UNITED NATIONS

ECLAC

Economic Commission for Latin America and the Caribbean

Subregional Headquarters for the Caribbean

LIMITED
LC/CAR/L.311
22 October 2011
ORIGINAL: ENGLISH

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

Acknowledgement

The Economic Commission of Latin America and the Caribbean (ECLAC) Subregional Headquarters for the Caribbean, wishes to acknowledge the assistance of Jwala Rambarran, consultant, in the preparation of this report.

Table of Contents

List of Tables

Executive Summary

Montserrat 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 presence of a 'persistently active' Soufrière volcano into, at least the next decade worsens the situation.

The total cost of climate change on international transportation in Montserrat was calculated by combining the impacts of changes in temperature and precipitation, new climate change policies in advanced countries, sea level rise and an eruption of the Soufriere Hills volcano. The impact for air transport could range from US$630 million (SRES B2 scenario), to US$742 million (SRES A2 scenario) and for maritime transport impact estimates range from US$209 million (SRES B2 scenario) to US$347 million (SRES A2 scenario). For international transport, as a whole, the impact of climate change varies from US$839 million under the SRES B2 scenario to US$1,089 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 - John A. Osborne Airport and Little Bay - 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 Montserrat. Mitigation strategies to deal with green house 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.

Montserrat 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.

INTRODUCTION

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-year 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).These States 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.

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 Montserrat 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 Montserrat 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 Montserrat 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 Montserrat to address the observed and projected impacts of climate change.

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 Montserratian 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's Treasury's Green Book recommends 3.5% and Dasgupta et.al. (2009) suggest 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.

CLIMATE CHANGE 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.

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 Montserrat while Section 4 discusses the role of the air and sea transportation sectors in the Caribbean and in Montserrat. Section 5 discusses the vulnerability of the international transport system in Montserrat 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 Montserrat. Section 9 concludes the study.

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 to 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 United States 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 is concerned 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 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 per cent. 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 (NGOs) 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.

ECONOMY OF THE CARIBBEAN SUBREGION AND MONTSERRAT

A. *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 SIDS. 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 the Bahamas, Montserrat, 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 1998-2009, 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 1998-2009. 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, seven 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 trading 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 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. The report estimated the cost of the global crisis to the Caribbean at a huge 10% of GDP in 2009. ECLAC 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.

B. *Economy of Montserrat*

Montserrat is a Caribbean island within the Lesser Antillean chain, lying 27 miles southwest of Antigua. It is an internally-governing United Kingdom Overseas Territory. With a per capita income of US$3,400 (PPP, 2004) Montserrat has one of the lowest standards of living in the Caribbean. Severe volcanic activity commenced in 1995 which had a devastating effect on the island's small, open economy. The eruption of the Soufriere Hills Volcano in 1997 destroyed the capital city, Plymouth, and closed the airport and seaports, causing further economic dislocation, hardship, and poverty for many citizens who became dependent on the government for welfare support. At that time two thirds of the population of 12,000 inhabitants left the island. Some began to return in 1998, but the lack of suitable housing and general infrastructure to the north of the island discouraged a return. About half of the island is expected to remain uninhabitable at least for another decade.

Table 3 shows the evolution of GDP in Montserrat over 2005-2009. Prior to 1995, tourism and its related services was the mainstay of the economy, contributing on average about 40% of GDP. Tourism remains negatively affected by the limited international transportation links and presently only contributes 15% of GDP. Traditionally, tourism in Montserrat had primarily been "residential tourism", with an upscale market of clients generally staying in rental villas or guests houses for longer periods of time than the package-resort tourism that many other islands promote. There is also a modest population of expatriate home-owners who spend all or part of the year in Montserrat.

Table 3: Gross domestic product by economic activity in Montserrat (Current Prices, EC$ million)

	2005	2006	2007	2008	2009
Agriculture	1.0	1.2	1.1	1.6	2.1
Mining and Quarrying	0.2	0.6	1.7	1.6	1.8
Manufacturing	0.9	0.8	0.8	0.9	0.9
Electricity and Water	7.4	7.6	7.7	7.8	8.3
Construction	13.3	9.2	9.3	10.4	12.9
Wholesale & Retail Trade	4.6	4.6	4.5	5.7	5.7
Hotels & Restaurants	1.2	1.1	1.3	1.4	1.2
Transportation	8.0	8.8	8.9	9.3	9.2
Communications	3.6	3.7	3.8	3.9	3.9
Banks and Insurance	11.0	10.6	13.0	13.9	14.4
Real Estate and Housing	13.4	14.4	14.9	15.8	16.5
Government Services	34.1	43.3	45.7	48.1	50.1
Other Services	8.1	8.1	8.6	9.1	9.4
Gross Domestic Product	98.7	105.5	109.8	117.3	123.7

Source: Eastern Caribbean Central Bank

Over the past few years, economic activity in Montserrat has been dominated by government services and construction. Government services have averaged about 40% of GDP for 2005-2009 while real estate and housing have averaged about 13%. Agriculture's importance is high to the island because of the food security it provides for a country with limited external links and because of the sustainable livelihood it provides for a segment of the population (CDB, 2007). Nevertheless, agricultural output contributes less than 2% of GDP, partly reflecting the relocation of farmers to safer, but less fertile areas in the north of the island.

Montserrat's domestic financial sector is very small and has seen a reduction in offshore finance in recent years with less than 10 offshore banks remaining. The insurance company and trust services sectors are negligible. No securities business is known to exist both in the domestic and offshore sectors. Banking and insurance together accounted for 11% of GDP in 2009. Like other offshore centers, Montserrat does not tax offshore corporations. In addition, there are no exchange controls below transactions totaling EC$250,000, and the official currency is the Eastern Caribbean dollar.

Montserrat is a member of the Eastern Caribbean Currency Union which includes Anguilla, Antigua and Barbuda, Dominica, Grenada, Montserrat, Saint Kitts and Nevis, Saint Lucia, and Saint Vincent and the Grenadines. All of these countries use the Eastern Caribbean dollar as their currency which is issued by the Eastern Caribbean Central Bank headquartered in St. Kitts and Nevis.

Real output in Montserrat rose for the third consecutive year, with real GDP increasing by 3.4% in 2009 following growth of 5.4% and 2.9% in 2008 and 2007, respectively. Continued increase in government services was the major underlying reason for the growth performance. A pick up in real estate and housing also helped to boost output. Growth prospects for Montserrat largely depend on a sustained resumption of private sector activity and are contingent on the severity of volcanic activity and on the receipt of United Kingdom grant funding.

THE INTERNATIONAL TRANSPORTATION SYSTEM IN THE CARIBBEAN AND IN MONTSERRAT

A. 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 illustrates some striking facts about the socio-economic importance of air transportation in the Caribbean. First, 13 of 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 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 & 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

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 the year 2006.

In the tourist dependent economies such as Antigua and Barbuda, Montserrat 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 Montserrat, no airline and Suriname, low activity with national airline.

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 & 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)

Foreign visitors to the Caribbean region 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 the 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.

C. *SEA TRANSPORTATION IN THE CARIBBEAN*

Marine transportation infrastructure includes ports and harbours 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 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/ United States of America 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.

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 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

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.

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 & Tobago	4	13
Turks and Caicos	0	2
Venezuela	7	20
Virgin Gorda (Virgin Islands	0	2

Source: Sanchez (2009)

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 (see table 6). Only 49% of the containers were carrying cargo, the rest of which were 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.

D. *AIR TRANSPORTATION IN MONTSERRAT*

Air transportation in Montserrat is critical to the island's economic regeneration and to re-establishing external links with the rest of the world. Montserrat is accessible to the rest of the world via Antigua and Barbuda. The completion of Gerald's Airport (renamed John A. Osborne Airport in 2005) allowed for the resumption of regular, but still limited, commercial airline service to Montserrat for the first time since 1997, when W. H. Bramble Airport, which had been the island's only aviation gateway, was completely destroyed by an eruption of the nearby Soufriere Hills volcano. Between 1997 and 2005, Montserrat had been only accessible by helicopters or boats.

Prior to the volcanic crisis in 2005, visitor arrivals fluctuated between 12,000 and 15,000. A sharp decrease in arrivals and expenditures took place from 2006. The shift from ferry to air service also had quite an impact on tourism island-wide. The current arrival rates are less than half the 1995 figures when arrivals approached 20,000 (see Table 8). According to the 2010 Budget Statement, as of November 2009, visitor arrivals to Montserrat were 14% lower than the corresponding 11-month period for 2008.

The recession being experienced in the major tourist markets also had negative impacts on Montserrat. The United Kingdom is the single largest market, accounting for over 28% of total market share in 2007. The rebuilding of a strong relationship with the Government of the United Kingdom has facilitated increased arrivals from that country. The United Kingdom is followed by the United States with 27.2% of the total market. There are also significant Organisation of Eastern Caribbean States (OECS) and other intra-Caribbean movements, representing a combined 35% of all air arrivals to Montserrat. The non-United Kingdom European market has seen a steady fall in arrivals, partly due to a reduction of airlift and partly due to increased competition from cheaper tourist destinations.

John A. Osborne Airport is a small airport located near the village of Gerald's, close to the northern tip of the island. The facility was formally opened on 11 July 2005. It features a 600 metre runway, a restaurant, modern air traffic control technology, immigration facilities, and is the only airport in the Caribbean with a public tunnel under its runway. The total cost of construction was approximately US$18.5 million or 40% of 2009 GDP at current market prices.

Montserrat does not have its own national airline and does not have an "open skies" agreement with the United States. At present, the airline service offering is extremely limited. SVG Air and Fly Montserrat are the only two airlines with direct service destinations to Antigua, which operates as a hub for Leeward Islands Air Transportation.

Table 8: Air passenger arrivals to Montserrat by country of residence, 2003-2007

Country	2003	2004	2005	2006	2007	2007 Share (%)
United States	1,541	2,084	2,034	2,153	2,109	27.2
Canada	297	334	404	393	388	5.0
United Kingdom	2,269	3,021	2,968	2,321	2,190	28.3
Other Europe	145	176	228	180	176	2.3
OECS	2,849	3,051	2,297	1,540	1,419	18.3
Other Caribbean	1,224	1,334	1,690	1,328	1,377	17.8
Rest of the World	65	138	69	76	87	1.1
Total	8,390	10,138	9,690	7,991	7,746	100.0

Source: Caribbean Tourism Organization

E. *SEA TRANSPORTATION IN MONTSERRAT*

In 2009, the total value of trade in goods in Montserrat amounted to US$30 million or 65 % of GDP. Most of this trade relates to imports, whereas domestic exports declined by 31.5 % in 2009 following the closure of three of the mining plants in the Trants Bay Area in October 2009. In terms of imports, the United States is by far the most important trading partner for Montserrat accounting for about one fifth of total imports. The United Kingdom ranks second. Other major trading partners are Trinidad and Tobago, Japan and Canada. Outside of Trinidad and Tobago, Montserrat has little merchandise import trade with other CARICOM countries. For exports, the situation is different. Most of the merchandise exports of Montserrat go to Antigua and Barbuda. Outside of the Caribbean region, the United States accounts for the lion's share of Montserrat's total merchandise exports.

The development and growth of the Little Bay Town Centre will be complemented with an upgrade and expansion of the seaport with facilities for cruise tourism and industry. Although the expansion will support the tourism sector, it will also enable the export growth potential of local business operations, resulting in increased throughput at the port. According to the 2010 Budget Statement, the long awaited port development project with an anticipated total cost of about US$28 million (or more than 60% of 2009 GDP) is now in the design phase. Phase 1, "Early Works" has commenced and includes land reclamation and hard surfacing of the foreshore works starting from the existing security offices to the ramp on the southern berth of the temporary jetty at Little Bay Port. This will create additional storage in the first instance and maneuvering space when the permanent breakwater and jetty is being constructed.

While tourism in Montserrat is predominantly driven by higher spending air arrivals, the "day-tripping" excursionist market has seen some revival in activity. Plans for a day-tour schedule connecting the ferry directly with cruise ships docking in Antigua and Barbuda, should help push the excursionist sector upwards, benefiting taxis, tour guides and retail outlets.

VULNERABILITY OF INTERNATIONAL TRANSPORT SYSTEM IN MONTSERRAT TO CLIMATE CHANGE

Montserrat, part of the Leeward Islands in the eastern Caribbean, is approximately 39.5 square miles in area. It lies approximately 27 miles southwest of Antigua and Barbuda and 1,150 miles north of the equator. This teardrop-shaped volcanic island is approximately 12 miles long and seven miles wide at its broadest point, with geographic coordinates of 16º45' N and 62º12' W. Its capital, Plymouth, was abandoned in 1997 due to volcanic activity, when most of the population either left the island, or were relocated to the northwest of the Island.

The island has since been divided into two zones: the safe northern area and the unsafe area. The safe area has been undergoing rapid development in terms of expanding road networks and the construction of buildings, all in an effort to provide facilities for the steadily re-increasing population. The unsafe area, however, has been excluded from all development and human activities.

No comprehensive inventory exists of the vulnerability of Montserrat's 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.

A. *Anthropogenic Effects*

Montserrat 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. Electricity is produced using containerized high-speed diesel generators. Apart from being a very unreliable and a high cost operation, the use of diesel raises concerns about the impact of CO_2 emissions from fossil fuels on the environment.

The Government is seeking to facilitate the exploration and development of viable alternative and renewable sources of energy that will provide the ideal conditions on which Montserrat can sustainably develop its economy. Geotechnical and geophysical studies associated with the development of a geothermal energy project were done during 2009 and areas for drilling were identified. Efforts are at present being made to secure the financing required for proceeding to the drilling phase where the plan is to drill a production well.

Further, the current power generating facilities are inadequate to support the strategic direction of the economy. A power station project is being developed to expand the power system to a level that can meet national demand in the most cost effective and efficient manner. The main components of the power project, which is estimated to cost just under US$8 million, are the procurement of a generator set and the construction of facilities to house generators and other equipment.

B. *Temperature and Precipitation*

Montserrat experiences a tropical, oceanic climate. Inter-annual variability in the Southern Caribbean climate is influenced strongly by the El Niño Southern Oscillation (ENSO). 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 annual temperature in Montserrat is around 28°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. According to projections from the PRECIS Regional Circulation Model at the Institute of Meteorology in Cuba (INSMET), the mean annual temperature in Montserrat is projected to rise by 0.8°C by 2030 relative to 1970-1999. Temperatures are expected to rise by 1.2°C by 2050. Moreover, locally, phenomena such as ocean acidification, which is likely to affect coastal lowlands in countries like Montserrat, 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 John A. Osborne 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. The runway at the John A. Osborne Airport is not sufficiently long enough to accommodate large aircraft. Thus, increases in extreme heat are likely to result in payload restrictions, flight cancellations, and service disruptions, and moreso since extension of the runway length is not feasible.

Annual rainfall in Montserrat is about 1,250-2,500 mm well distributed throughout the year, with a wetter season from July to January, coinciding with the Atlantic Hurricane season. According to projections from the PRECIS Regional Circulation Model at INSMET in Cuba, the mean annual precipitation in Montserrat 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.

C. *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.

Montserrat lies within the Atlantic hurricane belt and has been affected by hurricanes which occur throughout August, September and October. Table 9 shows the top five natural disasters that have affected Montserrat in 1990-2010. The last major hurricane to hit Montserrat was Hurricane Hugo in 1989, which caused some US$240 million in economic damage to the island. Volcanic activity in 1997 has affected a substantial part of the island's population with an estimated economic damage of US$8 million.

Table 9: Top 5 Natural disasters in Montserrat, 1900-2010

Disaster	Date	Number Killed	Total Affected	Economic Damage (US$ mn)
Storm	1989	11	12,040	240
Storm	1995	-	-	20
Volcano	1997	32	4,000	8
Volcano	1995	-	5,000	-
Volcano	1996	-	4,000	-

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

Based on the seventh meeting of the Scientific Advisory Committee on Montserrat Volcanic Activity, it was concluded that the continued rapid growth of the lava dome posed a serious hazard to the nearby occupied communities. These hazards were pyroclastic flow from dome collapse and column collapse, rock avalanches from the collapse of the crater walls, and explosions with ash and rock fallout (GOM, 2009).

D. *SEA LEVEL RISE*

Much of the coastline in Montserrat is made up of high cliffs, with only a handful of dark sandy beaches. A narrow coastal shelf drops to over 180m within a mile of the shore. Thus, Montserrat experiences a relatively high-energy coastline that is prone to erosion. There are no natural harbours, and only a small amount of coral reefs offer shoreline protection (McCauley and Mendes, 2006). With most of its population now living along the northern coast of the island, transport infrastructure in the coastal zone of Montserrat is an important connector to communities and the dominant tourism sector, and 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). Coastal erosion in Montserrat places critical air and sea transportation infrastructure, which is being reconstructed, at risk of inundation, with serious implications for the travel and tourism industries and other sectors. Roadways that presently serve as evacuation routes during hurricanes may be compromised in the future.

The Little Bay Port, which is under construction, is an important transport asset with a long design life. It is located in the coastal zone and will be affected by increased sea level rise. In this regard, design considerations for Little Bay Port must take into consideration that decking and wharves are likely to be exposed more frequently to larger uplift forces, ships could ride higher at the wharf, and cargo handling facilities may 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 to the ship, or else mooring and cargo handling facilities will need to be elevated. Failure to take these design considerations into account could likely result in increased weather-related delays and periodic interruption of shipping services.

Jetties or breakwaters protecting Little Bay Port will have to be high and strong enough to cope with the rise in peak tides. 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 Little Bay Port 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 (e.g. because the port authority is taking steps to adapt to such changes), its commercial well-being is critically dependent on secure transport links to other parts of Montserrat. 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 Little Bay Port 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.

E. *PHYSICAL IMPACTS*

The volcanic crisis that began in 1995 has had an indelible impact on the landscape of Montserrat. A catastrophic eruption in June 1997 closed the airports and seaports, causing further economic and social dislocation. The capital city of Plymouth, which was not physically buried in volcanic outfall, was burned by fire and acidic gases caused by numerous explosions, pyroclastic flows, and years of extensive mud and ashflow which blanketed most of the flanks of the Soufrière Hills. Plymouth was not the only area impacted. About 60% of the Island is currently in a volcanic Exclusion Zone where human entry is not permitted. It is speculated that over 80% of the population emigrated as a result of the volcanic crisis, although some have since started to return in 1998 but lack of housing limited the number. Most of the residents live in villages situated on the low, northwestern flanks of the Centre Hills. The agriculture sector continued to be affected by the lack of suitable land for farming and the destruction of crops. The Government of United Kingdom launched a three-year aid programme to help reconstruct the economy of Montserrat. Half of the island is expected to remain uninhabitable for another decade.

Although Montserrat has now emerged from the initial stages of the volcanic crisis, the volcano still remains active, and is expected to remain so into the next decade. The volcano is classified by expert scientists as 'persistently active'. Major volcanic events during 2003 were an unwelcome reminder of the impact the volcano can still have, even on the 'safe' northern third of the island, parts of which received heavy ash fall (GOM, 2008). This poses a number of challenges to the development of the island as it discourages investors and complicates the rebuilding exercise.

Loss of air and sea ports' infrastructure is a main climate change induced impact for Montserrat. Any climate-related damage to the runway and other airport facilities would have a serious negative impact on the island's tourism industry. The development of Little Bay Port is almost wholly dependent on coastal infrastructure. Severe damage that requires these facilities 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 Montserrat 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.

MODELLING FRAMEWORK

A. *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.

B. *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 Montserrat (MPCI), 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).

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

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

$$ST = f\,(MM, MGROWTH, OIL, \Delta T, \Delta P) \qquad (2)$$

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:

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

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

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 and the amount of time spent in travel. The general demand function is therefore relatively simple keeping in mind the concept of parsimony.

C. *DATA COLLECTION AND ECONOMETRIC ANALYSIS*

Several sources were used to collect the data used in the study over the sample period 1980-2009 (see table 10). Information on international transport expenditure, economic growth, per capita income and imports for Montserrat were sourced from the Eastern Caribbean Central Bank. 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 Precis Regional Circulation Model at INSMET, Cuba. 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 10: Variables used in the International Transportation Model

Variable	Unit	Source	BAU	A2	B2
Foreign Exchange Earnings from Air Transportation	U.S. mn	Eastern Caribbean Central Bank (www.eccb.org)	X	X	X
Foreign Exchange Expenditure on Sea Transportation	U.S. mn		X	X	X
Per Capita Income of Montserrat	US$		X	X	X
Economic Growth in Montserrat	%		X	X	X
Total Imports in Montserrat	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 11 and 12 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 11: Test for Cointegrating vectors – Air transportation expenditure

Null hypothesis	Alternative	Eigenvalue trace	
		Statistic	95% critical value
r=0	r>=1	75.57*	68.52
r<=1	r>=2	41.28	47.21

Source: Data compiled by author

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 12: Test for Cointegrating vectors – Sea transportation expenditure

Null hypothesis	Alternative	Eigenvalue trace	
		Statistic	95% critical value
r=0	r>=1	79.53*	68.52
r<=1	r>=2	41.19	47.21

Source: Data compiled by author

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 Montserrat to a much greater degree than precipitation.

$$\ln AT = 2.48 + 0.31 \ln MPCI + 0.29 \ln G\text{-}4GDP - 0.67 \ln OIL - 1.5 \ln \Delta T - 0.27 \ln \Delta P$$

(4.217) (7.472) (2.273) (-2.519) (-3.672) (-2.514)

n=30; R^2 = 0.7145; Theil U statistic 0.034; MAPE 15.8% (5)

$$\ln ST = 1.49 + 0.73 \ln MM + 2.15 \ln MGROWTH - 0.44 \ln OIL - 2.1 \ln \Delta T - 0.49 \ln \Delta P$$

(3.274) (5.621) (2.578) (-2.052) (-4.411) (-3.825)

n=30; R^2 = 0.6326; Theil U statistic 0.045; MAPE 14.6% (6)

The R^2 shows a relatively good fit. The air transportation model is able to predict over 70% of the variation in air transport expenditure in Montserrat, while the sea transportation can predict around 63% of the change in sea transport expenditure in Montserrat. 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 Montserrat under the relevant scenarios.

ECONOMIC IMPACT ANALYSIS OF CLIMATE CHANGE ON THE INTERNATIONAL TRANSPORT SECTOR

A. *TEMPERATURE AND PRECIPITATION AND INTERNATIONAL TRANSPORTATION*

The air and sea transportation demand models are used to generate forecasts of air and sea transportation expenditure for Montserrat until 2050. The forecasted expenditure data are used to cost the effects of climate change (temperature and precipitation) on the international transportation sector in Montserrat 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 13 shows the impact of temperature and precipitation on cumulative international transport expenditure for Montserrat 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 13: Impact of temperature and precipitation on cumulative international transport expenditure for Montserrat 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	65	45	52	38	27	31	103	72	83
2030	226	158	181	79	55	63	305	213	244
2040	614	430	491	127	89	101	741	519	592
2050	1,507	1,055	1,205	192	134	153	1,699	1,189	1,358

Source: Data compiled by author

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$1,055 million by 2050, an implied loss of some US$452 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$1,205 million by 2050, an implied loss of US$302 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$134 million by 2050, an implied loss of US$58 million when compared to the BAU scenario of US$192 million over the 40 year period. Sea transportation expenditures under SRES B2 reach a cumulative US$153 million by 2050, generating an implied loss of US$39 million.

For the combined international transportation sector, the total cumulative expenditure (in 2008 dollars) amount to US$1,189 million under the SRES A2 scenario and US$1,358 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$510 million by 2050, while that for the SRES B2 scenario reach US$341 million by 2050.

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

B. *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 Montserrat. 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 programme. The United States is considering similar cap and trade policies. The Aviation Passenger Duty (APD) has been doubled for travellers from the UK to destinations around the world and is expected to have a significant impact on travel to the Caribbean, including Montserrat. 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 an intermediate scenario basis, to reduce tourist arrivals to Montserrat by 6.3% in 2020 and by as much as 25.2% by 2050. Based on these estimates, Table 14 gives the cumulative loss in international transport expenditure in Montserrat due to the impact of climate change policies in advanced countries on international travel mobility. The potential cumulative economic loss for air transportation under the SRES A2 scenario is US$266 million and under the SRES B2 scenario is US$316 million. Losses for the BAU scenario are equal to zero since the assumption is made that there are no impacts of climate change and therefore no losses. The potential cumulative economic cost for maritime transportation under the SRES A2 scenario is US$34 million and under the SRES B2 scenario is US$39 million. The cumulative economic loss for the international transport sector in Montserrat arising from the climate change policies in advanced countries is US$300 million by 2050 under the SRES A2 scenario and US$355 million under the SRES B2 scenario over the forecast period.

Table 14: Impact of climate change policies in advanced countries on international travel mobility in Montserrat under A2 & B2 Scenarios
(2008 US$ millions)

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

Source: Data compiled by author

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 Montserrat. Sea levels are expected to continue to rise for many decades or centuries in response to a 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 fully to the sea port infrastructure since the airport, which is on a mountain top, is unlikely to be subjected to sea level rise. Table 20 gives the details of the calculations for land loss in Montserrat.

Annual international travel expenditure loss is estimated by assuming a loss of amenity factor where 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 & McSharry (2010), in analyzing the impact of SLR on the tourism sector in Montserrat make the assumption that beach loss would have a similar impact as rising temperature and use a median figure of a 17.5% reduction in tourist arrivals. In this vein, a similar assumption that the contribution of international transport expenditure to GDP is likely to decline by 17.5% for the proportion of sea port areas lost is made. The annual loss of international travel expenditure due to sea level rise is therefore estimated to amount to US$53 million (SRES A2 scenario) and US$62 million (SRES B2 scenario) by 2050.

The total rebuilding cost for Montserrat resulting from damage due to SLR is conservatively assumed as follows. The cost of the upgrade and expansion programme at Little Bay Port – US$9 million – is projected over the period 2010 to 2050 using an annual inflation rate of 5%. In line with compatible assumptions across the Review of the Economic Impact of Climate Change in the Caribbean project, about 80% of this value for the SRES A2 scenario and 40% for the SRES B2 scenario are assumed as the losses that will be generated by 2050.

Table 15: Impact of sea level rise on international transport infrastructure in Montserrat 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	34	34	68	68	68	68
Land Loss, km^2	0	0	1.4	0.7	1.4	0.7
2050 Value of Land Loss	0	0	140	70	140	70
2050 Value of International Transport Loss	0	0	6	7	6	7
2050 Value of Rebuilding Costs	0	0	61	30	61	30
Total Loss Due to Sea Level Rise	**0**	**0**	**207**	**107**	**207**	**107**

Source: Data compiled by author

In summary, the total loss facing the international transportation network in Montserrat due to sea level rise amounts to an estimated US$207 million by 2050 under the SRES A2 scenario and US$107 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.

ERUPTION OF SOUFRIERE HILLS VOLCANO ON INTERNATIONAL TRANSPORTATION

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

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

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

In this regard, a conservative approach is adapted and a catastrophic eruption of the Soufriere Hills volcano at the end of the forecast period in 2050 with the economic costs similar to that of the eruption in 1997 is assumed. The 1997 cost of US$10 million using an annual inflation rate of 5% over the forecast period is projected and about 80% of this value for the SRES A2 scenario and 40% for the SRES B2 scenario are assumed as the losses that will be generated by 2050. Table 16 shows that the impact of an eruption of the Soufriere Hills volcano on international transportation in Montserrat amounts to US$72 million under the SRES A2 scenario and US$36 million under the SRES B2 scenario by 2050.

Table 16: Impact of eruption of Soufriere Hills Volcano on international transportation in Montserrat under A2 & B2 Scenarios by 2050

(2008 US$ millions)

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

Source: Data compiled by author

TOTAL IMPACT OF CLIMATE CHANGE ON INTERNATIONAL TRANSPORTATION

The total cost of climate change on international transportation in Montserrat was calculated by combining the impacts of changes in temperature and precipitation, new climate change policies in advanced countries, sea level rise and an eruption of the Soufriere Hills volcano. Table 17 gives the breakdown of these costs and shows that the impact for air transport could range from US$742 million (SRES A2 scenario) to US$630 million (SRES B2 scenario) and for maritime transport impact estimates range from US$347 million (SRES A2 scenario) to US$209 million (SRES B2 scenario). For international transport, as a whole, the impact of climate change varies from US$1,089 million under the SRES A2 scenario to US$839million under the SRES B2 scenario.

Table 17: Total impact of climate change on international transport expenditure in Montserrat under A2 and B2 Scenarios to 2050

(2008 US$ millions)

Losses Due To	**Air Transportation**		**Maritime Transportation**		**International Transportation**	
	A2	**B2**	**A2**	**B2**	**A2**	**B2**
Changes in Temperature & Precipitation	452	302	58	39	510	341
International Transport Mobility	266	316	34	39	300	355
Sea Level Rise	0	0	207	107	207	107
Eruption of Soufriere Hills Volcano	24	12	48	24	72	36
Total Impact	**742**	**630**	**347**	**209**	**1,089**	**839**

Source: Data compiled by author

Table 18 presents the net present value of the total impact of climate change (in 2008 dollars) on the air and sea transportation industry in Montserrat for 2050. The net present value of the total impact under the SRES A2 scenario amount ranges from US$570 million (4% discount rate) to US$1,013 million (1% discount rate). The net present value under the SRES B2 scenario varies from US$428 million using a 4% discount rate to US$758 million under a 1% discount rate.

Table 18: Net present value of total impact of climate change on international transportation in Montserrat to 2050 under Scenarios A2 and B2

(2008 US$ millions)

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

Source: Data compiled by author

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

A. *MITIGATION STRATEGIES*

The technological and operational potential for mitigating international and domestic GHG emissions from aircraft and sea vessels is considerable. Table 19 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.

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.

Table 19: 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 et al., (2009)

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.

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 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 principle of, Common But Differentiated Responsibilities, in which different obligations are imposed on the Parties to 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).

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 are sizeable costs associated with adaptation.

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 20 adapts the Becken-Hay framework, showing key factors for strengthening the adaptive capacity of the international transportation sector to climate change.

Table 20: 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 programmes
'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

In addition to building adaptive capacity, adaptation strategies must be mainstreamed into national development policies, adopted and implemented before it is too late. Tables 21-22 show select potential climate changes, their impacts on air and sea transportation and adaptation options. A successful adaptation strategy would entail combining these various measures with the specific climate change impacts being experienced.

The most immediate and rapid adaptation response to the 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 John A. Osborne Airport and Little Bay Port 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 Montserrat.

Table 21: Montserrat - climate change, air transportation and adaptation options at John A. Osborne Airport

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

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

Table 22: Montserrat - climate change, sea transportation and adaptation options at Little Bay 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 t to provide adequate clearance Protection of terminal and warehouse entrances	More dredging of some channels Raising or construction of new jetties and seawalls to protect 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 Damage to cranes, other docks and terminal facilities	Emergency evacuation procedures that become more routine	Hardening of docks, wharves, and terminals to withstand storm surge and wave action	

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

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 areas vulnerable to flooding and storm surge might become more commonplace. Operators at John A. Osborne Airport and Little Bay 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 Montserrat, which are designed for a 40-50 -year service life, transportation planners and engineers must consider how climate changes will affect these facilities in the future. For John A. Osborne Airport, 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 Little Bay Port, the main adaptation options are building 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 changes in climate. Meyer (2008) found that forces resulting from water flows were found to be the most dominant impact on design elements across all climate changes. Climate extremes such as increased storm surges and greater wave heights are likely to place the greatest demands on air and sea infrastructure because they are likely to push the limits of the performance range for which these facilities were designed.

How should engineering design decisions be modified for a long-lived and expensive transportation infrastructure such as John A. Osborne Airport and Little Bay Port 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 is not feasible in Montserrat where a good part of the island is in an exclusion zone. A final option is to hedge by retrofitting the terminals at John A. Osborne Airport and Little Bay Port 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 Montserrat. 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 and the desirability of managed growth policies and protection of critical infrastructure.

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 Montserrat 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, ongoing 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 23:
MCA of the effects of climate change on international transport infrastructure in Montserrat

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 John A. Osborne Airport and Little Bay Port	Monitor coastal hazard risk (sea levels and waves)
Type	Research	Research	Research	Policy
Ownership	Montserrat – Ministry of Works, John A. Osborne Airport and Little Bay Port	Montserrat – Ministry of Works	Montserrat – Ministry of Works	John A. Osborne Airport and Little Bay 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 23(continued):

MCA of the effects of climate change on international transport infrastructure in Montserrat

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	Montserrat – Ministry of Works, John A. Osborne Airport and Little Bay Port	Montserrat – Ministry of Works, John A. Osborne Airport and Little Bay Port	Montserrat – Ministry of Works, John A. Osborne Airport and Little Bay Port	John A. Osborne Airport and Little Bay 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

Source: Data compiled by author
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.

Table 23 shows the MCA of the effects of climate change on international transport infrastructure in Montserrat. 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

C. *EXAMPLE OF MULTI-CRITERIA ANALYSIS: ADAPTING LITTLE BAY PORT 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.

The best adaptation measures tend to include a combination of responses. The threat of sea level rise has seen a renewed acknowledgement of the need for Integrated Coastal Zone Management (ICZM) – the approach that attempts to, "Consider over the long term to balance environmental, economic, social, cultural and recreational objectives, all within the limits set by natural dynamics" (Commission of European Communities 2000). ICZM theory is seldom disputed, but for local decision makers the difficulty is how to choose between the range of options available when responding to sea-level rise, and how to prevent piece-meal, knee-jerk reactions that compound the problem.

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 Little Bay Port may represent the best option for Montserrat, further 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, 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, social and institutional options tend to represent an appropriate first call. With regard to retaining flexibility and adaptation options, institutional responses tend to be better than biological options and significantly better than infrastructural approaches. The same options pose less threat of maladaptation and can offer high levels of protection. The ultimate institutional approach involves the implementation of a coastal buffer zone that is void of settlement. In some instances in Montserrat, 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.

CONCLUSIONS

Montserrat 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 presence of a ‘persistently active’ Soufrière volcano into at least the next decade worsens the situation. The total cost of climate change on international transportation in Montserrat was calculated by combining the impacts of changes in temperature and precipitation, new climate change policies in advanced countries, sea level rise and an eruption of the Soufriere Hills volcano. The impact for air transport could range from US$630 million (SRES B2 scenario) to US$742 million (SRES A2 scenario) and for maritime transport impact estimates range from US$209 million (SRES B2 scenario) to US$347 million (SRES A2 scenario). For international transport, as a whole, the impact of climate change varies from US$839 million under the SRES B2 scenario to US$1,089 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 - John A. Osborne Airport and Little Bay - 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 Montserrat. 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 IMO, but so far neither organization has reached agreement on binding actions, and many key issues remain unresolved.

Montserrat 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.

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.

Caribbean Development Bank (CDB). 2007. CDB Annual Economic Review 2007.

Commission of European Communities (2000). Integrated Management of Coastal Zones. http://www. ec.europa.eu.

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.

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). 2009a. *Economics of Climate Change in Latin America and the Caribbean (Summary),* Santiago, Chile.

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.

Government of Montserrat (GOM). 2008. Montserrat Sustainable Development Plan 2008-2020. Ministry of Economic Development and Trade.

Government of Montserrat (GOM). 2009. GIS in Hazard Mapping and Vulnerability Assessment. Ministry of Agriculture, Trade, Land, Housing and Environment.

Greene, W.H. 2008. Econometric Analysis (6th Ed.). Prentice Hall, U.S.A.

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

Inter-American Development Bank (IADB). 2009. IDB Country Strategy with Montserrat (2009-2013)

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.

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

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

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.

McCauley, C., and S. Mendes. 2006. Montserrat Centre Hills Socio Economic Assessment Report.

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.

McGuire, W. 2003. In the shadow of the volcano, *The Guardian*, October 16, 2003.

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.

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.

Norton, G. 2001. "Monitoring Soufriere Hills Volcano, Montserrat". *Earthworks Journal*, Issue 12. British Geological Survey.

Norwell, G. 2004: *Impact of Climate Change on Road Infrastructure.* Austroads Inc., Sydney, Australia.

O'Brien, K. 2004. The Economics of Adaptation. Stern Review Workshop, 9 May, UK. See http://www.hm-treasury.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).

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 Montserrat.

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

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. 2009a. Multi-Year Expert Meeting on Transportation and Trade Facilitation: Maritime Transportation and the Climate Change Challenge, Summary of Proceedings.

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

U.S. Department of Transportation, Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase 1. A Report by the US Climate Change Science Program and the Subcommittee on Global Change Research [Savonis, M.J., V.R. Burkett, and J.R. Potter (eds.)], 2008. Department of Transportation, Washington, DC, USA.

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. 2006. Caribbean Air Transportation: Strategic Options for Improved Services and Sector Performance, Finance, Private Sector and Infrastructure Department, Latin America and Caribbean Region.

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 Montserrat, 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.