of a 2 ºC 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. Adaptation to the impacts of climate change is a very different process from mitigation. In the broadest terms, adaptation involves households, communities, and planners putting in place initiatives that "reduce the vulnerability of natural and human systems against actual and expected climate change effects" (IPCC, 2007). This contrasts to the invention of new technologies and development paths required for mitigation. For this reason, insufficient progress on adaptation strategies could even reverse or threaten development. Just as with mitigation there sizeable costs associated with adaptation.

Table 23: Key factors for adaptive capacity in international transportation in small island countries and barriers to implementation

Adaptation Measures	Relevance to International Transportation	Barriers to Implementation	Measures to Remove Barriers
Mainstreaming adaptation in planning	Currently adaptation is not mainstreamed in international transportation planning	Lack of information on which to base policy initiatives	Improve targeted information, e.g. climate-risk profile for air and sea transportation
Include climate risk in air and sea transportation regulations, codes	Currently such risks are not reflected in air and sea transportation-related regulations	Lack of information on which to base regulatory strengthening	Improve information, such as climate-risk profile for air and sea transportation
Institutional strengthening	Shortfall in institutional capacity to coordinate climate responses across air and sea transportation-related sectors	Lack of clarity as to the institutional strengthening required to improve sustainability of air and sea transportation	Assess options and implement the most appropriate strategies
Education/awareness raising	Need to motivate and mobilize air and sea transportation staff	Lack of education and resources that support behavioral change	Undertake education./awareness programs
'Soft' Coastal protection	Many valuable air and sea transportation assets at growing risk from coastal erosion	Lack of credible options that have been demonstrated and accepted	Demonstration of protection for air and sea transportation assets and communities
Improved insurance coverage	Growing likelihood that air and sea operators will make insurance claims	Lack of access to affordable insurance	Ensure insurance sector is aware of actual risk levels and adjust premiums
Enhanced design and siting standards	Many valuable air and sea transportation assets at growing risk from climate extremes	Lack of information needed to strengthen design and siting standards.	Provide and ensure utilization of targeted information.

Source: Adapted from Becken and Hay (2007) – Tourism and Climate Change

The international transportation sector has shown an ability to cope with various shocks such as 9/11 and Severe Acute Respiratory Syndrome and therefore seems flexible enough to strengthen its adaptive capacity to deal with climate change. Becken and Hay (2007) outlined some possible measures to strengthen adaptive capacity of tourism for small island economies to climate change, along with the barriers to implementation. Table 24 adapts the Becken-Hay framework, showing key factors for strengthening the adaptive capacity of the international transportation sector to climate change.

In addition to building adaptive capacity, adaptation strategies must be mainstreamed into national development policies, adopted and implemented before it is too late. Tables 25-26 show select potential climate changes, their impacts on air and sea transportation and adaptation options for Barbados. 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 impacts of climate change is likely to result from changes in transportation operating and maintenance practices. With changes in the frequency and intensity of extreme weather events, operational responses at both the Grantley Adams International Airport and the Port of Bridgetown that are usually treated on an ad hoc, emergency basis are likely to become part of mainstream operations. The response to tropical storms or even hurricanes is a major focus of transportation operations in the Caribbean, including in Barbados, as most recently demonstrated with Hurricane Tomas. If strong (category 4 and 5) hurricanes are likely to increase in frequency, then widespread establishment of evacuation routes and use of contraflow operations in Bridgetown and other areas vulnerable to flooding and storm surge might become more commonplace. Operators at the Grantley Adams International Airport and the port also need to work more closely with weather forecasters and emergency response planners to convey their own lead-time requirements for providing the necessary personnel and equipment in an evacuation and for protecting their own transportation assets. Mainstreaming such responses will require expanding the scope of the ministry responsible for transport to include emergency management as a separate functional responsibility.

Operational responses are geared to addressing near-term impacts of climate change. To make decisions today about rehabilitating or retrofitting air and sea transportation terminals in Barbados, which are designed for a 40-50 year service life, transportation planners and engineers must consider how climate change will affect these facilities in the future. For GAIA, the main adaptation options are extending lengths of runways, if feasible, elevating some runways, and hardening of the air terminal and other key facilities. At the Port of Bridgetown, the main adaptation options are raising of the dock and wharf levels to provide adequate clearance, protection of sea terminal and warehouses, and hardening of the dock, wharf, and terminal to withstand storm surge and wave action.

Adapting to climate change will also require reevaluation, 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 or not current design standards are adequate to accommodate future climate changes. Meyer (2008) found that forces resulting from water flows were found to be the most dominant impact on design elements across all changes in climate. 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.

How should engineering design decisions be modified for a long-lived and expensive transportation infrastructure such as the Grantley Adams International Airport and the Port of Bridgetown for which uncertainties are greater regarding the magnitude and timing of climate changes? One option is to rebuild to a more robust standard, assuming a greater frequency and magnitude of extreme events, without a full understanding of future risks and presumably at greater cost. While this strategy could be appropriate for these major facilities in vulnerable locations, its high costs necessitate a highly selective approach. Another option is to upgrade parallel routes, but this alternative depends on the availability of land and the cost of upgrading. A final option is to hedge by retrofitting the terminals at the Grantley Adams International Airport and the Port of Bridgetown to current standards or making marginal improvements, recognizing that the infrastructure remains at risk and may require major improvements in the future. All three options involve important cost-risk reduction trade-offs that engineers and planners can best address through a more strategic, risk-based approach to design and investment decisions.

Scenario planning is another adaptation strategy that can take potential climate change into account in the development of future air and sea transportation plans in Barbados. For example, projections of current development patterns and supporting air and sea transportation infrastructure, when overlaid on maps showing current elevations and expected sea level rise, could illustrate the increased risks of allowing uncontrolled development in vulnerable coastal areas such as Bridgetown and the desirability of managed growth policies and protection of critical infrastructure.

Table 24: Barbados - climate change, air transportation and adaptation options at Grantley Adams International Airport

Potential Climate Change	**Impacts on Air Transportation**		**Adaptation Options**		
	Operations & Interruptions	Infrastructure	Operations	Infrastructure Design & Materials	Other
Temperature: Increases in very hot days and heat waves	Delays due to excessive heat Impact on GAIA 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 of airport 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 and improvement of drainage systems supporting runways and other paved surfaces	
Rising sea levels Erosion of coastal areas	Closure of or restrictions to airport	Inundation of runways		Elevation of some runways	Construction or raising of protective dikes and levees around Seawall Relocation of some runways, if feasible
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 U.S. Department of Transportation (2010)

Table 25: Barbados - climate change, sea transportation and adaptation options at Bridgetown Port

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 harbor infrastructure from wave damage and storm surge Changes in underwater surface and silt and debris buildup affect channel depth		Strengthening of harbor 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 harbor 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 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 harbor
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 harbor 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 to withstand storm surge and wave action	

Source: Adapted from U.S. Department of Transportation (2010)

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

Prioritizing adaptive measures based on the nature of the projected or observed climate change impacts is vital. The Stern Review (2006) stressed the importance of choosing adaptation options based on a careful assessment of efficacy, risks and costs. It is more cost effective to implement techniques that are proactive rather than reactive, to support no-regrets measures, that is, actions that make sense regardless of additional or exacerbated impacts from climate change, and to implement low-regret actions that are low cost but whose benefits are high under climate change scenarios. In the event that there is no major change in the climate, the proactive, no-regrets, low-regrets strategies would still meet other social, environmental, or economic objectives.

The best approach to prioritizing adaptation options involves applying cost-benefits analysis to the respective options. Gaining a sense of costs and benefits is clearly helpful, and can attract the necessary political attention and provide a sense of perspective. Where effective such studies can assist in distinguishing, for example, between measures that are cost negative and therefore create savings; measures for which economic benefits outweigh their costs; and measures that cost more than their savings. There are however limitations to cost-benefit analysis. It can be difficult to assess accurately both cost and benefits when the exact nature and timing of the threat is unknown; this type of analysis tends to treat options as discrete while in practice it is combinations of options and incremental progress that are likely to be most effective; and there is subjectivity involved in valuing environmental goods and services and heritage products that are not traded in markets but recognised as being valuable in preventing climate change impacts.

This study uses multi-criteria analysis (MCA) to prioritize adaptation options because MCA allows decision makers to include a full range of social, environmental, technical, economic, and financial criteria. A single-criterion approach such as cost-benefit analysis falls short as a decision analysis tool, especially where significant environmental and social impacts cannot be assigned monetary values. Multi-criteria assessments have been criticised for their subjectivity. Questions such as “Who gets to select the criteria?” and “Who gets to perform the assessment?” are legitimate.

One of the central benefits in applying this approach, however, involves not the results that are produced but the institutional capacity for better decisions that is created during the process of selecting criteria and assessing options. Climate change adaptation theory emphasises the importance of “socio-institutional learning” (Downing et al. 2007), monitoring, reflexive institutions, on going decision-making and iterative implementation. This is in contrast to efforts that aim to predict risks and provide “climate proof” solutions – an approach that is seldom tenable and often disingenuous in the context of climate change impacts.

Table 27 shows MCA of the effects of climate change on international transport infrastructure in Barbados. The adaptation options are grouped into four categories: (a) design issues, where changes in the design of the international transport network are proposed; (b) operational issues, where changes in the operation of the international transport network are proposed; (c) research issues, where further applied studies are required; and (d) policy issues, where recommendations would affect current policies

Z. EXAMPLE OF MULTI-CRITERIA ANALYSIS: ADAPTING THE PORT OF BRIDGETOWN TO SEA LEVEL RISE

Broadly, sea-level rise adaptation options can be categorised into: (a)engineering approaches: sea-walls, groynes, barrages and barriers, raising infrastructure, dolosse and gabions, off shore reefs, beach nourishment and replenishment, water pumps and beach drainage; (b) biological approaches: dune cordons, coastal mangroves, estuary and wetland rehabilitation, kelp beds; and (c) socio-institutional approaches: vulnerability mapping, risk communication, enforcing a buffer zone, preventing activity that compromises the coastline (sand mining), early warning system, insurance market correction, planned relocation.

Table 26: MCA of the effects of climate change on international transport infrastructure in Barbados

Aspect of the Effect	Adaptation Reference			
	A1	A2	A3	A4
Adaptation	Review the findings of this study on vulnerable sections of the air and sea transport network, and assess the adequacy of international transport asset protection structures under existing conditions	Map air and sea infrastructure assets and coastal margins at 1m scale or better, with at least 0.2 m precision in elevation across tidal reach	Model combined effects of inundation risk (sea level rise plus storm surge plus wave run up) at GAIA and Port	Monitor coastal hazard risk (sea levels and waves)
Type	Research	Research	Research	Policy
Ownership	Barbados – Ministry of Works, GAIA, Bridgetown Port	Barbados – Ministry of Works	Barbados – Ministry of Works	GAIA, Bridgetown Port and coastal property owners
Recommended Timeframe /1	Short	Short	Short	Short and ongoing
Cost/VFM	Good VFM	Good VFM	Good VFM	Good VFM
Scale /2	Localized in low-lying areas	Prioritize those air and sea assets that are at risk under existing conditions	Prioritize those areas and surrounding communities that are at risk under existing conditions	National
Co-benefits/Unintended Consequences	Economic: will prioritize which air and sea transportation assets are inadequate under current conditions	Economic: will enable climate change modelling to incorporate local topography	-	Will improve the accuracy of information available for decision makers
Priority	No regrets	No regrets	No regrets	No regrets

Table 26(continued): MCA of the effects of climate change on international transport infrastructure in Barbados

Aspect of the Effect	Adaptation Reference			
	A5	A6	A7	A8
Adaptation	Redesign/retrofit air and sea terminals and facilities with appropriate protection, or relocate. Dependent on A1, A2, A3 and A4.	Incorporate existing and predicted climate change conditions in new design of air and sea transport assets. Dependent on A3 and A4.	Incorporate predicted climate change conditions on existing air and sea transport assets where they require rehabilitation or improvement. Dependent on A3 and A4.	Incorporate predicted change in new and existing international transport assets when population growth is facilitated through land use changes in coastal areas.
Type	Operation	Design	Operation	Policy
Ownership	Barbados – Ministry of Works, GAIA, Bridgetown Port	Barbados – Ministry of Works, GAIA, Bridgetown Port	Barbados – Ministry of Works, GAIA, Bridgetown Port	GAIA, Bridgetown Port and local authorities
Recommended Timeframe /1	Medium to long	Short and ongoing	Short and ongoing	Short and ongoing
Cost/VFM	Good VFM	Good VFM	Good VFM	Good VFM
Scale /2	Localized in low-lying areas.	Localized in low-lying areas.	Localized in low-lying areas.	National
Co-benefits/Unintended Consequences /3	Economic: will prioritize which air and sea transportation assets are inadequate for current conditions	Minimizes risk of over-engineering.	Minimizes risk of over-engineering.	Social: minimizes the risk of disruption to communities.
Priority	Low regrets	Low regrets	Low regrets: preventative action.	Low regrets

Notes:
/1 Short = to 2011; medium = by 2040s; long by 2090s
/2 e.g. low cost and high return = priority
/3 e.g. social, economic or environmental consequences; alignment with policies.

The best adaptation measures tend to include a combination of responses. The threat of sea level rise has seen a renewed acknowledgement in Barbados of the need for Integrated Coastal Zone Management. For local decision makers, the correct responses to sea-level rise are location specific, and effective responses usually require a detailed study of in-shore current, wave dynamics, winds and sand transportation. Whilst the raising of the Port of Bridgetown may represent the best option for

Barbados, the Sandy Lane Golf Course just along the coast may be better served by relocation or the creation of vegetation buffers on the coastal dunes.

It is possible, however, to draw some generalisations. Firstly, from a financial perspective, there are a number of “no-regrets” options that would probably be desirable even if sea-level rise were not a risk for Barbados, and which save more money than they cost to implement. These options are closely aligned to conventional sustainable development and include an early warning system, the prevention of additional coastal land reclamation, improved quality housing and transport routes and conservation of estuarine vegetation and dune buffers. No-regrets options represent an appropriate point of departure for sea-level rise adaptation.

Secondly, institutional responses tend to be better than biological options and significantly better than infrastructural approaches. The ultimate institutional approach involves the implementation of a coastal buffer zone that is void of settlement. In some instances in Barbados, this will involve planned relocations with compensation. Finally, biological options can be highly cost effective, but are difficult to implement well.

The great advantage of these approaches is that they retain rather than truncate the option set available: it is still possible to build a sea-wall having attempted to provide protection with dune vegetation, but it is much more difficult to promote dune vegetation once a sea-wall has been constructed and the coastline habitat altered permanently.

IX. CONCLUSIONS

Barbados is a great risk from the economic impact of climate change on its international transportation sector, which brings nearly all of its visitors (mainly tourists) from the main markets in North America and Western Europe and moves virtually all of its merchandise trade. The total cost of climate change on international transportation in Barbados combined the impacts of changes in temperature and precipitation, new climate policies and sea level rise. The impact for air transportation ranges from US$10,727 million (SRES B2 scenario) to US$12,279 million (SRES A2 scenario) and for maritime transportation impact estimates range from US$1,992 million (SRES B2 scenario) to US$2,606 million (SRES A2 scenario). For international transportation as a whole, the impact of climate change varies from US$12,719 million under the SRES B2 scenario to US$14,885 million under the SRES A2 scenario.

While further study is needed to examine in more detail the potential impacts of climate change on the two key international transportation assets - the Grantley Adams International Airport and the Port of Bridgetown - the findings of this preliminary assessment are so important that transportation decision makers should begin immediately to assess them, in the development of transportation investment strategies in Barbados. Mitigation strategies to deal with GHG emissions from international aviation and shipping are especially challenging because the 1997 Kyoto Protocol to (UNFCCC) specifically excludes these from developed countries’ national targets. Instead, countries are expected to work through the ICAO and the IMO, but, so far, neither organization has reached agreement on binding actions, and many key issues remain unresolved.

Barbados has the institutions set up to implement the adaptive strategies to strengthen the resilience of the existing international transportation system to climate change impacts. Air and sea terminals and facilities can be hardened, raised, or even relocated as need be, and where critical to safety and mobility, expanded redundant systems may be considered. What adaptive strategies may be employed, the associated costs, and the relative effectiveness of those strategies will have to be determined on a case-by-case basis, based on studies of individual facilities and system-wide considerations.

REFERENCES

Allison, I., N. L. Bindoff, R.A. Bindschadler, P.M. Cox, N. de Noblet, M.H. England, J.E. Francis, N. Gruber, A.M. Haywood, D.J. Karoly, G. Kaser, C. Le Quéré, T.M. Lenton, M.E. Mann, B.I. McNeil, A.J. Pitman, S. Rahmstorf, E. Rignot, H.J. Schellnhuber, S.H. Schneider, S.C. Sherwood, R.C.J. Somerville, K.Steffen, E.J. Steig, M. Visbeck, A.J. Weaver, 2009. *The Copenhagen Diagnosis: Updating the world on the latest climate science*. University of New South Wales Climate Change Research Centre (CCRC), Sydney, Australia, 60 pp.

Anderson, A. J. (1976). Time Series Analysis: The Box_Jenkins Approach. London: Butterworth.

Andrey, J. and B.N. Mills. 2003: Chapter 9 – Climate Change and the Canadian Transportation System: Vulnerabilities and Adaptations. In: *Weather and Transportation in Canada* [Andrey, J. and C. Knapper (Eds.)], Department of Geography, University of Waterloo, Ontario, Canada.

Barbados Port Inc. 2008. Annual Report 2007.

Barrett, S. (2004). Increasing Participation and Compliance in International Climate Change Agreements. Working Paper Series, Harvard University, JFK School of Government.

Becken, S. and J. Hay. 2007. *Tourism and Climate Change – Risks and Opportunities*, Channel View Publications, Cleveland, Ohio, United States of America.

Dasgupta, S., B. Laplante., C. Meisner., D. Wheeler., and J. Yan. 2009. *Sea Level Rise and Storm Surges: A Comparative Analysis of Impacts on Developing Countries*. Policy Research Working Paper 4901. World Bank.

Department of Economic Affairs. 2009. Economic Outlook – Barbados 2009. Department of Economic Affairs, commerce and Industry: The Government of Barbados.

Doganis, R. 2001. The Airline Business in the Twenty-First Century. London, United Kingdom: Routledge.

Downing, T. E., Cartwright, A. & Smith, B. 2007. Defining the food and agriculture's role in climate change adaptation. Report in partial completion of the compilation of FAO's Climate Change Adaptation Strategy. Available at: http://www.fao.org/climatechange/home/en/

Economic Commission for Latin America and the Caribbean (ECLAC). 2010a. *Climate Change Profiles in Selected Caribbean Countries*, Review of the Economics of Climate Change (RECC) in the Caribbean Project (Phase 1).

Economic Commission for Latin America and the Caribbean (ECLAC). 2010b. Annual Economic Survey of Latin America and the Caribbean.

Environmental Protection Agency (EPA). 2006. Greenhouse Gas Emissions from the U.S. Transportation Sector, 1990-2003. Washington, DC, United States, Office of Transportation and Air Quality, EPA420-R-06-003.

Johansen, S. 1995. Likelihood Inference in Cointegrated Vector Autoregressive Models. Oxford University Press.

Johansen, S. 1988. Statistical Analysis of Cointegrating Vectors. *J. Econ. Dynam. Control* 12: 231-254.

Haites, E. 2002. Assessment of the Impact of Climate Change on CARICOM Countries: *Environmentally and Socially Sustainable Development – Latin America and Caribbean Region*, The World Bank. http://www.margaree.ca/reports/ClimateChangeCARICOM.pdf

Intergovernmental Panel on Climate Change (IPCC). 1996: *Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change.* IPCC. Cambridge University Press, Cambridge, United Kingdom.

Intergovernmental Panel on Climate Change (IPCC). 2001: *Climate Change 2001: Impacts, Adaptations, and Vulnerability*. IPCC. Cambridge Press. New York, New York.

Intergovernmental Panel on Climate Change (IPCC). 2007**,** *Climate Change 2007: The Physical Science Basis, Summary for Policy-Makers, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC. Cambridge Press. New York, New York, February

International Centre for Trade and Sustainable Development (ICTSD). 2010. International Transportation, Climate Change and Trade: What are the Options for Regulating Emissions from Aviation and Shipping and what will be their Impact on Trade? ICTSD Global Platform on Climate Change, Trade Policies and Sustainable Energy, Background Paper.

International Energy Agency (IEA). 2008. CO_2 Emissions from Fuel Combustion (2008 Edition), Paris, France, Organization for Economic Co-operation and Development (OECD).

International Institute for Environment and Development (IIED). 2010. Climate Change Adaptation in Developing Countries: Issues and Perspectives For Economic Analysis.

International Maritime Organization (IMO). 2008. Updated Study on Greenhouse Gas Emissions from Ships.

Lee, D.S., H. Preston, L. L. Lim, B. Owen, V. Eyring and J. Faber. 2009. Taking Responsibility: Setting a CO2 Emissions Cap for the Aviation and Shipping Sectors in a 2-Degree World.

Lenton T, A. Footitt and A. Dlugolecki. 2009. *Major Tipping Points in the Earth's Climate System and Consequences for the Insurance Sector*. 89 pp., (http://knowledge.allianz.com).

Martin, R. (2010). Economics of Climate Change on the Tourism Sector in the Bahamas. Draft report to ECLAC.

Mc Collum, D., G. Gould and D. Greene. 2009. Greenhouse Gas Emissions from Aviation and Marine Transportation: Mitigation Potential and Policies, Solutions White Paper Series, Pew Center on Global Climate Change.

Meyer, M.D. 2008: Design Standards for U.S. Transportation Infrastructure: The Implications of Climate Change. In: *The Potential Impacts of Climate Change on U.S. Transportation*. The National Research Council, National Academy of Science, Transportation Research Board and Department of Earth and Life Sciences, Washington, D.C.

Mimura, N. 2007. Small Islands. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contributions of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. eds. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson. pp. 786-716. Cambridge University Press, Cambridge, United Kingdom.

Mishra, P. 2006. Emigration and Brain Drain: Evidence from the Caribbean, *IMF Working Paper* WP/06/25, (Washington, January).

Nakićenović, N. O. Davidson, G. Davis, A. Grübler, T. Kram, E.L. La Rovere, B. Metz, T. Morita,W. Pepper, H. Pitcher, A. Sankovski, P. Shukla, R. Swart, R. Watson, and Z. Dadi. 2000. *IPCC Special Report on Emissions Scenarios*. Cambridge: Cambridge University Press.

Nicholls, R. J. and R. S. J. Toll. (2006). Impacts and Responses to Sea Level Rise: A Global Analysis of the SRES Scenarios Over the Twenty First Century, Philosophical Transactions of the Royal Society: Mathematics, Physical and Engineering Services 364 (1841).

Nicholls, R.J., S. Hanson, C. Herweijer, N. Patmore, S. Hallegatte, J. Corfee-Morlot, J. Château, R. Muir-Wood, 2007. *Ranking Port Cities With High Exposure And Vulnerability to Climate Extremes: Exposure Estimates*. OECD ENV/WKP 2007-1. 62 pp.

O'Brien, K. 2004. The Economics of Adaptation. Stern Review Workshop, 9 May, UK.Seehttp://www.hmtreasury.gov.uk/d/stern_review_supporting_technical_material_karen_obrien_231006.pdf

Overman, H., S. Redding and A. Venables. 2003. "The Economic Geography of Trade, Production and Income: A Survey of Empirics." In: K Choi and J. Harrigan, editors. Handbook of International Trade. Oxford, United Kingdom: Blackwell Publishing.

Sahay, R. 2005. Stabilization, Debt & Fiscal Policy in the Caribbean *IMF Working Paper* WP/05/26, (Washington, February).

Sanchez (2009)

Smit, B. 1999. The Science of Adaptation: A Framework for Assessment. *Mitigation and Adaptation Strategies for Global Change* 4: 199 – 213.

Simpson, M. (2010), The Impact of Climate Change on Tourism in Barbados.

Song, H. and S.F. Witt. 2000. Tourism demand modelling and forecasting. Modern Econometric Approaches. Oxford, Pergamon.

Sookram, S. 2009. The Impact of Climate Change on the Tourism Sector in Selected Caribbean Countries – *Caribbean Development Report* 2(30): 204-225, New York: United Nations.

Stern, N. 2006. "The economics of climate change". *The Stern Review*, Cambridge University Press, Cambridge, United Kingdom.

Uddin W, McCullough B.F, Crawford MM. 1986. Methodology for Forecasting Air Travel and Airport Expansion Needs. *Transportation Research Records*, 1025: 7-16.

United Nations Conference on Trade and Development. 2009b. Review of Maritime Transportation 2009, Report by the UNCTAD Secretariat.

U.S. Agency for International Development. 2009. Latin American and the Caribbean Selected Economic and Social Data. Washington, D.C.: United States Agency for International Development.

Vergara, W. 2009. Assessing the Potential Consequences of Climate Destabilization in Latin America. World Bank, Latin America and Caribbean Region, Sustainable Development Working Paper 32.

Warnock-Smith, D. 2008. The Socio-economic Impact of Air Transportation in Small Island States: An Evaluation of Liberalization Gains for the Caribbean Community (CARICOM). PhD Thesis, College of Aeronautics, Cranfeld University.

World Bank and Organization of American States (OAS). 2009. *Caribbean: Accelerating Trade Integration: Policy Options for Sustained Growth, Job Creation and Poverty Reduction*, (Washington, April).

World Bank 2010. World Development Report 2010 - Development and Climate Change. The International Bank for Reconstruction and Development. The World Bank: Washington, D.C.

World Travel and Tourism Council (WTTC). 2010. Country Report on Barbados, Executive Summary.

Zhuang, Juzhong, Z. Liang, T. Lin, and F. De Guzman. 2007. Theory and Practice in the Choice of Social Discount Rate for Cost-Benefit Analysis: A Survey, ERD Working Paper No. 94, Asian Development Bank.