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AN ASSESSMENT OF THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE COASTAL AND HUMAN SETTLEMENTS SECTOR IN BARBADOS

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Table of contents

List of figures

List of tables

List of Acronyms

HadCM3	Hadley Centre Coupled Model, version 3
AOGCM	Atmosphere-ocean general circulation model
IPCC	Intergovernmental Panel on Climate Change
UNFCCC	United Nations Framework Convention on Climate Change
TAR	Third assessment report
VAT	Vulnerability Assessment Tool
LECZ	Lower elevation coastal zones
NOAA	National Oceanic and Atmospheric Association
CCCCC	Caribbean Community Climate Change Centre
ECLACC	Economic Commission for Latin America and the Caribbean
SIDS	Small Island developing states

Executive Summary

This study assesses the potential economic impact of climate change on coastal human settlements in the Caribbean, with specific reference to Barbados, and evaluates the costs and benefits of undertaking various adaptation strategies. The aim is to assist Caribbean territories in developing the strategies and capacity needed to deal with the potential impact of severe weather events that are anticipated to occur with increased frequency and intensity as a result of climate change.

Some of the key anticipated manifestations of climate change for the Caribbean include elevated air and sea-surface temperatures, sea-level rise, possible changes in extreme events and a reduction in freshwater resources.This research focuses on how human settlements distributed along the coast of Guyana, especially those in low elevation coastal zones (LECZ)are affected by these impacts. Focusing on three potential transmission sources - sea-level rise, stronger storm hazards and increased precipitation – the study considers the vulnerability of populations in the LECZ areas and estimates the overall threat posed by climate change to coastal populations and infrastructure.

Vulnerability to climate change (measured as exposed assets) was estimated for four emission scenarios as outlined by the Special Report on Emissions Scenarios (SRES), namely the A1, A2, B1 and B2 scenarios for the period 2010 to 2100 and as detailed by the Intergovernmental Panel on Climate Change (IPCC), using global circulation models (GCM) and storm surge hazard maps.

1.Vulnerability within the LECZ

The infrastructures at risk are churches, cemeteries, Government buildings, Post Offices, petroleum storage facilities, Police Stations, Power Stations, the Pier, Recreation sites, Schools, Transport Centre and the Wharf.

The housing system in Barbados dates back to the colonial British colonial times. The designs of urban housing are a combination of West African and English architecture. The variation in urban housing quality is reflective of the colonial past. Of the 91,406 dwellings in Barbados, 53.25% are located in the Parishes of St. Michael and Christ Church with average occupancy rate of 93.38%.

Vulnerability of the coastal zone includes risk of flooding and erosion, saltwater intrusion, loss of arable lands, freshwater shortage and contamination, and potential loss of coastal eco-systems. As most of the infrastructure, settlements and facilities are located on or near the shore, loss of land due to sea level rise (SLR) is expected to disrupt the economic and social sectors, for example the tourism industry and agriculture. Erosion, along with saltwater intrusion and inundation, would result in the loss of arable lands.

Economy: The main economic activities located within LECZ of Barbados are shipping, manufacturing and tourism. The clustering of infrastructure has significant economic benefit to the national economy, but it also presents a disadvantage in that it increases the vulnerability of the economy to the impact of climate change. Ports constitute an important economic activity to the economy and also account for a large proportion of employment. The Bridgetown Portfacilitates 72% of the Gross Domestic Product (GDP) through the export and import of merchandise into the economy. In addition, the tourism sector which is the backbone of the Barbados economy, has earned about $172 million out of GDP that was estimated at $1.15 billion for the year 2008.Over 90% of all hotels in Barbados are within or proximal to the beach and are therefore highly vulnerable to climate

change - induced SLR. Cruise ship passengers arrivals rose 20% for the 7 year period ending 2009. The vulnerable[1] road network was estimated to stretch over 288 km.

Population: Climate change will increase the risk of coastal human settlements to sustain damage with the occurrence of high tides combined with storm surges and/or severe weather changes such as precipitation or drought. The poor within the economy are those who are least able finance the adaptation to climate change. The United Nations estimates that there exist 7,000 households or 35,000 persons with per capita annual income less than US$2,751, and as such are deemed to be living below the poverty line. The latter translates into approximately 14% the population and 9% of the household. 60% of the poor households are headed by females. Unemployment within poor households was estimated to be 31% or 250% of that which prevail in non-poor households.

Coastal Ecosystems and Services: Coastal ecosystem encompasses sub-ecosystems such as mangrove swamps, corals, seagrass beds and, most of all; the coast that supports human settlements and economic activity including agricultural fishing, port and docking services for the fishing industry, and tourism. The World Resource Institute[2] (WRI) stipulates that, to date the coastal eco-systems are already under severe threat from the impacts of human activities (e.g. pollution, over-exploitation of resources, urbanisation).

Corals function as a natural breakwater along the coasts and represent one of the most important natural sea defences available for Barbados. These coastal ecosystems are increasingly being threatened by SLR, a rise in sea surface temperature and an increase in extreme weather events. Vulnerability to sea level rise includes induced land loss which is most evident in Christ Church and Saint James. Both parishes' accounts for 89% of the reported land loss associated with CC induced land losses.

The Government of Guyana (GoG) has already made significant investment in the country's adaptive capacity and improves its disaster response strategy as part of its disaster mitigation efforts and additional efforts are currently underway to reduce the vulnerability of the economy. The adaptation efforts comprised both hard engineering structure and policy to prevent infrastructure deficits in the pass to be continued in the future. The main pillars of Barbados' adaptation strategy are legislative changes and engineering investments along the coast.

2. Key findings

The study concludes that the potential benefits to be derived from adaptation exceed the estimated cost. The analysis has shown that based upon exposed assets and population, sea level rise can be classified has having the potential to create catastrophe in Barbados. The main contributing factor is the concentration of socioeconomic infrastructure along the coastline in vulnerable areas. Climate change threatens to cause serious losses to coastal housing, tourism and critical lifeline infrastructure in coastal areas of Barbados.

The research finds that Barbados' vulnerability to climate change, especially within the LECZ, will decrease significantly with adaptation. The exposed assets reached an estimated US$4.7 billion in 2020 with a maximum of US$44 billion, with the business as usual (BAU) case having the greatest exposed asset. With adaptation, the reduction in average annual vulnerability within the LECZ is approximately US$12.7 billion or approximately 270% of the estimated GDP for the year 2010.

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[1]assuming equal distribution of road

[2] WRI (2004), "Reefs at Risk" http://pdf.wri.org/reefs_caribbean_full.pdf

3. Policy recommendations

Adaptation initiatives should comprise enabling activities especially when vulnerability and adaptation assessments are done. The adaptation to climate change should be mainstreamed into a sustainable development programme of action. The protection of areas within the LECZ against climate change should be promoted as a means of fostering development. Development is the means through which the sustainable finance of adaptation can be achieved.

Adaptation strategy should be anticipatory for the coastal zones. This strategy should include a combination of accommodation and protection, especially if the residual vulnerability is unacceptably high. As is in the case of Barbados, the residual vulnerability within the LECZ to climate change is still high. The progressive abandonment of land and structures in highly vulnerable areas is not a viable option for Barbados due to land constraints and the type of tourism product that the country offers. The government must place significant effort in ensuring that adequate investment in and maintenance of engineering coastal defense structures as part of the sustainable development plans for the economy exist

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I. THE INTRODUCTION

A. OVERVIEW

The United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1[3], defines climate change as a change of climate, which is directly or indirectly the outcome of human activity that alters the composition of the global atmosphere and which is, in addition to natural climate variability, observed over comparable time-periods. Some of the key manifestations of climate change in the Caribbean include elevated air and sea-surface temperatures, sea-level rise, possible changes in extreme events and reduction in freshwater resources. These manifestations, if not planned for and adaptation strategies implemented, will have negative impacts on the economic and social development of Barbados.

In Barbados approximately 70% of the population lives in coastal cities, towns and villages, a result of the abundance of natural harbours relatively easy to navigate and therefore easily accessible. The enumerated non-institutional population of Barbados is 268,800. (Barbados Census[4]).

IPCC (2001)[5] projected climate change and their associated manifestations imply important ramifications for coastal communities. Climate change will include a range of changes of which the acceleration in sea level rise is one. Also included are further rise in sea surface temperature, changes in rainfall volume and patterns, increased incidence of extreme weather events and storm surges, and ocean acidification will increase the risks to human settlements associated with increased coastal erosion, flood, saltwater intrusion, and freshwater availability, altered and accelerated loss of coastal ecosystems. The most vulnerable industries and human settlements are generally those in the Low Elevation Coastal Zones (LECZ) that land area contiguous with the coastline up to a 10-metre rise elevation.

The Barbadian economy is highly dependent on climate-sensitive resources such as tourism. These industries are located in areas prone to the manifestations of extreme weather events, for example storm surges. With rapid urbanization is occurring within the LECZ, the country is extremely vulnerable to the manifestations of climate change. For example, the parishes of Christ Church and St. Michael will be extremely vulnerable. The direct impact of climate change – for example storm surge and SLR - will be concentrated within LECZ. The concentration of socioeconomic infrastructure within the LECZ will multiply the vulnerability of the economy to manifestation of climate change. This reality is a binding constraint on future development because it increases the rate of depreciation of both natural and physical capital[6] and not only that, increase cost of future development efforts because adaptation must be factored in.

B. OBJECTIVE

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[3] http://unfccc.int/resource/docs/convkp/conveng.pdf

[4] http://www.caricomstats.org/Files/Publications/NCR%20Reports/Barbados.pdf

[5] **HadCM3** (*Hadley Centre Coupled Model, version 3*) is a coupled atmosphere-ocean general circulation model (AOGCM) developed at the Hadley Centre in the United Kingdom. It was one of the major models used in the IPCC Third Assessment Report in 2001

[6] Adapted from IPCC 2007

This report seeks to assess the potential economic impact of climate change in the Caribbean specifically Barbados along with the evaluation of the costs and benefits of undertaking adaptation strategies.

The aim of the study is to assist Caribbean territories with the development of adaptation strategies and capacity needed to deal with the potential impact of severe weather events anticipated to occur in association with climate change. It is anticipated that this will drive the impetus to incorporate cost benefit analysis into the long-term development strategies of town planners, risk transfer specialists and other allied professionals. The report has further serve to enhance prevention, preparedness and mitigation capacities of emergency managers and community groups.

C. GENERAL METHODOLOGICAL APPROACH

This report presents two general methodologies to assess the exposure associated with the manifestations of climate change in Barbados. First, a place based approach is used for the identification, analysis, and visualization of both the physical system and the human dimension of the LECZ. Given the limitation in the availability of micro-data, an aggregate costing/exposure methodology according to Nicholls (2008) was adapted for the estimation of the cost benefit analysis.

The steps adhered to are as follows:

- Identification of the LECZ which the literatures describe as land area with a vertical height 10 metre above median/peak tide level

- Vulnerabilities to the manifestation of climate change are assessed according to the prediction of the global circulation models. That is, a place base approach is used to identify the spatial distribution of biophysical and socio-economic vulnerabilities. The intersecting biophysical vulnerable and socioeconomic vulnerable is identified by overlaying the different maps. Thereby enabling the identification of the overall hazard vulnerability within the LECZ.

- The estimation of aggregate exposure within the LECZ according to Nicholls (2008).

The assessment includes:

- The assessment of the vulnerability of the critical elements within the LECZ to storm surge hazards; and

- The utilization of the storm surge hazard maps and the vulnerability assessment to determine exposure associated with storm surge impact.

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II. MANIFESTATION OF CLIMATE CHANGE

Barbados, a Small Island Developing State (SIDS) is 431 km^2 in area and is located in the Caribbean at latitude 13^o 4' North and longitude 59^o 37'. The island is low lying and is surrounded by coral reefs which are ideal for snorkeling and diving expeditions (figure 20). In the Scotland District a section of the raised reefs has been eroded. This is also the highest section of the island and home to Mount Hillaby, which is 340m above sea level.

The geology of the island is largely made up of underlying sedimentary deposits capped by a layer of coral up to 300 feet (90m) thick (raised reef terraces). Limestone caps can be found in some sections of the Island and these are characterized by huge cracks and form a complex series of gullies running mainly from this higher, eastern portion of the island to the west coast.

The Island is water scarce and as such these gullies help to recharge the limestone aquifers, by transporting water via underground streams. Tropical in nature, it experiences an oceanic climate with average Island temperatures. The Island experiences a wet and a dry season, with the wet season coinciding with the Atlantic hurricane season, June to November of each year.

A. SEA LEVEL RISE

Sea-level rise and extreme water levels are important components of climate change for coastal areas. An increase in sea surface temperature is strongly evident at all latitudes and in all oceans. The scientific evidence indicates that increased surface temperature will intensify cyclone activities and heighten storm surges[7].These surges[8] will, in turn, create more damaging flood conditions in coastal zones and adjoining low-lying areas. The destructive impact will generally be greater when storm surges are accompanied by strong winds and large onshore waves. The historical evidence highlights the danger associated with storm surges.

Coastal zones have high ecological value and economic importance, and typically are more densely populated than inland areas, Mcgranahan, Balk and Anderson (2007); Small and Nicholls, (2003). The potential impact is extremely huge relative to that of developed countries because of the relatively large percentage of the population and the associated economic activities that are concentrated in coastal and low-lying coastal cities.

Nicholls and others (2008) stipulate that few Small Island Developing States (SIDS) coastal cities are prepared for the impact of climate change particularly sea-level rise and storm events. Coastal communities are typically undergoing fast and unplanned growth relative to inland areas and they have high population densities and overburdened infrastructure, all of which will exacerbate the vulnerability to any potential impact associated with changes in extreme water levels associated with the manifestations of climate change over the next century.

Sea level rise impacts to low-lying coastal areas are flooding, erosion, increased frequency of storm surges, and saltwater intrusion. The magnitude of these sea level change impacts will vary from place-to-place depending on topography, geology, natural land movements and any human activity

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[7]A sea-surface temperature of 28^o C is considered an important threshold for the development of major hurricanes of categories 3, 4 and 5 (Michael, Knappenberger, and Davis 2005; Knutson and Tuleya 2004)
[8]*Storm surge* refers to the temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions: low atmospheric pressure and/or strong winds (IPCC AR4 2007)

which contributes to changes in water levels or sediment availability (subsidence due to ground water extraction).

As reported in the Third Assessment Report (TAR) of the IPCC, tide gauge records have indicated sea level rise in the region of 1 to 2mm year^{-1} since the a 1950s, according to Church and others (2001). The latter is consistent with tide gauge estimates provided by Woodworth and Player, (2003), Douglas, (2001); Peltier, (2001), Miller and Douglas (2004), Holgate and Woodworth (2004), Church and others (2004) Church and White (2006). Satellite altimetry imagery estimates has put sea level rise to 4mm year^{-1} according to Nerem and Mitchum (2001), Cazenave and Nerem (2004), Leuliette and others (2004), Cabanes and others (2001).

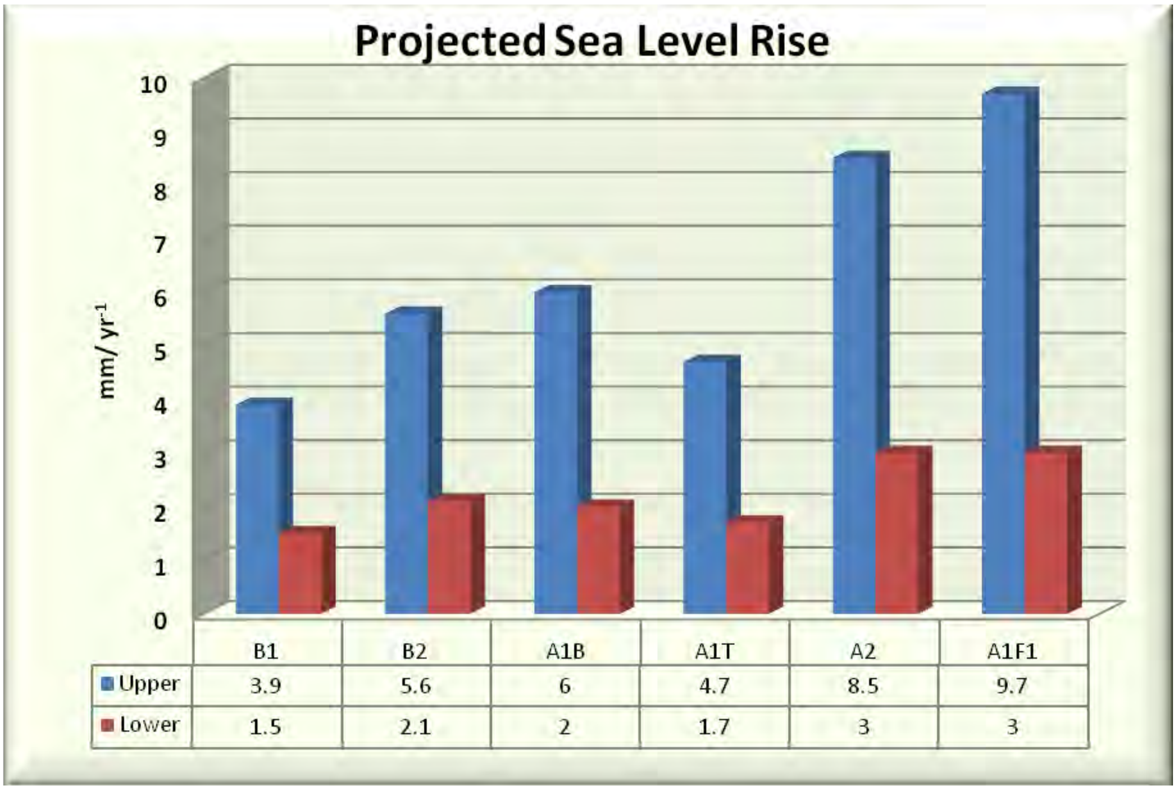
Douglas (1992) and Lambeck, (2002) have shown via the use of tidal sea gauges that sea level rise is not uniformly distributed across the world. In some regions the estimated sea level rise is 5 times that of the global mean; hence the need to go to local estimates of sea level rise for the analysis in the next section of this paper. This is consistent with discrepancies put forward by the IPCC TAR and local meteorologists. In Barbados, it is assumed that the estimated sea level rise is projected to be as high as 10 mm year^{-1}, taking into account the marginal error of the estimate.

Climatic condition and anthropogenic factors do contribute to sea level rise. The IPCC TAR uses the Permanent Service for Mean Sea Level (PSMSL) to project rises in sea level. Leading sea level rise from authors such as Church and others (2004) and Church and White (2006) have shown that the estimated spatially specific sea level rise varies by the time period 1855 to 2003 vs. 1955 to 2003 and 1990 to 2003. That is, estimates of sea level rise per location varies by methodology and changes in spatial sea level patterns through time and time period of the analysis.

Irrespective of the methodology used to estimate sea level rise it is concluded that the level of increase will vary significantly by region. In addition, the models used to estimate sea level rise are not consistent as to the cause of global sea level rise. There is a plethora of reasons given within the literature for the causes of sea level rise, most of which are also location specific. According to IPCC[9] , the projected sea level over 100 years, ranges from a low of 1.5 mm year^{-1} to approximately 10 mm year^{-1} over the next 100 years (figure 1). The latter assumption consistent with scenarios used CPACC (2002).

[9]http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter10.pdf

Figure 1: Average sea level rise[10]



Sea-level rise will increase the vulnerability of the country to flood hazards considerably by increasing the areas that are exposed to the highest flood risk, hence increasing the number of critical facilities, properties and people to the risk of flooding. For this paper, the average of the upper limits of the A2 and B2 scenario to the nearest metre is 1m or 10 mm year^{-1}.

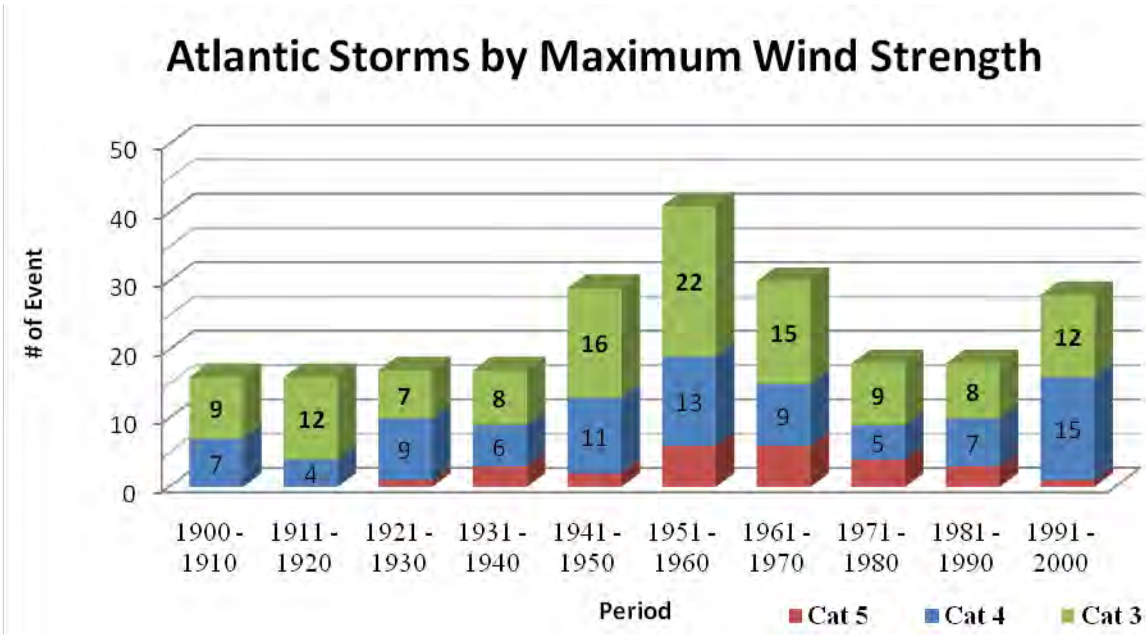
B. CHANGE IN WEATHER CONDITION

The NOAA[11] data has shown that the number of tropical storm systems within the Atlantic Ocean will increase over the next century (figure 2). With the formation of these systems it is likely that the outer band of clouds will create the possibility of high intensity rainfall.

[10] http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter10.pdf

[11] Stanley B. Goldenberg from the NHC (TPC) Best Track dataset. http://www.aoml.noaa.gov/hrd/Storm_pages/Atl/ATLwind.dat

Figure 2: Atlantic storms[12]

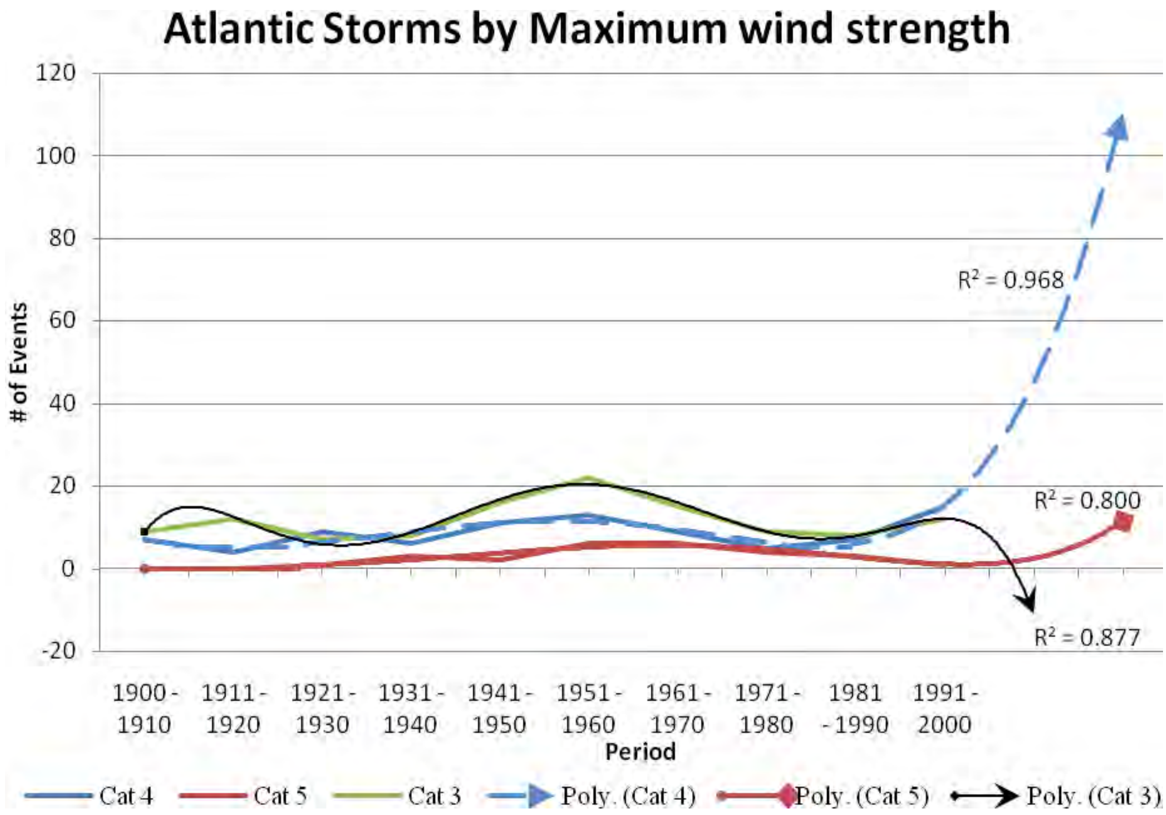


1 .Projection for the Atlantic Storm

The general circulation models have predicted an increase in the frequency of high intensity storms over the next 100 years (figure3). The polynomial trendline fitted to the data for category 3, 4 and 5 storms indicate that it is likely that there will be a reduction in the number of category 3 storms within a decade while that of categories 4 and 5 will increase. This is consistent with the general findings among the general circulation models. The trendline for each storm category explains at least 80% of the variations in the number of decadal events by category, with 97% of the variation in occurrence of category 5 events being explained (figure 3).

[12]NOAA estimates,http://www.aoml.noaa.gov/hrd/Storm_pages/Atl/ATLwind.dat

Figure 3: Trends in Atlantic Storms[13]



C. CHANGES IN PRECIPITATION

The general circulation models are predicting that for a decrease in rainfall for Barbados, the median changes are negative, UNDP[14]. The range in projection ranges between -53 and 15% by the year 2090. Extreme weather events such as heavy rainfall decrease with a range in predictions are between -53 to 15% until the 2090. This is also true for 5-day rainfall.

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[13] NOAA estimates http://www.aoml.noaa.gov/hrd/Storm_pages/Atl/ATLwind.dat
[14] UNDP Climate Change Country profile. http://country-profiles.geog.ox.ac.uk/index.html?country=Barbados&d1=Reports

III. VULNERABILITY METHODOLOGY

A. Literature Review

The vulnerability of coastal areas to sea-level rise report was published by the IPCC[15] in 1992, where the common methodology was developed. This refers to a process that comprises of seven consecutive analytical steps that allow for the identification of populations and physical and natural resources at risk, and of the costs and feasibility of possible responses to adverse impacts.

That is:

a) People affected: The people living in the hazard zone affected by sea-level rise;

b) People at risk : The average annual number of people flooded by storm surges;

c) Housing value at loss: The market value of houses which could be lost due to sea-level rise;

d) Land at loss: The area of land that would be lost due to sea-level rise;

e) Wetland at loss: The area of wetland that would be lost due to sea-level rise;

f) Adaptation costs: The costs of adapting to sea-level rise, with an overwhelming emphasis on protection;

g) People at risk: The average annual number of people to be impacted.

Nicholls, (1995) has shown that the common methodology has been applied to at least 46 countries inclusive of quantitative base case studies (figure 4). This study will serve as a preparatory assessment to identify priority communities and regions that are highly susceptible to climate change. One of the objectives here is to identify the potential magnitude of climate change and its possible consequences to coastal communities in Barbados. Thereby creating the momentum towards the implementation policies that reflect long-term thinking in regards to combating the likely impact of climate change. According to Burton (1997), the focus of the study places significant emphasis on the current problems that affect the coastal housing communities in Barbados and how these vulnerabilities will be exacerbated by climate change over the next 100 years.

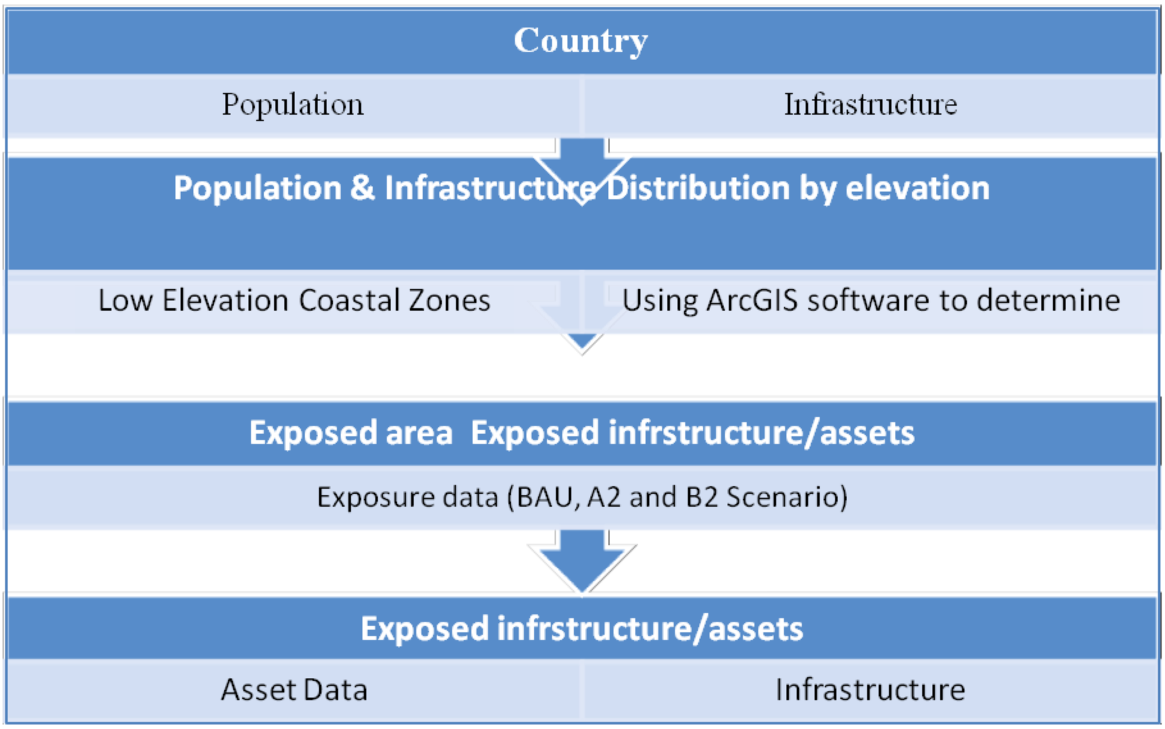
Watson and others (1996), as it relates to the coastal housing settlements, identifies vulnerable people to be those living in low lying coastal areas and or being prone to floods, a definition that is used in this analysis. According to the IPCC 2000, the manifestations of climate change will be a significant threat to coastal settlements. The increased vulnerability associated with socio-economic characteristics of the dwellers in coastal communities will give a significant indication of the private capacity to adapt and as it reflects in the aggregate, strategies that the government must implement to mitigate against climate change.

[15] Vulnerability of Coastal Areas to Sea-Level Rise, (IPCC CZMS, 1992)

According to IPCC (2001), sea-level rise represents the most significant vulnerability to climate change for SIDS. For Barbados, the spatial concentration of human settlements within the LECZ increases the vulnerability to the predicted sea level rise scenarios. Of significance, is that 18% of landmass in Barbados forms a part of the LECZ with a population of approximately 47,000 inhabitants.

B.Methodology

Figure 4: Flowchart of the Methodology[16]



C. Estimates of Exposure

The simulations to estimate the exposed number of persons and associated economic assets that are located within the LECZ, that is, the socioeconomic asset and persons that exist within the 10 metre vertical contour of the Island. The ideal situation is to calculate the 1 in 100 year return period extreme water level for each scenario based on the national population distribution data and a Digital Elevation Model (DEM) resolution elevation data, this was not possible due to data constraints.

Estimates of the population for the exposed area will be extracted from the national dataset. The population by elevation on a horizontal map of geographical cells is then estimated by mapping the population distribution for each division of the district onto the DEM (extracted, again from the national dataset), which allows the total population distributions against elevation to be estimated.

Note that these exposure estimates are the potential impacts on population and assets of the 1 in 100 and or 1in1000 year return period extreme water level events *in the absence* of sea flood

[16]Adapted From NICHOLLS And others, 2008

defenses. In estimating the infrastructure assets exposed to the extreme weather or water level, a method used in Nicholls *and others* (2007) is adopted here to relate assets to the population exposed within the LECZ.

(Equation 2). This rule is widely used to estimate asset exposure.

$Ea = Ep \times GDP_{percapita}\ (PPP) \times 5$ ……………………................……………… (Eq. 2)[17]

Where,

Ea= Exposed assets

Ep= Exposed population

$GDP_{percapita}$ *(PPP)* = the nation's per capita Gross Domestic Product (GDP) Purchasing Power Parity (PPP).

Country-level population and downscaled projections based on the SRES B2 Scenario, 1990-2100 Country-level GDP and downscaled projections based on the SRES A1, A2, B1, and B2 marker scenarios, 1990-2100[18].

D. Value of Exposed Assets Methodology

Estimates for each indicator were calculated by overlaying the inundation zone with the appropriate exposure surface dataset (land area, GDP, population, urban extent, agriculture extent, and wetland)[19].10 Exposure surface data were collected from various public sources.

Unless otherwise indicated, latitude and longitude are specified in decimal degrees. The horizontal datum used is the World Geodetic System 1984. For area calculation, grids representing cell area in square kilometers were created at different resolutions, using length of a degree of latitude and longitude at cell center.

For the exposure surfaces, two GIS models were built for calculating the exposed value.

Since the units for GDP and population are in millions of U.S. dollars and the number of people, respectively, the exposure was calculated by multiplying the exposure surface with the inundation zone and then summing to a country total. Exposure indicators, such as land surface, urban extent, agriculture extent and wetlands were measured in square kilometers.

For exposure indicators such as land area, population and GDP, which have measured country "coastal zone" totals available, the exposed value is adjusted to reflect its real value by using the following formula:

$$V_{adj} = \frac{CT_{mea}}{CT_{cal}} * V_{cal}$$

[17]Used in absence of detailed information on property value estimates.
[18]http://sedac.ciesin.columbia.edu/mva/downscaling/ciesin.html
[19]The delineated surge zones and coastal zone are at a resolution of 3 arc seconds (approximately 90 m). The resolution of indicator datasets ranges from 9 arc seconds to 30 arc seconds. Due to this difference in resolution, a surge zone area may occupy only a portion of a single cell in an indicator dataset. In this case, the surge zone is allocated only a proportion of the indicator cell value.

Where:

Vadj: Exposed value adjusted; set equal to Exposed assets calculated from equation 2
Vcal: Exposed value calculated from exposure grid surfaces;
CTmea: Country “coastal zone” total obtained based on statistics;
CTcal: Country “coastal zone” total calculated from exposure grid surface.

E. IPCC SOCIO-ECONOMIC SCENARIOS

The analysis for future impact projections for future socioeconomic changes is based on future population projections, changes in urbanization and GDP following the country’s growth trend.

Future projections for A2 and B2 scenario will be obtained from the country level predictions, following the methodology of Hanson and others (2009), equations 1 and 2 will be used to determine the different socioeconomic impact. In addition, focusing on worst-case impacts, consultations with the local experts will determine the rate of urbanization scenario and construction patterns for the areas of interest. Two population growth distribution scenarios, according to the A2 and B2 scenarios for the period 2010 to 2100 were considered relative to the most recent population census, in this case the 2000 census report. For the analysis we assume that population growth uniformly distributed according to the most recent census data.

1 .Climate Change Scenarios

The scenario estimates for population and GDP projections for this research came from the Centre for International Earth Science Information Network (CIESIN)[20]. The specific databases[21] are Country-level Population and Downscaled Projections based on the B2 Scenario, 1990-2100 and the Country-level GDP and Downscaled Projections based on the A1, A2, B1, and B2 Marker Scenarios, 1990-210.

From this database, baseline scenarios of different socio-economic and technological developments, A2 and B2, were accepted as projections of GDP and population data until the year 2100.

IV. OVERVIEW OF BARBADIAN ECONOMY

Figure 5: Bridgetown Barbados[22]

[20]CIESIN, (2002)
[21]published at http://www.ciesin.columbia.edu/datasets/downscaled/
[22]Copied from http://www.climate.org/climatelab/Barbados#ref_12 (Feb, 2011)

A. Economy

Due to its historical past the Islands economy was a sugar-based one. However with post-independence period, the country has diversified its economic base to include:

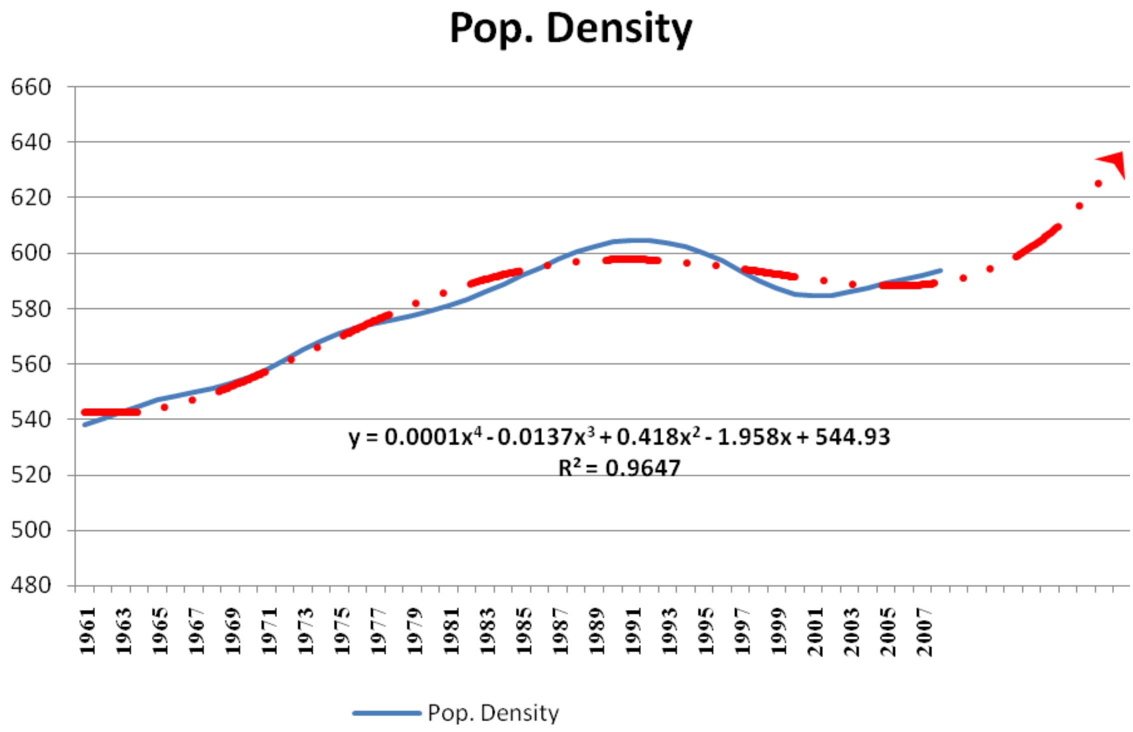
- Tourism
- Sugar
- Manufacturing, and
- Finance and Business Services sectors

These industries generate the foreign exchange needed to support the country's imports as the country imports a significant portion of its food stuffs, fuels, construction materials and other goods. One of the main economic activities within the Barbadian economy is the offshore banking services; these financial centers are concentrated in the financial districts between St. Michael and Christ Church.

B. Social Characteristics and Demography

The main areas of population concentration have not changed since independence, although some of the sparsely populated regions had positive changes in population. The demographic trends in Barbados since 1980 have shown a concentration of human settlements along the south and west coast of the Island.

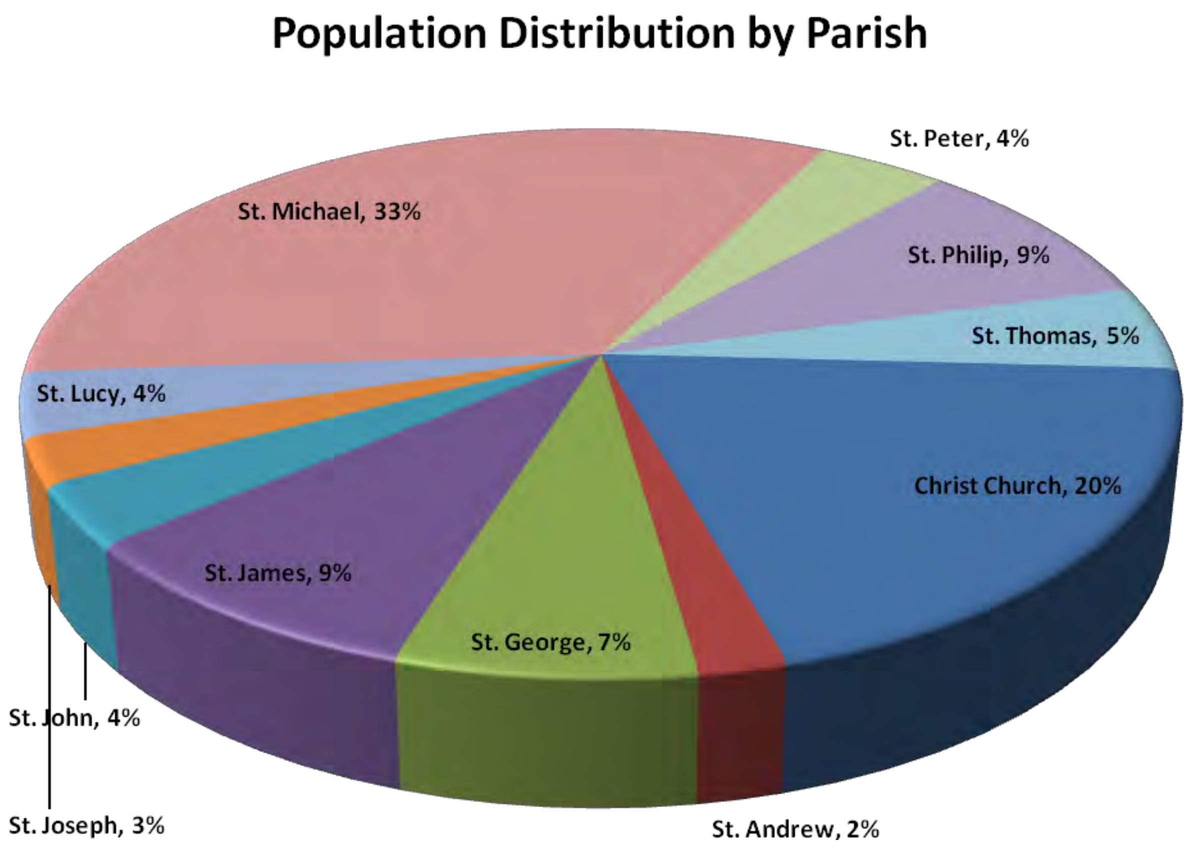
Figure 6: Population density of Barbados



Source: Data compiled by author

The population density trend line is forecasting an increased population density for Barbados over the next 100 years. The outcome of which is increased vulnerability within the LECZ, This was estimated from a 4th order polynomial trend line that explains 96.5% of the variations in population density for the period 1961 – 2008 (figure 6). The implication here is that the population growth in Barbados will result in the increase population density especially for the south and west coast relative to the 2008 levels. This projection is consistent with the international migration patterns outlined in the 2000 population census. The main influence is the concentration of economic infrastructure within the LECZ and the concentration within St, Michael and Christ Church. The implication is the increased vulnerability of Barbados to the manifestations of climate change. In this case, sea level rise and storm surges, according to the HAD3m model predictions.

Figure 7: Population distribution by Parish[23]



The Island is a former British colony that supported the slave trade and as such export and trading was centred along the coast. Currently, the majority of the population lives within three coastal parishes on the south-east, south and west coasts of the Island, and 25% live within 2km of the coast, in a so-called "urban corridor", which runs along the entire length of the west and south coasts, St. Phillip, Christ Church, St. Michael, St. James, and the southern reaches of St. Peter[24] (figure 7).

.

[23]Source: Barbados National Census Report 2000
[24]Government of Barbados**,** **()** **"**Barbados National Assessment Report, "*Ministry of Housing Lands and the Environment*

V. LOW ELEVATION COASTAL ZONE AND CLIMATE CHANGE

The coastal regions are the outermost frontiers of exposure of an economy to the manifestations of climate change. The characteristics of these areas relative to the higher elevated land make this location particularly vulnerable to climate change impacts, namely:

- 18% of the population, 47,169 persons are living within the LECZ[25];
- Concentration of socio-economic activities and infrastructure along the coastal zone;
- High sensitivity to extreme weather conditions (e.g. hurricanes, sea level rise, storm surges, floods);
- Closeness of water resources (coastal aquifers) to the land-sea interface, hence high sensitive to sea level changes and sea water intrusion.

The coastal regions of interest for this research are those which fall within the LECZ (figure 8). From figure 8 along with the population density according to the population census of the year 2000, there is a joint spatial distribution of the population density and LECZ across Barbados.

[25]Center for International Earth Science Information Network (CIESIN), Columbia University, 2007. National Aggregates of Geospatial Data: Population, Landscape and Climate Estimates, v.2 (PLACE II), Palisades, NY: CIESIN, Columbia University. Available at: http://sedac.ciesin.columbia.edu/place/.

Figure 8: Low Elevation Coastal Zone[26]

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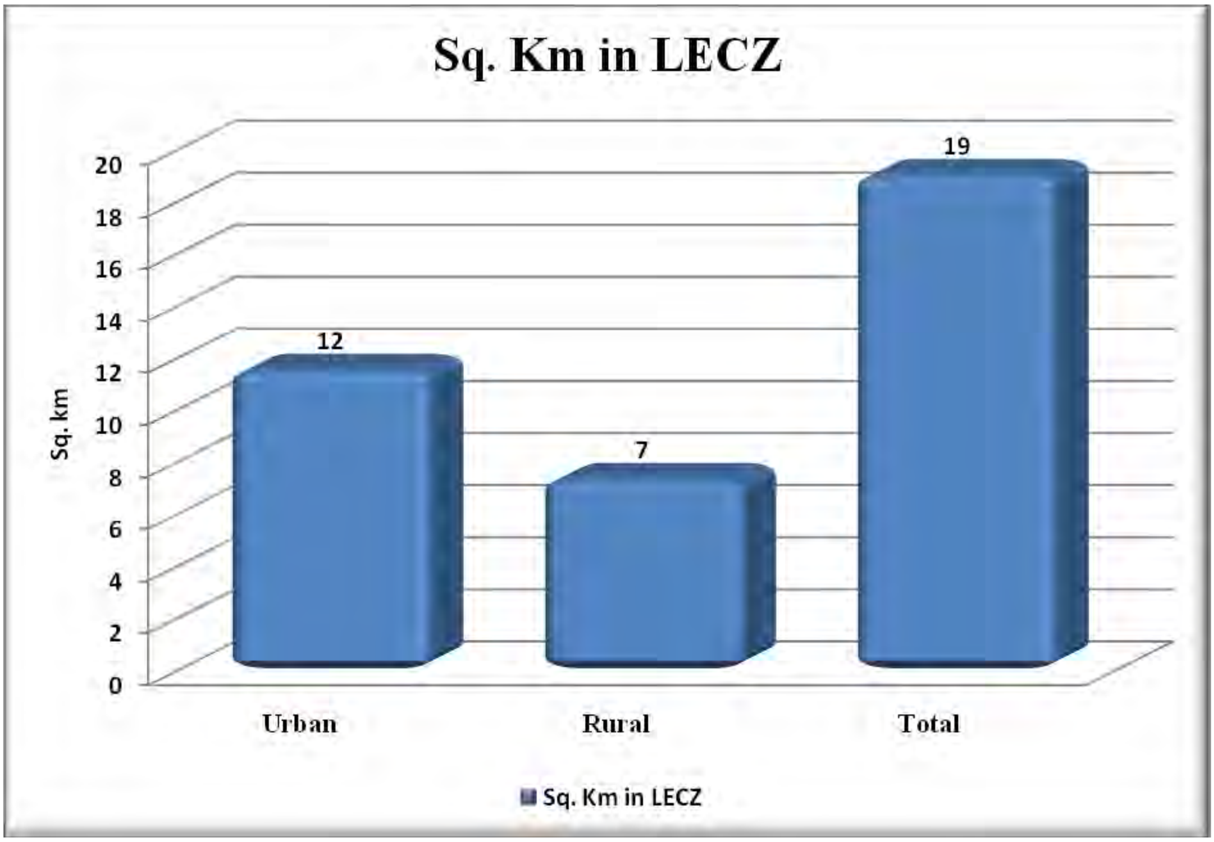
[26]Author generated

Barbados is 430km² of land. The LECZ of Barbados is 78 km² of land or 18% of the land mass[27], of which 7 km² is considered rural and the other 12 km² is considered urban (figure 9). Only 24% of the LECZ is occupied by human settlements[28].

Figure 9: Size of the LECZ[29]



The LECZ of interest is located in the parishes of St. Peter, St. James, St. Michael and Christ Church. Economic activities within these parishes form the backbone to the Barbadian economy (figure 8). The LECZ in St. Michael' and Christ Church goes the furthest inland. With a population of 2,146 and 868 per km² respectively, these population densities are the highest among all the parishes of Barbados, according to population density of the year 2000[30] (figure 10). Figure 10,shows that the 1 in 100 year flood zone falls within the LECZ.

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[27]Center for International Earth Science Information Network (CIESIN), Columbia University. Low Elevation Coastal Zone (LECZ) Urban-Rural Estimates, Global Rural-Urban Mapping Project (GRUMP), Alpha Version. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available at http://sedac.ciesin.columbia.edu/gpw/lecz . (Feb 20, 2011).

[28]Comparison of the Low Elevation Coastal Zone (LECZ) Urban-Rural Estimates, Global Rural-Urban Mapping Project (GRUMP and Center for International Earth Science Information Network (CIESIN), Columbia University, 2007. National Aggregates of Geospatial Data: Population, Landscape and Climate Estimates,

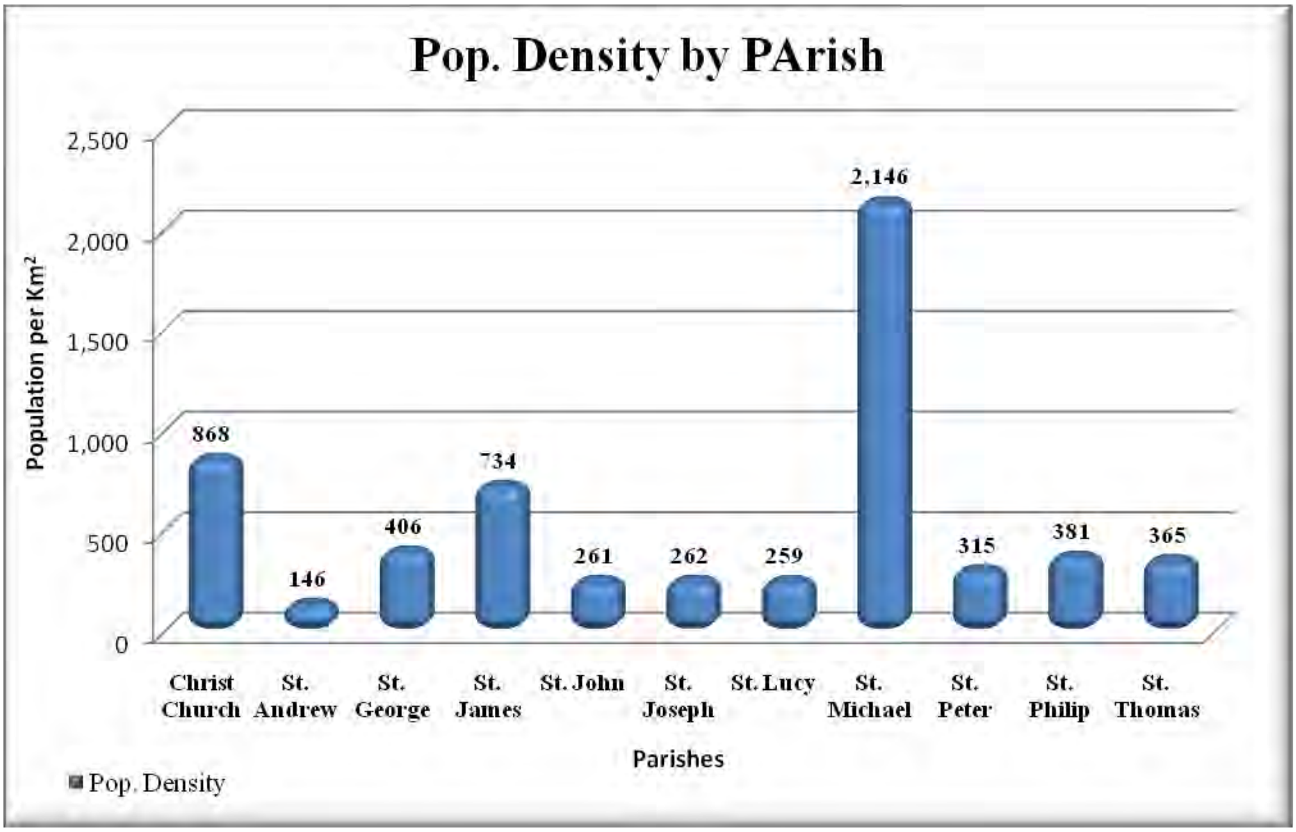
[29] Center for International Earth Science Information Network (CIESIN), Columbia University. Low Elevation Coastal Zone (LECZ) Urban-Rural Estimates, Global Rural-Urban Mapping Project (GRUMP), Alpha Version. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available at http://sedac.ciesin.columbia.edu/gpw/lecz . (Feb 20, 2011).

[30]Center for International Earth Science Information Network (CIESIN), Columbia University, 2007. National Aggregates of Geospatial Data: Population, Landscape and Climate Estimates, v.2 (PLACE II), Palisades, NY: CIESIN, Columbia University. Available at: http://sedac.ciesin.columbia.edu/place/.

Figure 10: Flood hazard for Bridgetown[31]

[31]Barbados Coastal Zone Management Unit http://www.coastal.gov.bb/category.cfm?category=15 (Feb 26, 2011)

Figure 11: Population density[32]



However, the directly exposed population within the LECZ were estimated by the UNISDR that there is a 2% increase in directly exposed population every 5 years[33] (figure 11).Assuming that the exposure is consistent with the population distribution per parish, over 50% of the exposed population[34] is within the parishes of Christ Church and St. Michael.

A. PHYSICAL ASSETS IN LECZ

1. Socioeconomic

The vulnerability of the coastal zone includes risk of flooding and erosion, salt water intrusion, freshwater shortage, contamination and potential loss of coastal eco-systems. The infrastructures at risk are churches, cemeteries, Government buildings, Post Offices, petroleum storage facilities, Police Stations, Power Stations, the Pier, Recreation sites, Schools, Transport Centre, UWI and the Wharf.

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[32]Source: Barbados National Census Report 2000

[33]Calculated from the data taken from[33] Center for International Earth Science Information Network (CIESIN), Columbia University. Low Elevation Coastal Zone (LECZ) Urban-Rural Estimates, Global Rural-Urban Mapping Project (GRUMP), Alpha Version. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available at http://sedac.ciesin.columbia.edu/gpw/lecz. (Feb 20, 2011).

[34]This number may be higher, however due to data constraints, distribution of exposed population was assumed equivalent to the population distribution.

2. Road network at risk

The Island has a large network of roads that includes main arterial roads that ran along the coast linking Bridgetown to the rest of the Island along the coastal corridor. One of the highways ran northward along the west coast, and the other towards the southeast. Both of these highways are within the LECZ for Barbados[35].

The World Bank has estimated that there exist on average for every $100km^2$ of land, 372 km of road[36]for the years 2002 to 2004. This road density will be assumed for the rest of paper. With a total land area of 430 km^2, then it is plausible to assume that there exist approximately 1600 km of roads in Barbados. The LECZ is assumed to be 18% of the land mass; the vulnerable[37] road network was estimated to be 288km.

3 .Shipping Port in Bridgetown

The main transshipment port in Barbados is the Bridgetown Shipping Port which realized 344 cruise ship calls in 2010[38], which represents an 11% decline relative to 2009. Passenger arrivals were up 22% in October, relative to 2009 but year over year passenger arrivals declined by 5%.

Being the main port for Barbados, it also facilitates exports and imports of goods. Tonnage handled by the wharf increased by 2% to 871,526 in 2010. However, the number of containers handled decreased by 2% to 65,177 for the year 2010. Also for the year 2010 there was a decline in Cargo Vessel calls for the main port of 20%.

The Barbados shipping port is located within the LECZ. This facilitates the export and import of merchandise goods into the economy which was estimated at 72% of GDP for year 2007[39] (figure 12). Since 1960, the Barbados shipping port has facilitated in excess of 50% of the annual GDP for the country.

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[35]UNFCCC National Communications Report - Barbados
[36]World Bank World Development Indicators, 2010
[37]assuming equal distribution of road
[38]Barbados Port Inc.http://www.barbadosport.com/index.php?option=com_rokdownloads&view=folder&Itemid=103 (Feb 22,2011)
[39] World Bank, World Development Indicators 2010. http://data.worldbank.org/country/barbados (Feb, 2011)

Figure 12: Export[40]

4. Tourism

a) Cruise Ship[41]

Tourism which is the backbone of the Barbados economy, has earned about $172 million out of GDP that was estimated at $1.15 billion for the year 2008[42].A significant proportion of the tourist arrivals in Barbados is cruise ship passengers (figure 13). Stop over visitors have shown an upward trend since the 2002 with just over 500,000 to just over 600,000 in the year 2009. That represents a twenty percent rise for the 7 year period ending 2009 (figure 13).

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[40]World Bank, World Development Indicators 2010. http://data.worldbank.org/country/barbados (Feb, 2011)
[41]http://www.juneau.org/tourism2/cbjtourism/barbados.pdf
42 Barbados Central Bank

Figure 13: Trends in Cruise Ship arrivals

Source: Data compiled by author

The risk of damage to coastal infrastructure posed by sea level rise along with the increased occurrences of hurricane induced storm surge has created a serious threat to the tourism sector in Barbados. In addition, as most tourists come to Barbados to enjoy the beaches, coastal erosion can have negative impacts. As Uyarra and others[43] (2005) posited that more than 80% of tourists in Barbados saw the width of the beach as a significant and positive contributor to their willingness to come to Barbados. So reduced beach width will result in a decline in tourism revenues for Barbados, hence a potential decline in per capita GDP within the economy is expected from a rise in sea level.

5. Light and Power[44]

The Barbados Light and Power Company Limited (BLPC) is the primary supplier of electrical energy in Barbados. BLPC has a developed infrastructure, comprising generation stations, transmission and distribution systems, maintenance facilities and offices. Since 1980, there has been an upward trend in generating capacity (figure 14). Presently, BLPC operates three generating stations:

- The Garrison Hill Generating Station provides peak-load power via a single gas turbine generator;
- The Seawell generating station provides peak-load power with several gas turbine Generators and the Spring Garden Generating Station, which is the main base-load plant has recently undergone expansion. Each of the above sites is essentially developed to its full potential and there is insufficient space for expansion to meet future needs.

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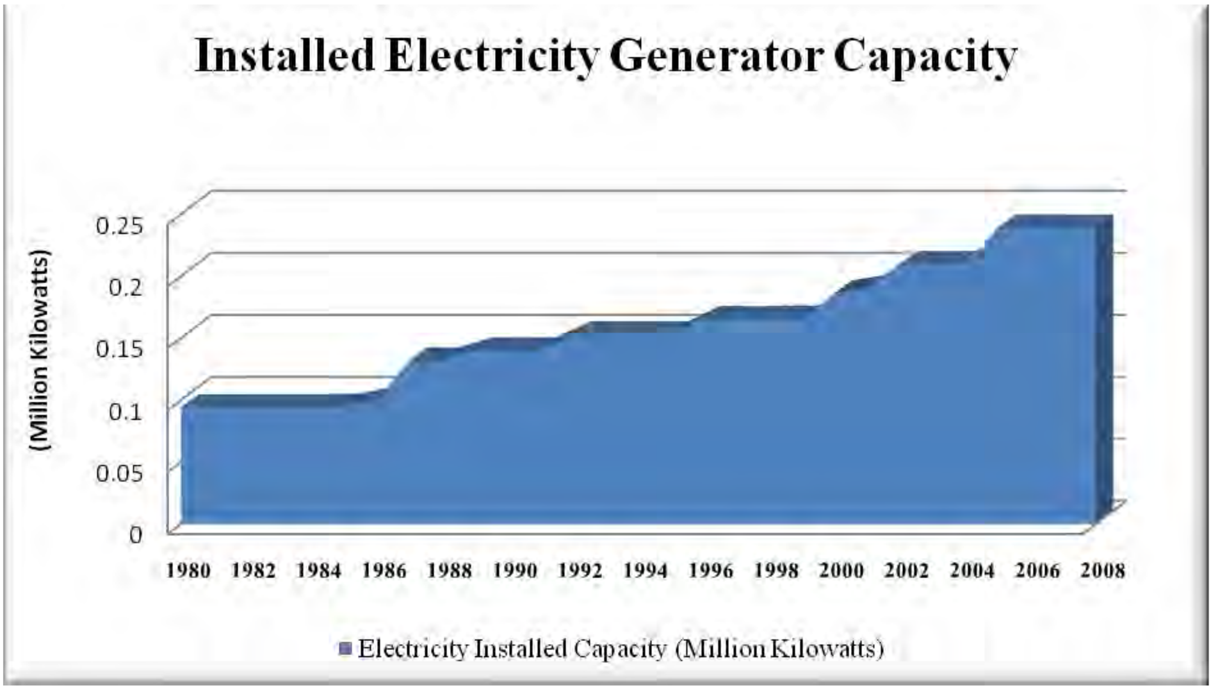
43 Uyarra and others Island-specific preferences of tourists for environmental features: implications of climate change for tourism-dependent states. Environmental Conservation 32 (1): 11–19. 2005. p. 11.

[44] http://tonto.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=2&pid=2&aid=7&cid=regions&syid=1980&eyid=2008&unit=MK

Figure 14: Trends in electricity generation



Source: Data compiled by author

6. Human settlements

Barbados has self-help, self-build housings system that dates back to the colonial British rule (Potter, 1989)[45]. The designs of urban housing are a combination of West African and English taste that gave rise to the movable chattel housing. The variation in urban housing quality is reflective of the colonial pass. The 2000 Housing Census of Barbados[46]defines a building as a permanent structure separate and independent from any other while a dwelling unit is a building that is used for and or intended for use as living quarters.

Of the 91,406 dwellings in Barbados, 53.25% are located in the Parishes of St. Michael and Christ Church. Of all the parishes, St. Michael had the highest occupancy rate of 93.38% which was higher than the national average of 90.83%. The national average household size was approximately 3 persons per household; both St. Michael and Christ Church were at the national average.

The Census Report (2000) reported that:

- The most common type of occupied units in 2000 and 1990 werethe separate house and the flat/apartment, which comprised 88% and 11% respectively of all units;

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[45]Potter (1989).“Urban Housing in Barbados, West Indies.”*The Geographical Journal*
[46]http://www.caricomstats.org/Files/Publications/NCR%20Reports/Barbados.pdf

- separate house was the dominant type of structure in all parishes in Barbados, accounting for more than 80% in all instances;
- Highest proportion of the flat/apartment type was found in Christ Church (17%), St. James and St Michael (15%). A total of 5,141 units of the separate house type were added between 1990 and 2000, while the increase in flats/apartments amounted to about 2,900;
- Of the total stock of units existing in 2000, 58% was built before and including 1980, indicating that more than a half of the existing units were over 20 years old. Another 19% of the units were built in the 1980s with 22% being built in the 1990s.

a) Characteristics of Households

The 2000 Census showed that almost three quarters of the dwellings were owner-occupied. The majority of the dwellings had their source of lighting from the power grid. 10,697 of the occupied dwellings distributed across Barbados used natural gas for cooking. The highest usage was found in the parishes of St. Michael, Christ Church and St. James with a natural gas penetration rate of 22%, 18% and 13% respectively.

b) Construction Materials

Concrete block material was the dominant material used in construction of houses in Barbados, representing a 44% or 36,819 dwelling units. The other dominant material used was board/wood, this represented 27% of the dwelling units. In 1990, wood was the main construction material used for new homes, the number of occupied wooden dwellings declined by 66% since 1990 to 7600 units in the year 2000. While the construction of concrete structures increased by 11,000 units over the same period. The latter occurred in the parishes of Christ Church, St. James and St. Phillips.

The dominant type of roofing material as reflected in the 2000 Census used was corrugated metal sheeting or galvanized zinc, which was utilized in 77% of all cases.

7. Aggregate physical assets exposed

The exposed asset was calculated according to Nicholls (2008)[47]. This was necessary because of:

- The limited availability of datain regards to the number of and market value for the economic infrastructure within the LECZ. An aggregate exposure methodology was the only methodology available to estimate the economic vulnerability within the LECZ.

- Projections for population and GDP were also not available. This included A2 and B2 projections for GDP and population growth.

According to Nicholls (2008), the estimates of aggregate asset exposure is defined, according to equation 2.

c) Estimate of asset exposure.

[47]Nicholls, R. J. *and others* (2008), “Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates”, *OECD Environment Working Papers*, No. 1, OECD Publishing. doi: 10.1787/011766488208.

$Ea = Ep \times GDP_{percapita}\ (PPP) \times 5$ ……………………….............……………… (Eq. 2)[48]

Where,
Ea= Exposed assets
Ep= Exposed population[49] = 47,169
$GDP_{percapita}\ (PPP)$ = Gross Domestic Product (GDP)/ Population. = 14049.9937468734
$Ea = Ep \times GDP_{percapita}\ (PPP) \times 5 = 47{,}169$x 14049.9937468734 x 5 = 3, 313,620,599.085

The estimated value of assets exposed[50] is approximately US$3.3billion. The adjusted[51] asset exposure was not used because most of the production infrastructure is located within the LECZ.

B. NATURAL CAPITAL AND CLIMATE CHANGE

As most of the infrastructure, settlements and facilities are located on or near the shore, loss of land due to SLR is expected to disrupt the economic and social sectors. Furthermore erosion will have profound adverse impacts on the tourism industry (figure 12). Nevertheless, erosion rates differ widely across the different outermost regions.

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[48]Used in absence of detailed information on property value estimates.
[49]Taken from Center for International Earth Science Information Network (CIESIN), Columbia University, 2007. National Aggregates of Geospatial Data: Population, Landscape and Climate Estimates, v.2 (PLACE II), Palisades, NY: CIESIN, Columbia University. Available at: http://sedac.ciesin.columbia.edu/place/. (Fed 25, 2011)
[50]For exposure indicators such as land area, population and GDP, which have measured country "coastal zone" totals available, the exposed value is adjusted to reflect its real value by using the following formula:

$$V_{adj} = \frac{LECZ_{mea}}{CT_{cal}} * E_a$$

Where:
V_{adj}: Exposed value adjusted;
E_a: Exposed value calculated from exposure grid surfaces;
$LECZ_{mea}$: Country "Low elevation coastal zone" total obtained based on statistics[50];
CT_{cal}: Country "coastal zone" total calculated from exposure grid surface.

[51]World Development Indicators (2010) estimate of the 2009 GDP per capita

Figure 15: Sediment loss[52]

In Barbados the coastline is currently subject to erosion of sand and undermining of cliffs especially on the West Coast of the Island. Estimates of the erosion associated with a 1metre rise in sea level are shown in table 1. An example of which is land loss at the Worthing Beach (figure 15).

Table 1: Expected land loss - 1m sea level rise[53]

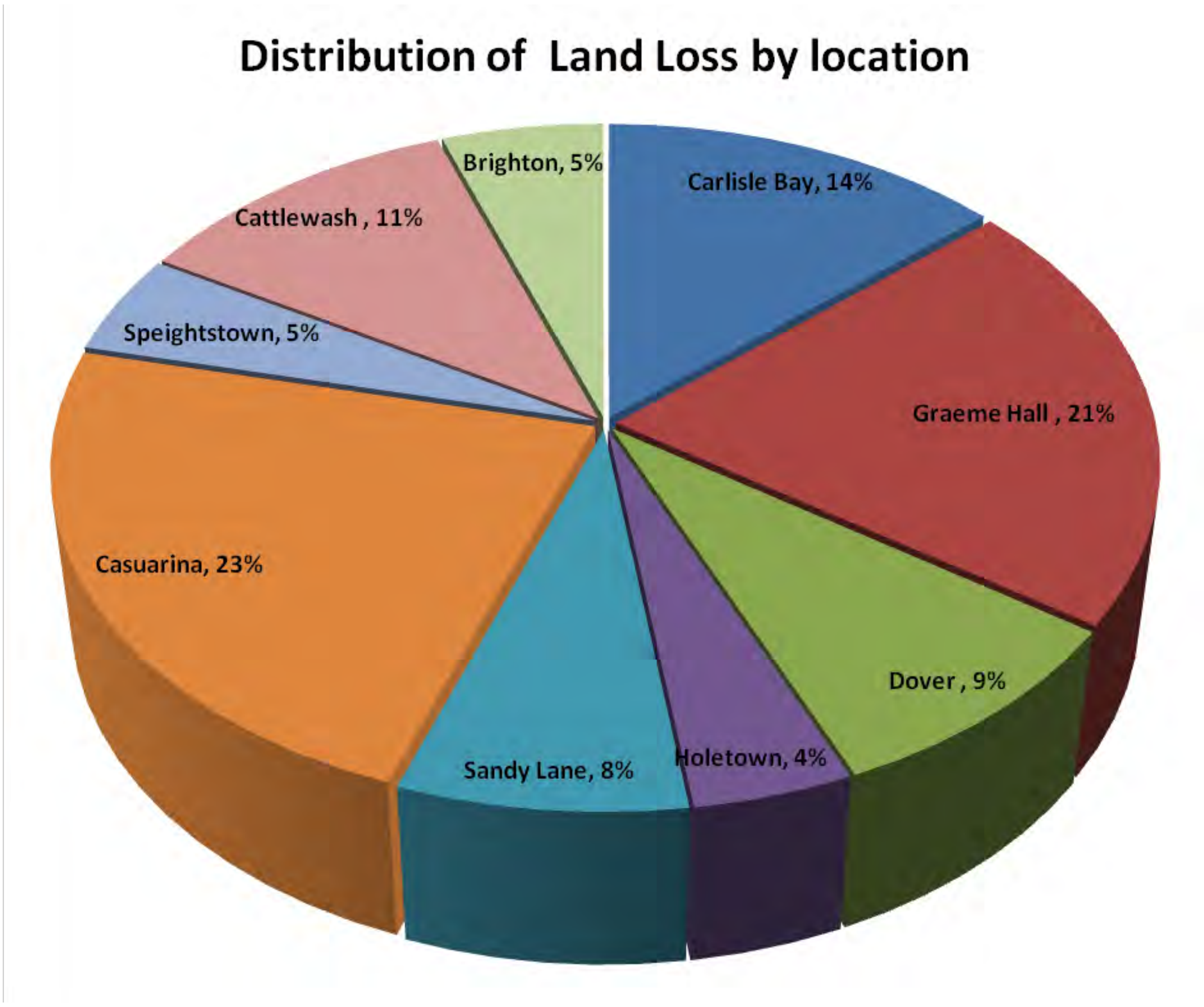
Parish	Coast	Location	Land Loss (M):
Christ Church	South	Carlisle Bay	18.44
Christ Church	South	Graeme Hall	28.60
Christ Church	South	Dover	12.12
Saint James	West	Holetown	5.79
Saint James	West	Sandy Lane	10.42
Saint James	West	Casuarina	31.54
Saint Peter		Speightstown	6.50
St. Joseph	East	Cattlewash	15.10
St. Michael	South West	Brighton	7.40
Adapted from UNFCCC National Communication Report Table 2.1: Land Loss scenarios under various scenarios of sea level rise.			

The vulnerability to erosion might be aggravated by the expected increase in high intensity extreme weather events such as hurricanes and floods. The coast is particularly vulnerable to sea-level

[52]Barbados Coastal Zone Management Unit
[53]Barbados Coastal Zone Management Unit

rise because the land is relatively flat, so a small increase in sea level will result in a wide expanse of the land being inundated and possibly loss (figures 15 and 16).

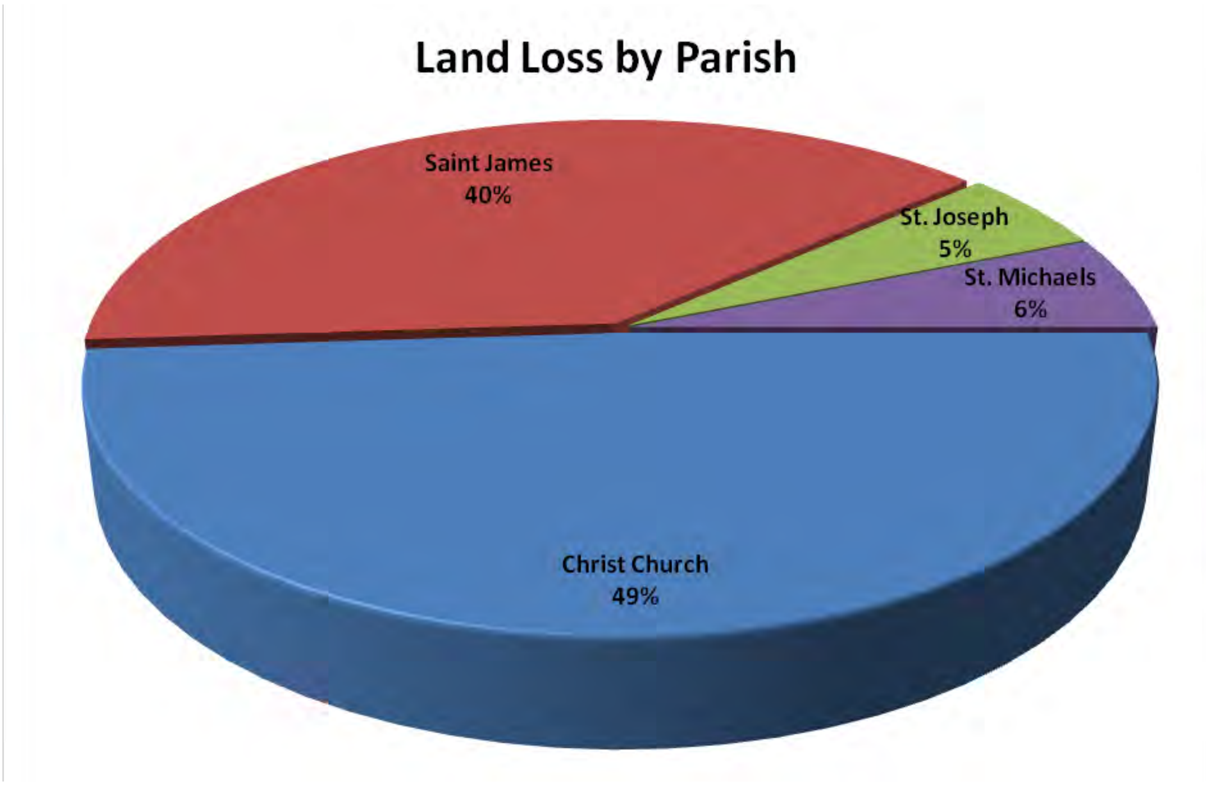
Figure 16: Distribution of land loss by location



Source: Data compiled by author

This is most evident for the Coastal Zone Management Sub-areas 3, 6, 7 and 8. Sub-areas 6–8 are highly populated areas, in addition to hosting some of the largest beach front properties on the Island in these regions.

Figure 17: Land loss by Parish



Source: Data compiled by author

Vulnerability to sea level rise includes induced land loss which is most evident in Christ Church and Saint James. Both parishes' accounts for 89% of the reported land loss associated with climate change induced land loss (figure 17). In a context where the market for tourist is North America and Europe, beach quality plays an important role in the selection of the travel destination; the environmental quality is also a significant determinant for demand for the tourism product offered within Barbados.

Figure 18: Land loss in Worthing Beach[54]

The beaches in Barbados are at most 15m wide, so it is expected that many of the beaches in Barbados will be lost, in addition to the impact of storm surges (figure 18).The Barbados National Communication report has shown that over 90% of all hotels in Barbados are within or proximal to the beach, with 80% of the Island's hotels located within 250 metres of the high water mark. The hotels in Barbados, especially the larger ones, are on average located within the LECZ, which is consistent with the 1 in 100 inundation zones, placing them at risk of major structural damage associated with sea level rise and storm surges.

1. Valuing beach erosion via Benefit Transfer methodology

A Schuhmann (2010) estimate that the implicit price of beach-width is $28.67per meter person per night in Barbados, this estimate was used to calculate the value of beach width in Barbados. The CTO estimates that there were 532,180 stopover visitors for the year 2010[55], with 7.4 or 7 nights on average

[54] Barbados Coastal Zone Management Unit http://www.coastal.gov.bb/category.cfm?category=15 (Feb 23, 2011)

[55] Caribbean Tourism Organisation (2011) "Table 3: Tourist Arrivals by Main Market – 2010, *Latest Statistics 2010"*. http://www.onecaribbean.org/content/files/Feb152011Lattab10.pdf (Feb 25, 2011)

per stopover visitor entering Barbados. It follows that the estimated aggregate value of the lost beach width is US$106.8 million per metre. The present value of the losses is estimated at US$14.5 billion, table 2.

Table 2: Value of Land Loss and SLR (1 M)

1m Sea Level Rise				
Parish	**coast**	Location	Land Loss (M):	Value of Land Loss[1]
Christ Church	South	Carlisle Bay	18.44	1,969,451,085.45
Christ Church	South	Graeme Hall	28.6	3,054,571,640.12
Christ Church	South	Dover	12.12	1,294,454,834.90
Saint James	West	Holetown	5.79	618,390,552.32
Saint James	West	Sandy Lane	10.42	1,112,889,387.76
Saint James	West	Casuarina	31.54	3,368,573,060.47
Saint Peter	West	Speightstown	6.5	694,220,827.30
St. Joseph	East	Cattlewash	15.1	1,612,728,383.42
St. Michael	South West	Brighton	7.4	790,343,711.08
			135.91	14,515,623,482.82

Source: Data compiled by author

For the analysis on the projections, following ratios assumed fixed at the 2010 value

- Tourist stopover visitor population ratio: 2.128634855
- Average nights per stop-over[56]: 7
- Value of land loss per metre[57]: US$28.67
- Linear rate of land loss between 2010 and 2100

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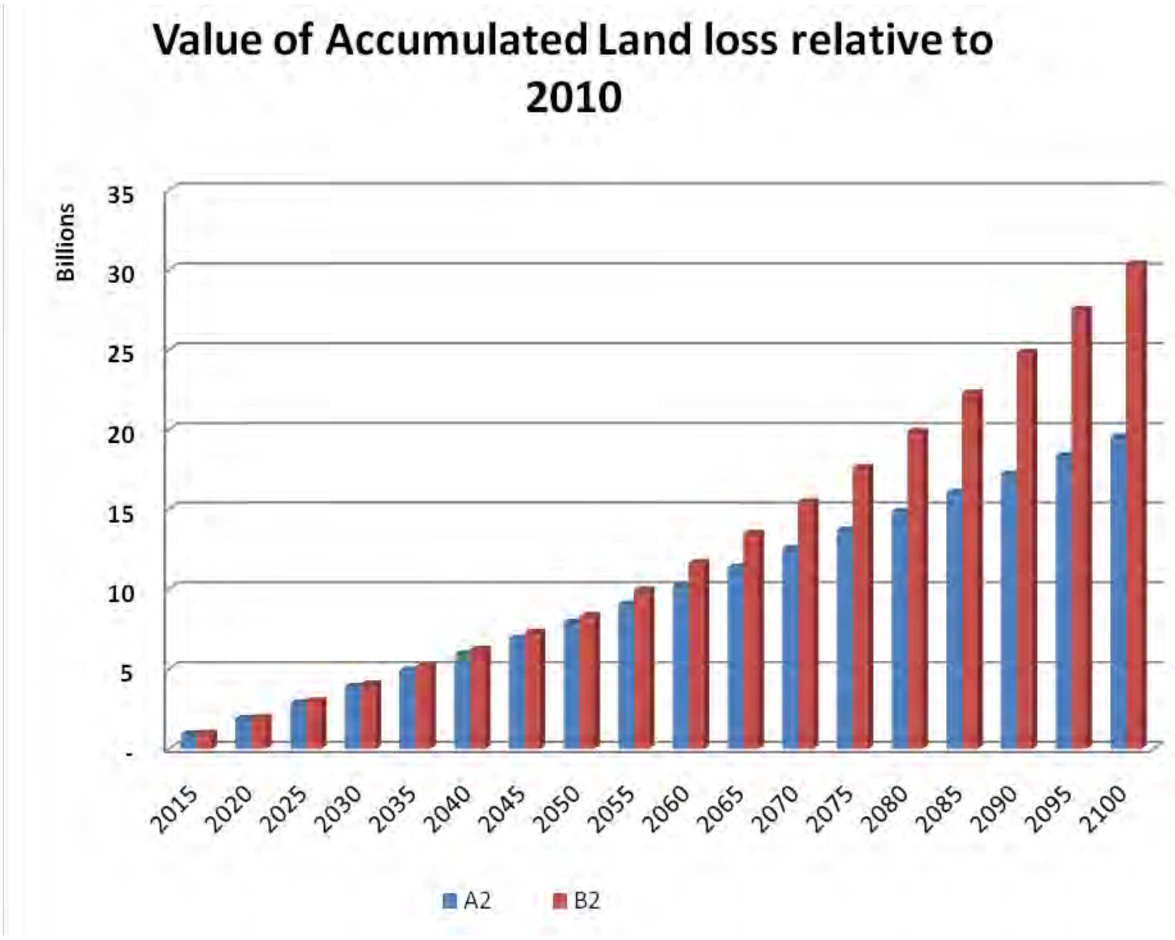
[56]Caribbean Tourism Organization estimate

[57]Schuhmann, P. W. (2010) The Economic Value of Coastal Resources in Barbados: Vacation Tourist Perceptions, Expenditures and Willingness to Pay. Project Report: The Economic Value of Coastal and Marine Resources in Barbados. UNCW, CERMES, UWI and the Barbados Ministry of Tourism

The accumulated value of land loss was estimated according to the A2 and B2 population projections given the above assumptions (figure 19).

Figure 19: Value of accumulated land loss



Source: Data compiled by author

2. Freshwater shortage

Climate impact through SLR is likely to threaten freshwater resources through saltwater intrusion within freshwater aquifers. Furthermore, the frequency and intensity of droughts are expected to intensify in the future, rainfall is also expected to decline as well.

Climate change will increase the risk of coastal human settlements to sustain damages with the occurrence of high tides combine with storm surges and/or increased river flows and precipitation. Of the manifestations of climate change, sea level rise will increase the vulnerability of these communities to flooding associated with severe weather systems; this represents 18% of the population. Low-income groups living on flood plains are especially vulnerable. The distribution of the affluent compared with poor settlements along the coastline will ultimately add to the coastal vulnerabilities and value at risk for Barbados.

3. Coastal ecosystems

Barbados is home to a great number of animal and plant species and has a rich biodiversity compared to the rest of the world. The WRI stipulates that currently, the coastal eco-systems are already under severe threats from the impacts of human activities (e.g. pollution, over-exploitation of resources, urbanisation). This is consistent with regional trend and it is estimated that one-third[58] of Caribbean coral reefs are threatened by coastal development. This includes sewage discharge, urban runoff, construction, and tourist development. Climate change is likely to exacerbate this threat, through increased sea temperatures, the consequences of loss of biodiversity is a decline in the capacity to achieve economic growth whether it be through increased tourist attraction and the welfare effects via the impact on human well-being.

Coral reefs function as a natural breakwater along the coasts and represent one of the most important natural resources for food, beach sand and building materials. These corals are being threatened by SLR, a rise in sea surface temperature and an increase in extreme weather events.

Diseases and rising sea temperatures threaten to damage coral reefs across the Caribbean region. Diseases have caused profound changes in Caribbean coral reefs in the past 30 years, with very few areas unscathed by the disease, even reefs far removed from human influence. In addition, coral bleaching episodes, the most direct evidence of stress from global climate change on Caribbean marine biodiversity, are on the rise. Coastal communities and national economies of the Caribbean region will sustain substantial economic losses through the continued increase in sea surface temperatures impact on corals. In addition, the problem of ocean acidification is expected to reduce coral reef calcification rates. This is because oceans are absorbing more carbon dioxide – the ocean is now 30% more acidic when compared with the last 30 years, thus lowering the pH of seawater. By 2060 the oceans could become 120% more acidic.

Coral reefs provide valuable goods and services to support local and national economies, and degradation of coral reefs can lead to significant economic losses, particularly to coastal infrastructure (figure 20). The manifestations will be through loss of fishing livelihoods, loss of tourism revenues, and increased coastal erosion.

d) Sand, sea and coral reef

There exist some 90 km^2 of reefs around Barbados, with continuous bank reefs around the west and south coast (figure 21). The tourism industry is one of the largest contributors to GDP in Barbados, second only to the financial sector. Figures 20 and 21 outline the natural capital base of Barbados that supports the tourism sector. Notice, all of the sites shown are within the LECZ.

The tourism sector is largely a leveraging of the natural capital base of the country, that is, the sun, sea and sand. The sea and the sand will be impacted directly by sea level rise directly and indirectly through the impact of increase in sea temperature on the health of the coral reef ecosystem.

Figure 20: Distribution of Corals Bed[59]

[58] http://pdf.wri.org/reefs_caribbean_front.pdf (February 2, 2011)
[59] Barbados Coastal Zone Management Unit

Source: Data compiled by author

Sea level rise and increase ambient sea temperature will only exacerbate the impact of anthropogenic activities such as coastal pollution, rapid coastal development and overfishing.

Figure 21: Barbados beach profile[60]

[60]Barbados Coastal Zone Management Unit


Map of Beach Profile Locations Around Barbados
North Point
Morgan Lewis
Speightstown
Goddings
Lakes North
Cattlewash South
Read's Bay
Miramar
Bathsheba
Tent Bay
Colony Club
Beachlands
Dive Shop South
Sandy Lane Access
Paynes Bay North
Caribbean House
Paynes Bay Main
Bath
Treasure Beach
Smugglers Cove
Buccaneer Bay North
Tamarind Cove North
Skeetes Bay
Buccaneer Bay South
Tamarind Cove South
Paynes Bay South
Coconut Creek North
Coconut Creek South
Little Rum Shop A
Palmetto Bay
Little Rum Shop Main
Fitts Village
Bottom Bay
Harrismith
BL&P North
Paradise South
Samlords North
BL&P South
Samlords South
BL&P Central
Brandons
Crane
Foul Bay
Esso Lower Bay Street
Brownes Beach
Carlisle Bay
Rockley A
Graeme Hall
Asta
Dover
Casuarina
Long Beach Main
Rockley B
Enterprise
Rendezvous
Long Beach South
St. Lawrence Apartments
Sandhurst Dover
Welches
Sandhurst Main
Womans Bay Main
Coastal Zone Management Unit BARBADOS

4. Valuation via Benefit Transfer

Edwards (2009)[61]estimated via a contingent valuation methodology applied to stopover visitors to Jamaica, the value for coastal ecosystem services[62] in Jamaica to have a mean per person value of $16.16 per day for the tourism product, and per person value of **$20.52** per day for preserving the coastal ecosystem services. The majority of the respondents were from North America and Europe[63] with similar tourism product offered by both Islands, hence the applicability of transferring these values to the Barbadian case. With 532,180 stopover visitor for the year 2010[64], with 7.4 or 7 nights per stopover visitor entering Barbados, the sand sea and coral reef have an estimated value of annual welfare value of US$60,200,201.6 and preservation/existence value of US$76,442,335.2 per annum. The total annual value to tourist in the year 2010 is US$136,642,536.8.

Under both the A2 and B2 scenarios, the preservation value of the coastline is expected to increase, while for the BAU preservation value is declining over the medium to long term. The B2 scenario provides the greatest increase over the period 2015 to 2100. This is with the assumption that current stopover visitor to population ratio remains constant, and the number of nights per person[65] on average remains fix at 7. The driving force within this outcome is the increased population and stopover visitor rates held constant; this implies an increase in the tourism product offering. That is, implicit in this analysis, is the increase construction of hotels within Barbados. If the trend for the past 50 years is continued with a 30 to 50 year shelf for constructed hotels, this implies that there will be massive investment in the tourism product within the LECZ in Barbados.

[61]Edwards (2009), "Sustainable financing for ocean and coastal management in Jamaica: The potential for revenues from tourist user fees". Marine Policy

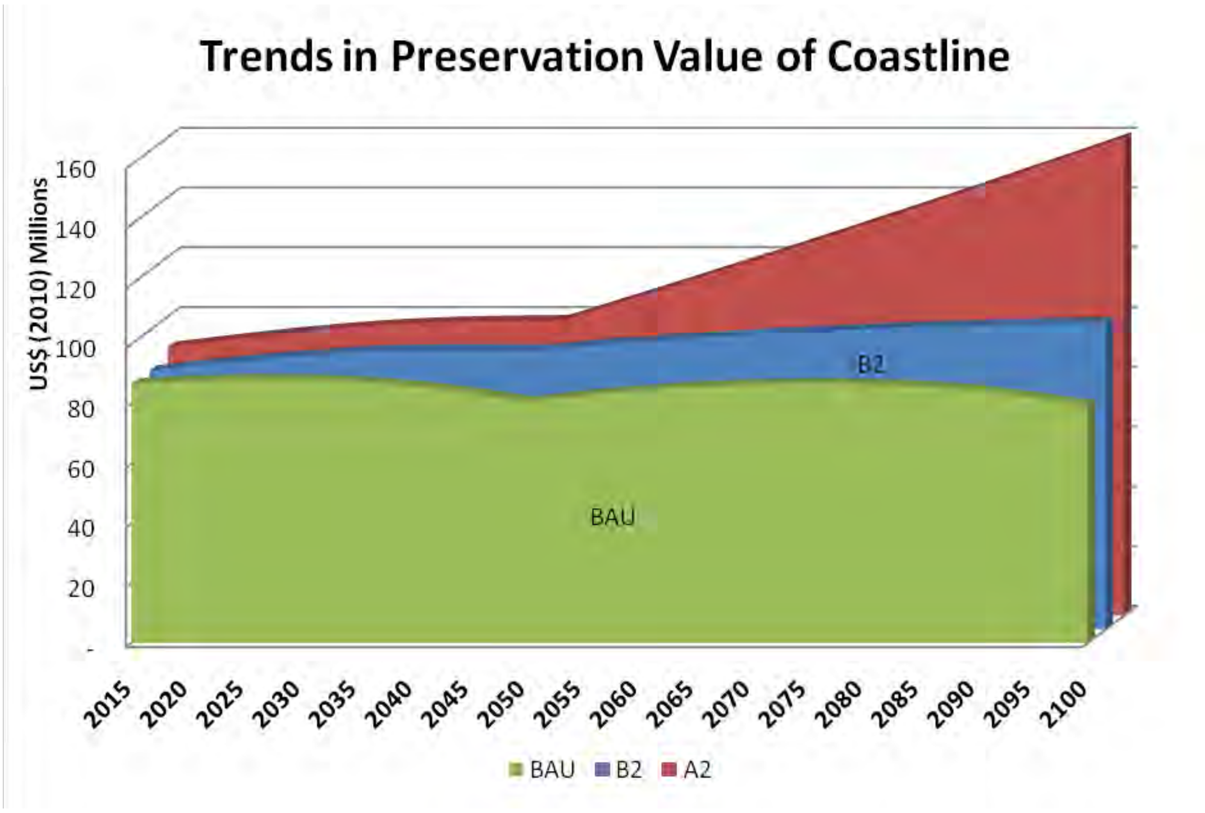
[62]2009 US$

[63] Caribbean Tourism Organisation (2011), "Table 3: Tourist Arrivals by Main Market – 2010, *Latest Statistics 2010"*.http://www.onecaribbean.org/content/files/Feb152011Lattab10.pdf (Feb 25, 2011)

[64]Caribbean tourism Organization (2011) "Table 3: Tourist Arrivals by Main Market – 2010, *Latest Statistics 2010"*. http://www.onecaribbean.org/content/files/Feb152011Lattab10.pdf (Feb 25, 2011)

[65]Caribbean Tourism Organization

Figure 22: Preservation value of coastline



Source: Data compiled by author

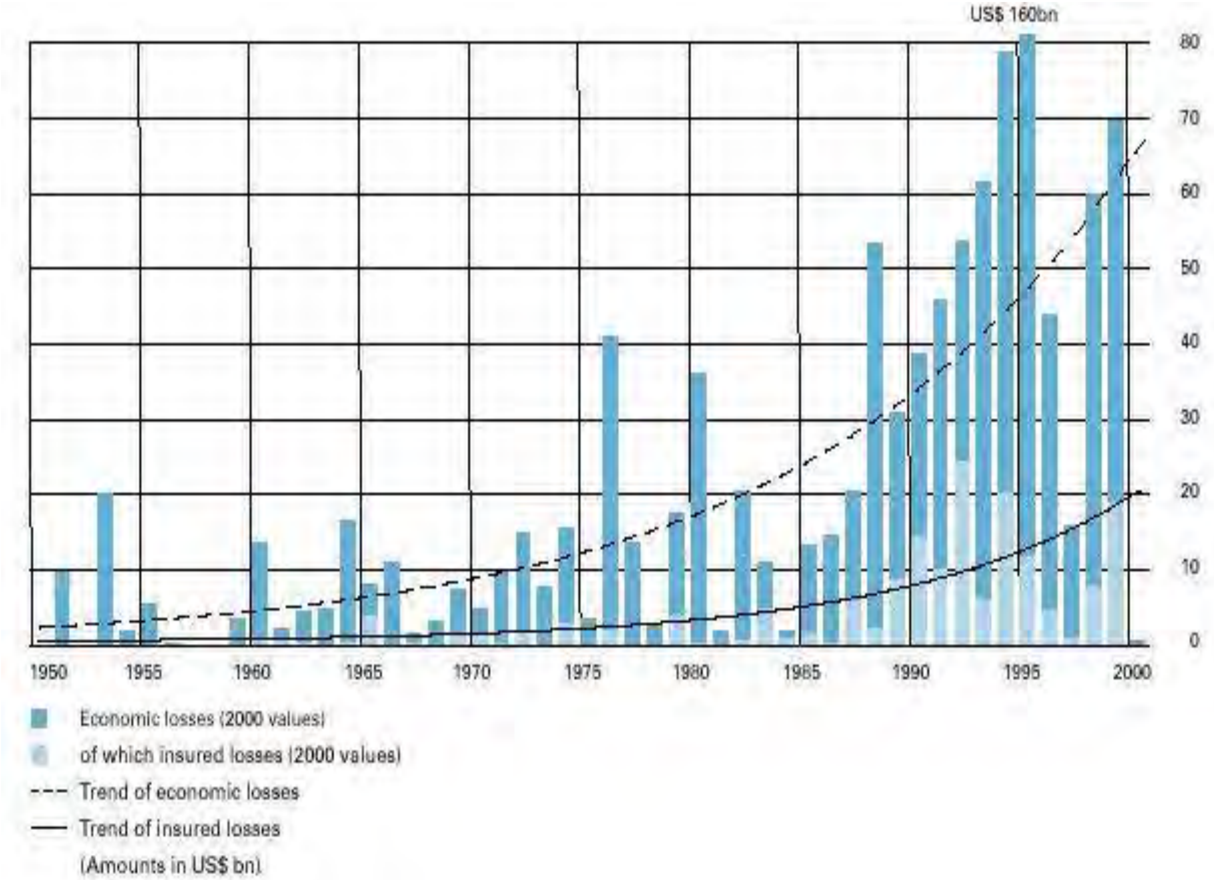
Given the value of the physical capital in the ground within the LECZ (figure 22), along with projects in the pipeline over the next 10 to 15 years, the relocation of this quantum of infrastructure may not be a feasible task at the moment. The cheaper alternatives may include the increased use of sea defences. This is also evident from the expenditures now undertaken in Barbados. For example the investment in hard shoreline defence structures and continued development of physical tourism related structures along the coastline.

a) Scenario analysis

Consistent with the trends in Global Asset exposure to climate change induced sudden-onset weather, the findings for Barbados is consistent with the Munich Re's findings (1999) that show that the Caribbean has one of the highest asset and relative population exposure in the world, Munich Re (2009). This is attributable to the rapid population growth and concentration of people and infrastructure in coastal areas, especially in Barbados, has increased the potential losses from extreme weather events.

Direct losses represent the financial value of damage to and loss of capital assets. Since the 1950s there has been an upward trend in economic losses due to natural catastrophes. The losses in the year 2000 was more than 6 times what it was in 1950, see table 3**.** The analysis as estimated that vulnerable assets in the year 2100 is 13 times that of 2010 estimates, an exponential growth in vulnerable assets in Barbados. This finding is consistent with the Munich Re projections of an upward trend in economic and insured losses associated with the natural catastrophes projecting an upward trend for the foreseeable future, see table 3.

Table 3: Economic losses from natural catastrophes in the 20th century



Source: Data compiled by author

The Government of Barbados is the main financial responders to offer financial support for the reconstruction after a natural event. This is especially so in the context of low insurance penetration rates relative to high level of exposure to extreme events. With critical facilities and industrial zones located within the vulnerable coastal zones, the productive base and social infrastructure are all highly vulnerable to the manifestations of natural disasters.

Disaster risks faced by the Government of Barbados cannot be absorbed without major difficulty. Ex ante financing of losses and relief expenditure through calamity funds, regional insurance pools, or contingent credit arrangements are insufficient to the reconstruction needs if the manifestations of climate change according to the A2 and B2 scenarios are realised.

C. FINANCING OPTION

The Caribbean Catastrophe Risk Insurance Facility (CCRIF) provides a 40 to 50% reduction in premium cost for up to 20% of the estimated loss, and claims parametrically linked to hurricanes (wind speed) and earthquakes (ground shaking) to participatory states.

Caribbean Islands have been incapable of sustaining and maintaining profitable and effective disaster risk management schemes due in part to inadequate legislation and financial resources. In addition, limited management knowledge of agricultural insurance schemes, for example, technical challenges in designing policies dealing with floods and storms have hindered the development of other insurance policies to replace the failed Dyoll Insurance Company. For example, Dyoll Jamaica Ltd collapsed after Hurricane Ivan 2004 when it could not settle storm damage claims from the coffee sector. In addition the inadequate knowledge of producers, producer organizations and private insurance companies in agricultural risk financing and assessment have limited their ability to participate in agricultural insurance schemes, which has been further compounded by the inadequate number of public technicians.

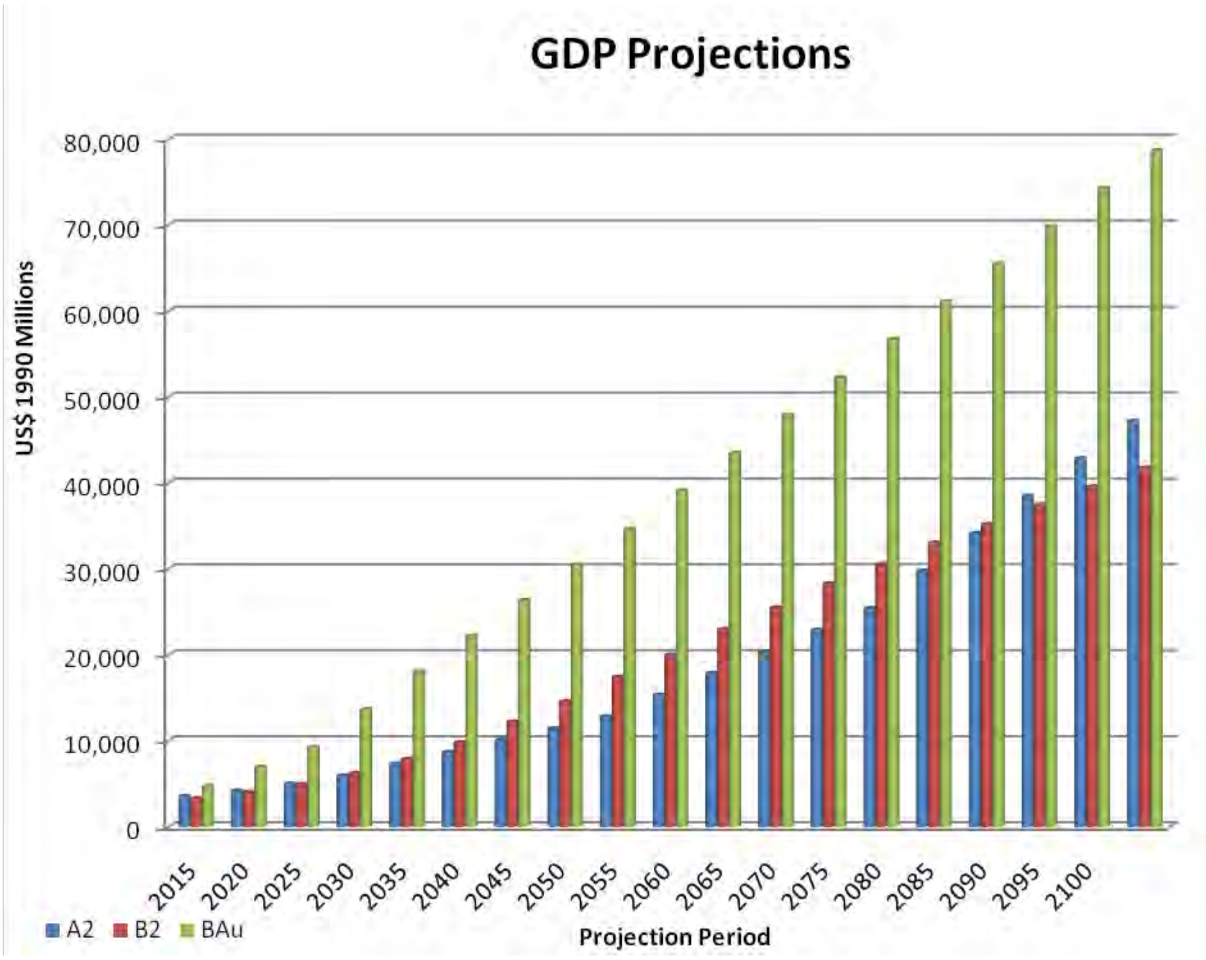
For decades, the financing of natural disasters in the Caribbean has taken on an inefficient “ex post” funding approach, consisting of a poorly targeted diversion of funds from domestic budgets and extensive financing from international donors. Fiscal allotments and aid financing are usually insufficient, while not providing any incentives for proactive risk reduction measures such as improved urban planning and higher construction standards.

In the context of climate change, with the manifestations being projected to be increased frequency of the destructive hurricanes, flooding and sea level rise the financing option targeted by the respective governments will ultimately determine the cost of climate change in Barbados.

VI. VULNERABILITY PROJECTIONS

According to IPCC definition of A2 and B2 scenarios, the projections shows the B2 scenario as having a relatively higher GDP growth rate over the projection period, due to relatively less abatement.

Figure 23: Projected GDP



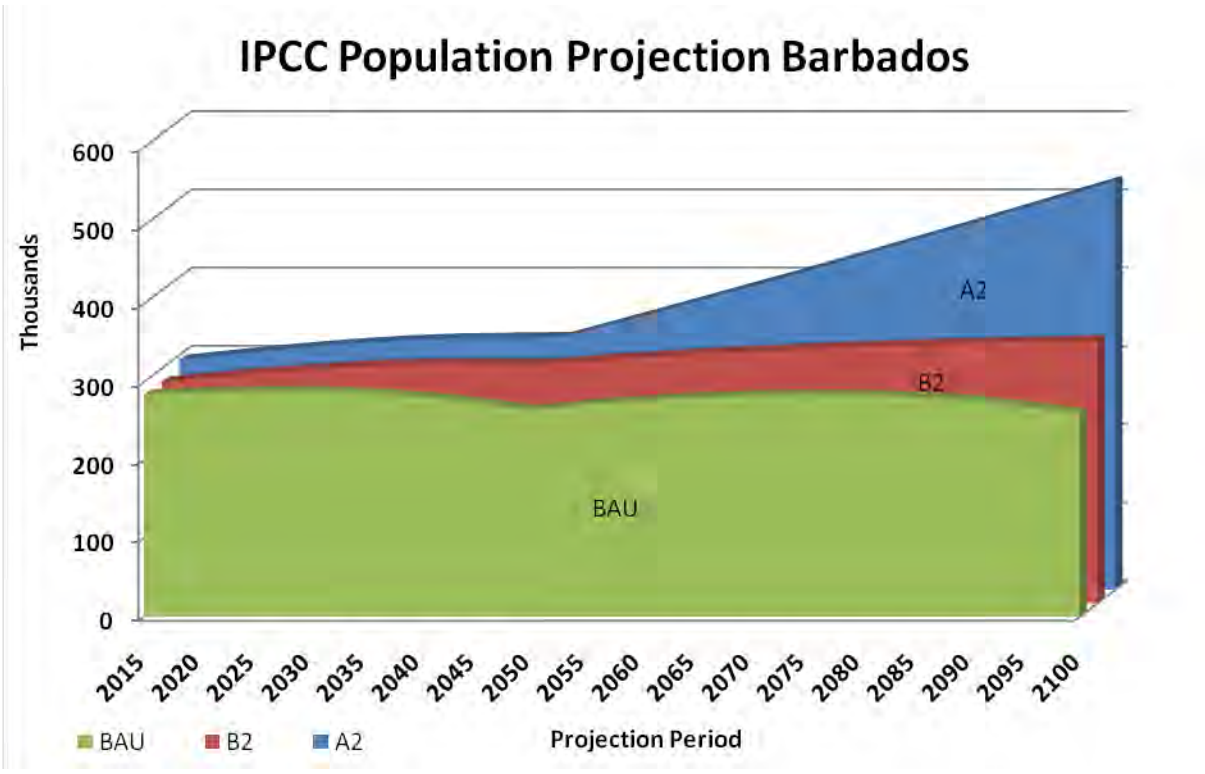
Source: Data compiled by author

The projected mean real[66] GDP for Barbados was US$20billion and US$21 billion under the A2 and B2 scenarios (figure 23).

Over the projection period, the mean population for Barbados was 314,275 and 378,418 persons under the B2 and A2 scenarios respectively.

[66]constant 1990 US$

Figure 24: Population projection[67]



The average difference in GDP projections according to the A2 and B2 scenarios was US$1.756 billion for Barbados. The average difference in population projections were estimated at 65,154 inhabitants (figure 24).

A. EXPOSURE ESTIMATES

The vulnerable area in Barbados stretches from Husbands southwards to the left of Highway 1B, then onto the Spring Garden highway then Highway 7. This zone continues to Chancery Lane opposite Long Bay. The Bridgetown Port and beach front properties are some of the most exposed infrastructure along the coast.

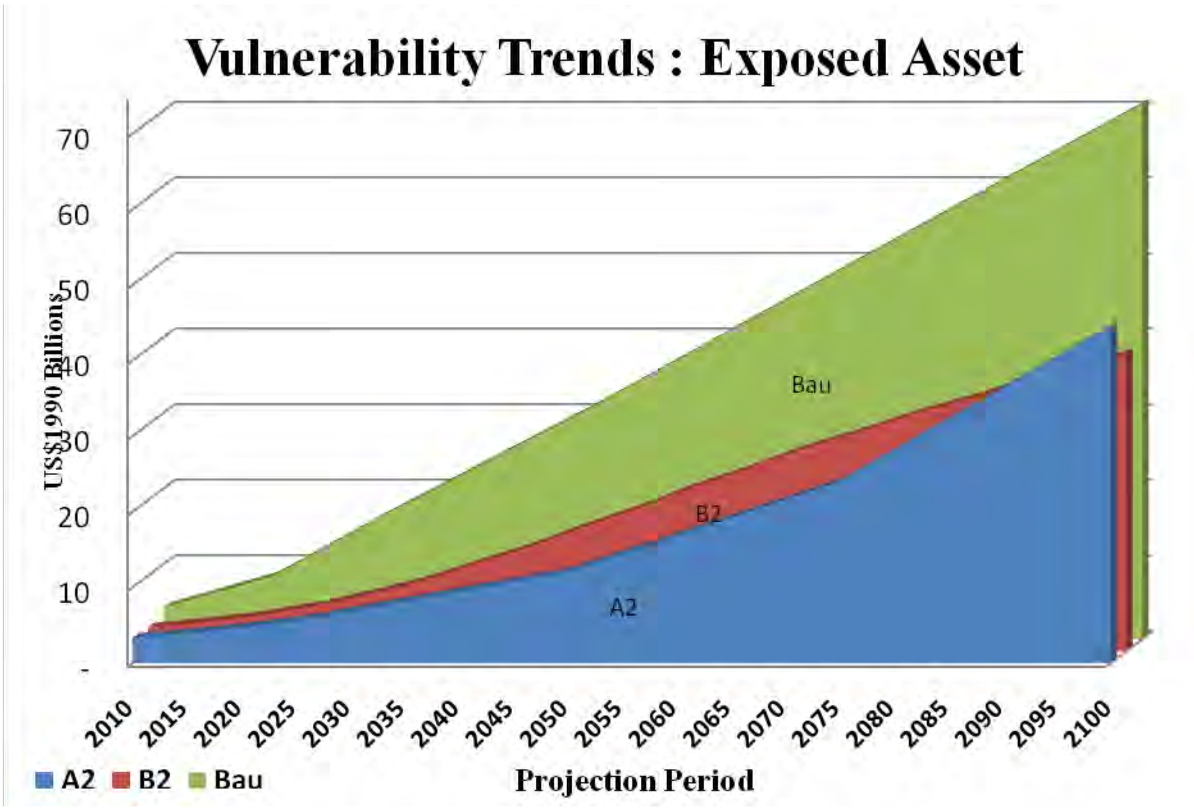
[67]Centre for International Earth Science Information Network (CIESIN), 2002.*Country-level Population and Downscaled Projections based on the B2 Scenario, 1990-2100,* [digital version]. Palisades, NY: CIESIN, Columbia University. Available at http://www.ciesin.columbia.edu/datasets/downscaled. (February 22, 2011))

Figure 25: Exposed Socioeconomic Infrastructure

Source: Data compiled by author

The B2 scenario resulted in a greater exposed asset than the A2 scenario. Exposed asset value reached an estimated US$4.7 billion in 2020 for the A2 scenario while peaking in excess of US$44billion with a US$39.4 billion in the year 2100 for the B2 scenario (figure 25).

Figure 26: Vulnerability trends



Source: Data compiled by author

In excess of 50% of the exposed assets are located in St. Michael and Christ Church for both the A2 and B2 scenarios.

Of the exposed population, it is estimated that 20% and 33% is from Christ Church and St. Michael respectively. This ratio is so for the entire projection period from 2020 to 2100[68]. For the B2 scenario, exposed assets reached the US$4 billion mark between the years 2015 and 2020. The latter is also true for the B2 scenario also. The 10 billion dollar mark was however reached between the years 2040 and 2045, while this mark was passed between the years 2030 and 2035 for the B2 scenario (figure 26).

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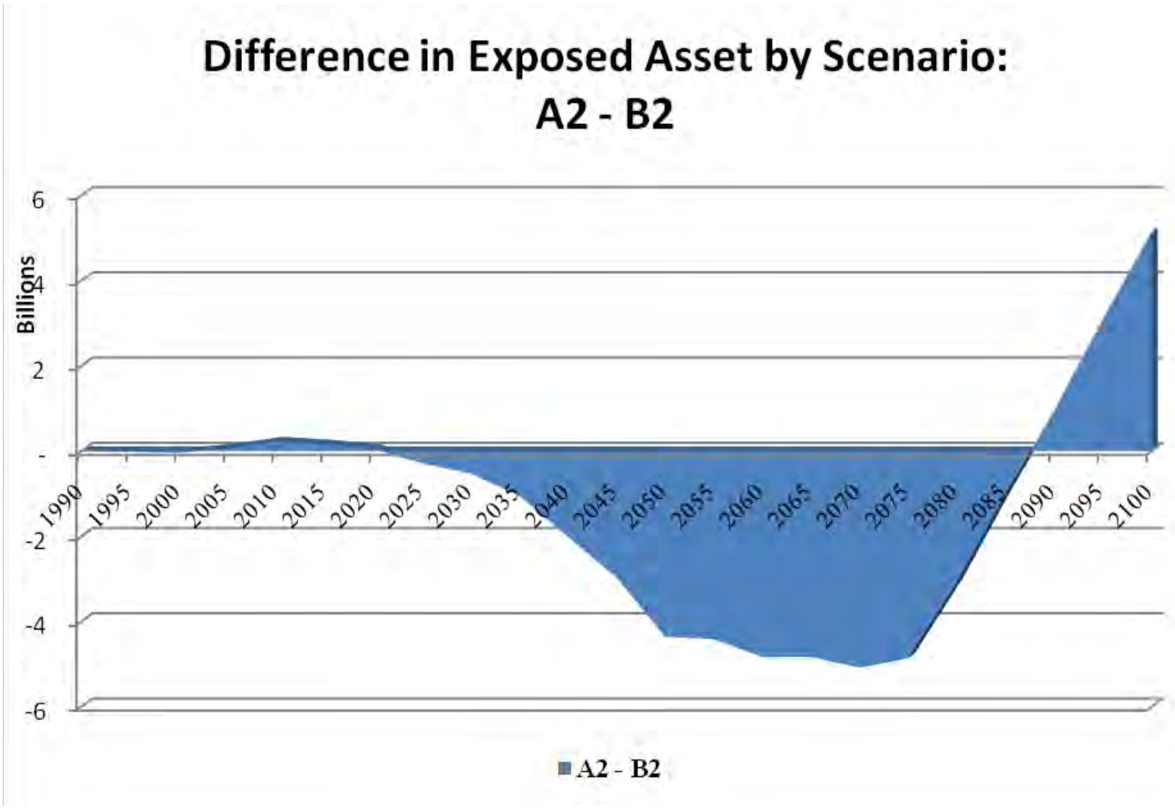
[68]A outcome directly related to population distribution being constrained to be equal to that of current day Barbados

Figure 27: Scenario difference in exposed assets



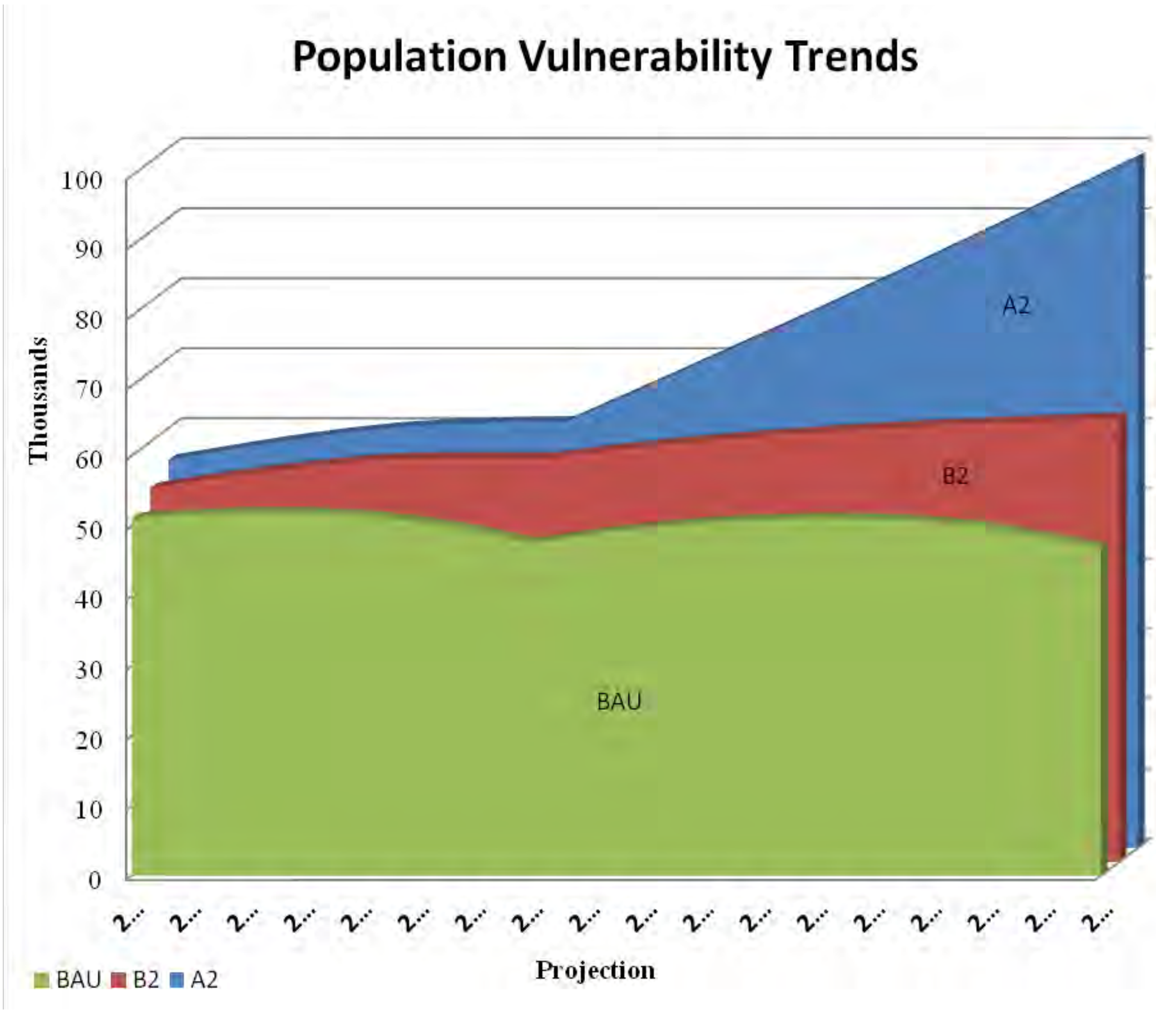
Source: Data compiled by author

There is an overall increase in exposed assets; the distribution of exposed assets by parishes remains the same with St. Michael and Christ Church accounting for the bulk of the exposed population with 34% and 20% respectively. Asset exposure under the A2 and B2 scenarios tend to be equal for the years 2025 and 2085 (figure 27). For the years 2025 to 2085, the projected exposed assets according to the B2 scenario is on average US$3billion greater than that of the A2 scenario. The annual rate of asset exposure for the period 2050 to 2100 for the A2 scenario was greater than that of the B2 scenario.

B. TRENDS IN EXPOSED POPULATION

Exposed population was constrained to be adhering to the current relative population density in year 2010 (figure 28), with an exposed population of 19%. This ratio was adhered to over the IPCC projection period; exposed population was constrained to be equivalent to 19% of the total population projection for the period ending 2010[69]. The population trends according to the A2 and B2 scenario accounts for the difference in population (figure 28). By the IPCC definition of A2, the exposed population will be greater than that of the B2 scenario.

Figure 28: Exposed population

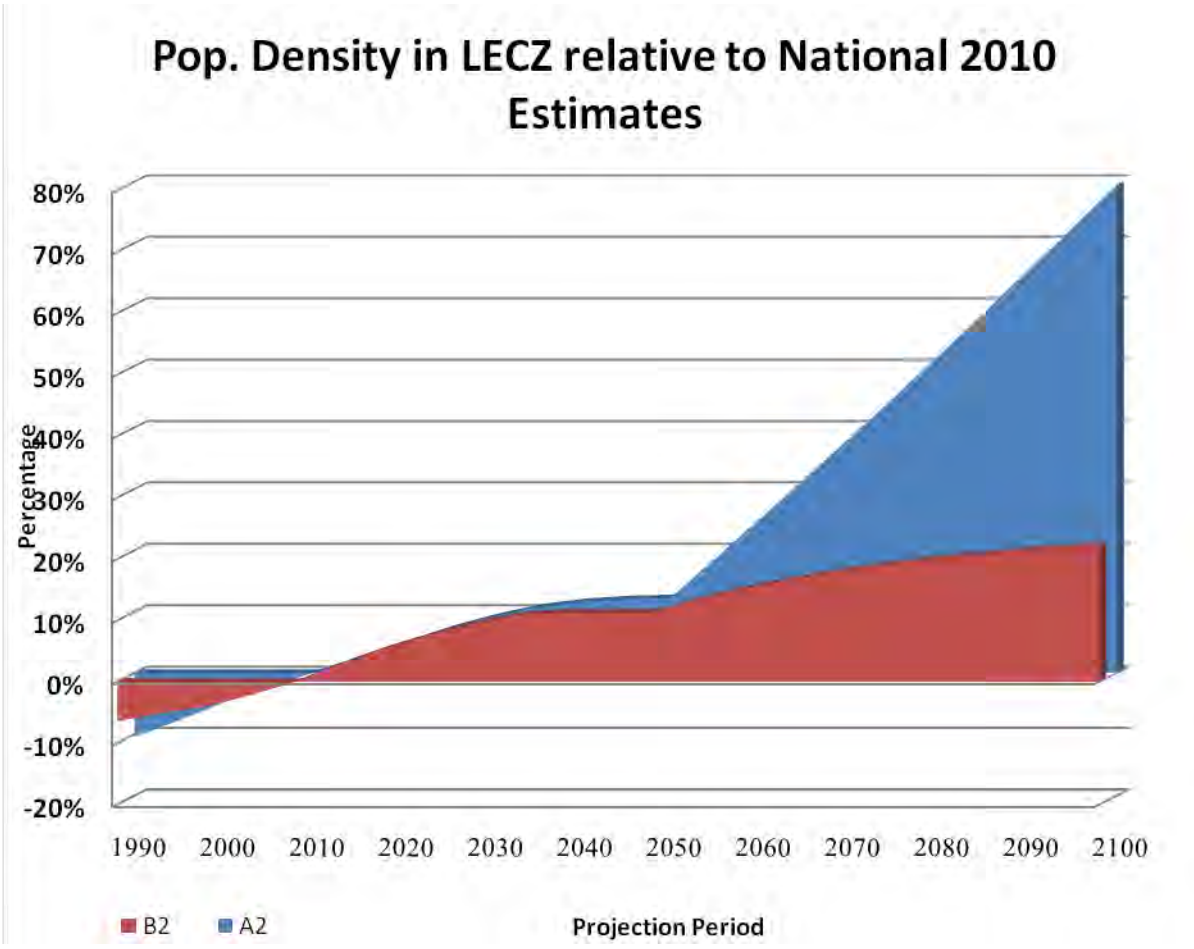


Source: Data compiled by author

[69]Due to insufficient data

Projected changes in the rate of increase in exposed population diverge in the year 2050 with a massive increase in the relative growth rate of the A2 population growth scenario. The exposed population is expected to double by the year 2100 according to the A2 scenario. For the B2 scenario, the exposed population has increased by 50% of the 1990s level.

Figure 29: Relative pop. density in LECZ



Source: Data compiled by author

Both the A2 and B2 scenarios are predicting an increase in population density within the LECZ of up to 80% and 20% for the A2 and B2 scenarios respectively (figure 29)

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VII. CLIMATE CHANGE ADAPTATION

A. BACKGROUND

The IPCC[70] defines adaptation to climate change as the engineering adjustment to the natural and physical capital base of an economy along with changes in the processes and practices in response to the manifestation of and possible climatic stimuli such as changes in precipitations, intensity and frequency of storms, and the occurrence of droughts and floods. Other definitions are given by the authors Burton (1992)[71], Smit (1993)[72], Smithers and Smit (1997)[73], Smit and others (2000)[74]. Variables such as exposure, sensitivity and autonomous adaptive capacity determine the vulnerability to climate change within the LECZ. Adaptations are manifestations of adaptive capacity, and that which represent ways or means of reducing vulnerability.

The adaptation strategies pursued by a country is aimed at reducing the magnitude of any possible shock to the economy that may arise due to the occurrence of the manifestations of climate change – sea level rise and adverse weather conditions. The main objective of adaptation is to reduce the climate-change vulnerability of socio-economic systems. Adaptation is an effective means of reducing climate-related damages. The benefit-cost ratios of adaptation expenditure are larger than one in all scenarios, and for high and low climate damages and discount rates.

Adaptation refers to the efforts within an economy that is geared towards reducing the vulnerability of human and natural systems to a shift in a climate regime, Fankhauser (2009[75]). The uncertainty about the exact manifestation of climate has increase the difficulty associated with adaptation to climate change, the outcome of which is the high importance being placed on strategies to yield yearly benefits almost immediately. Of importance is the timing and sequencing of adaptation strategy that facilitates development within the economy. Given the momentum of climate change and the predictions over the next 100 years along with the vulnerability profile of the economy, the adaptation needs are specific over the medium to long term.

Smit and others(2000) categorise an adaptation strategy as including actions that can be classified as being accommodative, retreat, protect, prevent, tolerate etc.

- Anticipatory adaptation implies building a stock of defensive capital that must be ready when the damage materializes. It is subject to "economic inertia": investment in defensive capital translates into protection capital after some years. Hence, it needs to be undertaken before the damage occurs. By contrast, reactive adaptation is immediately effective and it can be put in place when the damage effectively materializes.

- Reactive adaptation is represented by all those actions that need to be undertaken every period in response to those climate change damage that cannot be or were not accommodated by

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[70]IPCC Second Assessment
[71]Burton, I., 1992: *Adapt and Thrive*. Canadian Climate Centre unpublished manuscript, Downs view, Ontario
[72]Smit, B. (ed.), 1993: *Adaptation to Climatic Variability and Change*, Environment Canada, Guelph.
[73]Smithers J., and Smit B., 1997: Human adaptation to climatic variability and change. *Global Environmental Change,* 7 (2): 129-146
[74]Smit, B., Burton, I., Klein, J.T. and J. Wandel, 2000: An anatomy of adaptation to climate change and variability, *Climatic Change,* 45 (1), 223-251
[75]Fankhauser (2009[75]), "A Perspective Paper on Adaptation as a Response to Climate Change". http://fixtheclimate.com/uploads/tx_templavoila/PP_Adaptation_Fankhauser_v.3.0.pdf (May 3, 2011)

anticipatory adaptation. They usually need to be constantly adjusted to changes in climatic conditions. Examples of these actions are energy expenditures for air conditioning or farmers' yearly changes in seasonal crops mix.

B. THE PHILOSOPHY OF ADAPTATION

The guiding principle behind an adaptation strategy is to protect public health and safety along with critical infrastructure. The latter does include protection of the natural capital base. These objectives are normally the outcome of a multi-criteria analysis. This method does incorporate the views of stakeholders and NGOs. The basic tenet of the adaptation strategy is to facilitate sustainable development through the promotion of sustainable coastal communities. The expected outcome of which are improved coastal natural capital and robust economic activities within the LECZ. In addition, climate change adaptation strategies do facilitate coastal recreation whether it is for the tourism sector or locals by protecting and maintaining the provision and amenity capacity of coastal ecosystems. Sustainable ocean and coastal ecosystem management is also critical to achieving the objective of the sustainable development through adaptation to climate change.

The main approaches to adaptation are:

1) Protection of areas within the LECZ.

   a) Developed – because with development comes the issues of decline in the environment associated with climate change vulnerabilities;

   b) Undeveloped: less pollution of all anthropogenic factors;

   c) Both A and B;

2) Protect only „economically worthwhile areas'– this is normally based on comparing avoided damage and protection costs.

Adaptation for the coastal zones, are categorised into three main categories (Nicholls and Klein, 2005; Nicholls and others, 2007c). The latter is also consistent with the three generic options outlined in the IPCC CZMS, (1990):

1) (Planned) retreat – to reduce the risk of the event by limiting its potential effects; the impacts of sea-level rise are allowed to occur and human impacts are minimised by pulling back from the coast via land-use planning and development control. (lack of space to retreat);

2) Accommodation – to increase society's ability to cope with the effects of the eventthe impacts of sea-level rise are allowed to occur and human impacts are minimised by adjusting human use of the coastal zone to the hazard via increasing flood resilience (e.g. raising homes on pilings), warning systems and insurance;

3) Protection– to reduce the risk of the event by decreasing the probability of its occurrence; the impacts of sea-level rise are controlled by soft or hard engineering (e.g. nourished beaches and dunes or seawalls), reducing human impacts in the zone that would be impacted without protection. However, a residual risk always remains, and complete protection cannot be achieved. Managing residual risk is a key element of a protection strategy that has often been overlooked in the past.

These approached is discussed in the IPCC CZMS (1990).

Each adaptation strategy (table 4), has a different consequence on the natural capital along the coast, for example:

- Retreat and accommodation prevent the "coastal squeeze" between fixed defences and rising sea levels. Though land intensive in most cases, onshore migration of coastal ecosystems is not hindered. Given the distribution of physical infrastructure within 30 meters of the high tide mark, the cost to retreat is extremely probative.

- Protection can cause coastal squeeze, again given the density of coastal infrastructure especially for the tourism sector, this approach necessitate minimised use of soft approaches such as beach nourishment and sediment re-cycling.

Socio-economic trends over the past decades – population growth, economic expansion, the deployment of new technologies have both shaped the vulnerability profile of the country to climate conditions. For example, the urbanisation of coastal communities worsens flooding by restricting the flow of floodwaters. Additionally there will be increased water runoff associated with large concrete pavements and roads obstructing the natural water channels.

Table 4: Adaptation by vulnerability

Philosophy	Natural System Effect		Interacting factors: Climate	Interacting factors: Non-climate	Adaptation: Approach	Cost	Expected Life
Protection of areas within the LECZ	Inundation (including flood and storm damage)	Surge (from the sea)	Wave/storm climate, erosion, sediment supply	Sediment supply, Flood management, erosion, land reclamation	Protection of areas within the LECZ Dikes/surge barrier (P) Building codes/flood wise buildings (A) Land use planning/hazard delineation (A/R)		90 – 95%
		Backwater effect (from rivers)	Run-off	Catchment management and land use			90 – 95%
	Morphologicalchange	Wetland loss (and change)	CO2 fertilisation of biomass production, sediment supply, migration space	Sediment supply, migration space, land reclamation (i.e. direct destruction)	Land use planning (A/R) Managed realignment forbid hard defences (R) Nourishment/sediment management (P)		90 – 95%
		Erosion (of beaches and soft cliffs)	Sediment supply, wave/storm climate	Sediment supply	Coast defences (P) Nourishment (P) Building setbacks (R)		90 – 95%
	Hydrological change	a. Saltwater intrusion					90 – 95%
		Surface waters	Run-off	Catchment management (over-extraction), land use	Saltwater intrusion barriers (P) Change water abstraction (A)		90 – 95%
		Ground water	Rainfall	Land use, aquifer use (over-pumping)	Freshwater injection (P) Change water abstraction (A)		90 – 95%
		Rising water tables impeded drainage	Rainfall, run-off	Land use, aquifer use, Catchment management	Upgrade drainage systems (P) Polders (P) Change land use (A) Land use planning/hazard delineation (A/R)		90 – 95%

(A-accommodate, P- protect, R-Retreat)adapted from Nicholls (2007)
Source: Data compiled by author

VIII. CLIMATE CHANGE ADAPTATION

In Barbados the adaptation to CC within the LECZ comprises of legislation and reengineering of vulnerable areas within the LECZ. Given the lack of space, planned retreat is not a viable option for Barbados. The other strategies implemented and currently being designed can be categorised as a combination of policy and engineered structures.

A. INSTITUTIONAL FRAMEWORK

1. The Barbados Coastal Management Plan

The Barbados Coastal Zone Management Unit, (CZMU) was established with the passing of the Coastal Zone Management Act of 1998, for sub-areas (figure 30). One of the mandates of the CZMU is to ensure that the LECZ is sustainably used by businesses and citizens. In addition, ensuring that development within the coastal zone is consistent with the sustainable use of the coastline. For example, non-point pollution from sewage exacerbates the impact from increased sea water temperature (bleaching) which decreases the reef capacity to produce sand. Hence, decrease in the size of the beaches.

Figure 30: Coastal Zone Management sub-areas[76]

To improve the water quality is consistent with improving reef health, the Marine Pollution control along with the Coastal Zone were designed to also prevent this issue.

The CZM area has been defined along the Caribbean coast of the Island, the boundary defined as follows:

1. Landward: the first coastal road or the limit of the predicted 100-year storm surge modelling or whichever is further inland. This boundary is of significance since the coastal road has

[76]Barbados Coastal Zone Management Unit

been traditionally used as the boundary when considering coastal development applications by the TCPO;

2. Seaward: The 100m isobath or 200m seaward of the outer edge of the bank reef or whichever is further seaward. This area therefore includes the coastal sand reserves and the reef environments that produce them. Also included within this area are the near shore ecosystems most easily influenced by land-based effects.

The coastal management plan for Barbados comprises of three volumes:

- Policy Framework;
- Atlantic Coastal Management Plan (ACMP) ;
- Caribbean Coastal Management Plan (CZMP).

The CZMP of Barbados is divided into the ACMP and CZMP. This division represents a strategic move by the Government of Barbados to draft sub-plans for the Atlantic and Caribbean sides of the Island according to the prominence of a particular vulnerability relative to the other side.

a) Atlantic Coastal Management Plan, CZM zones 2-4

The Atlantic side of the Island of the adaptation strategy is mainly policy. This area includes the main roads near the coast and geomorphological landscape features found along the area. The seaward boundary runs along the 100m isobath, which demarcates the shelf/slope boundary, found approximately 1-2 km offshore, Barbados CZMU (2011)[77].

The vulnerability to landslide is concentrated within the Scotland District area on the Atlantic coastal zone and prominence cliffs on the Atlantic region of the Island. In addition, the Atlantic region of the Island is less populated with less physical capital but is also prone to cliff failures. The main adaptation policy is set-backs and fostering of timber structures, impermeable structures. Set-backs can reach as much as 200m along the Atlantic side.

b) Caribbean Coastal Management Plan, CZM Zones 5 to 1

While for the Caribbean region, Zones 5 to 1, the strategy comprises both legislation and defence. This strategy speaks specifically to:

1. Landward: the first coastal road or the limit of the predicted 100-year storm surge modelling or whichever is further inland.
2. Seaward: The 100m isobath or 200m seaward of the outer edge of the bank reef or whichever is further seaward.

c) The Strategic Objectives

a. Objective 1: Sustainability

This includes policy development and enforcement that enables the maintenance and the enhancement of environmental quality while fostering sustainable economic development. The specific objective is developing programmes that reduce environmental degradation,

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[77]http://www.coastal.gov.bb/pageselect.cfm?page=44 (May 23, 2011)

while achieving congruence between economic development and environmental sustainability along the coast. Specific emphasis is also placed on the amenities services provided by the coastal zone. In addition, the carrying capacity of the coastal zone is factored in all decision by the CZMU through the Town Planning Department as relates to the granting of permits to proceed.

b. Objective 2: Legal, institutional and administrative framework

The creation of synergy amongst the legal[78], institutional and administrative framework as it relates to the implementation of the ICZM facilitates congruence among key private and public sector stakeholders as it relates to the sustainable management of the coast as a means of enabling sustainable economic development. The key to this objective is participation by all Barbadians in the coastal management process.

2. Residual Vulnerability Management

The Department of Emergency Management (DEM) secretariat will be replaced by the Barbados Emergency Management Agency (BEMA). This will be the administrative and operational headquarters for disaster management. BEMA would be a fully established Government Department under the Ministry of Home Affairs.[79]

The National Emergency Management System (NEMS) is the umbrella programme that facilitates post response in Barbados. Department of Emergency Management is the primary institution responsible for the coordination of stakeholders and activities pertaining to:

- Emergency Management Advisory Council
- Emergency Operations Centre /Emergency Management Teams
- Fifteen (15) Emergency Management Standing Committees
- Thirty (30) District Emergency Organisations (DEOs)
- Emergency Management Advisory Committee

NEMS utilises experts from the National Disaster Committee or Emergency Management Advisory Council (EMAC). The membership of which comprises of representatives from:

- Emergency Services
- Key government ministries and departments
- The Private Sector and Non-Governmental Organisations (NGOs)
- Community Based Organisations CBOs, along with international and regional emergency management organizations.

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[78]For example: Physical Development Plan and Environmental Management Plan
[79]Taken from http://www.cero.gov.bb/pages/newstruc.html

The EMAC comprises of fifteen (15) standing committees that are organised around key post response themes, which includes:

- Shelter
- Evacuation,
- Mass Feeding,
- Emergency Telecommunications and Public Utilities.

The Standing Committees are chaired by Technical Heads of Government agencies which have responsibility for the execution of national disaster management policy and programmes in their respective areas of expertise. The Committees include:

- Public Information (PIEC)
- Damage Assessment and Statistics (DASC)
- Health and First Aid Services (HFASC)
- Food and General Supplies (FGSC)
- Public Utilities (PUC)
- Emergency Transport (ETC)
- Road Clearance and Tree Trimming (RCTTC)
- Welfare Services (WSC)
- Shelter Management (SMC)
- Telecommunications (TEC)
- Emergency Housing and Rehabilitation (EHRC)
- National Mitigation (NMC)
- Tourism Emergency Management (TEMC)
- Technical Standing Committee on Coastal Hazards (TSCCH)

At the community level of the DEMS there exist 30 District Emergency Organisations (DEO). The DEO's organize and coordinate community post event response efforts

Under this framework there has been an establishment of emergency shelters in all parishes across Barbados.

Table 5: Post response adaptation

Parish	# of Shelters	First Aid Posts
St. Michael	26	3
St. Phillip	8	1
St. George	10	2
St. James	7	2
St. Peter	5	2
St. John	2	1
St. Thomas	4	1
St. Lucy	3	3

Source: Data compiled by author

The DEMS is organized as a post response agency not only for climate change related events, but for all disasters, whether it is natural or manmade. Though the capacity is in place, it is extremely difficult to delineate the cost of operation that is related to climate change induced events.

B. LEGISLATIVE FRAMEWORK

1. Marine Pollution Control Act 1998

Designed to prevent, reduce and control pollution of the marine environment of Barbados from sources such as, air & land based sources and activities related to the sea-bed, dumping. This Act works in conjunction with the Coastal Management Act. The Act states that

> "*No person shall release or cause to be released any pollutant into the environment which is in violation of any applicable standards, conditions or requirements specified under this Act or regulations*."

Under this Act, all pollutants must be registered, in addition, it is also mandatory that programme for the prevention, reduction and control be developed. For known pollutants prohibited level of concentration of must be developed, the enforcement of which is done by marine pollution inspectors, which also has the powers to enter on land to reduce level of pollution.

Other Acts of significance as it relates to the management of the coastal zone includes[80]

2. Fisheries Act 1993

This legal-institutional framework is one of the dimensions of the adaptation strategy applied to the fisheries sector in Barbados in an attempt to ensure that sustainable fishing is adhered to within coastal waters.

This Act defines the physical boundaries, that is, the exclusive territory to be controlled by the Barbadian Government as part of the adaptation strategy of the coastal economic zone. The main aspects of this Act are fisheries management and access agreements for locals and foreigners via the fishing licensing system.

[80] Adapted from http://www.coastal.gov.bb/category.cfm?category=5

3. Marine Areas Preservation and Enhancement Act (1976)

This Act is one of the key legislation used to prevent pollution of the coastal zone from inland sources. Pollution of the coastal zones will exacerbate the impact rising sea surface temperature. In addition, this Act is one of legislation used to ensure that the removal of sand from the shoreline is not done. Consistent with rights of all Barbadians to have access to its beaches, this Act permits the use of marine protected area for its amenities ecosystem services. Scientific research is also fostered under this Act. An example of which is the Marine Areas Act being used as a direct adaptation strategy, is the designation of the Carlisle Bay and the Rockley Breakwater as Protected Areas

4. Barbados Territorial Waters Act (1977)[81]

This Act defines the territorial waters of Barbados, over which the government has full autonomy to manage as a component of a strategy towards enabling the sustainable development of the Barbadian economy. The territorial waters are defined as that which comprises those areas of sea within the seaward limit comprising every point within a distance of 12 nautical miles.

5. Marine Boundaries and Jurisdiction Act (1978)[82]:

This Act defines the waters of the Exclusive Economic Zone (EEZ) of Barbados. This Act also complements the Territorial Waters Act of 1977.

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[81] http://faolex.fao.org/docs/pdf/bar1040.pdf (May 3, 3011)
[82] http://www.un.org/Depts/los/LEGISLATIONANDTREATIES/PDFFILES/BRB_1978_3.pdf (May 3, 2011)

6. Defense Act (1979):

This Act enables the multi-purpose surveillance in the EEZ and territorial waters of Barbados.

7. Shipping Act (1994):

Enables the registration and inspection of large vessels

8. Town and Country Planning Act (TCPA) of 1985:

One of the most crucial legislation in the Barbadian adaptation strategy is the TCPA. This Act defines coastal setback lines for construction and establishes all planning requirements for development, table 6. In addition, it gives the Chief Town Planner independence from the minister to implement the law. However it allows the minister to overrule the chief town planner but the minister cannot direct the chief town planner to act counter to his findings.

The setback policy for Barbados was developed and enforced under the Town and Country Planning Act of 1985. Setback Policy on the South and West Coast is set at a minimum of 30 metres from the high tide mark. West Coast CZM adaptation includes both policy and management that includes setback from the cliff edge at a minimum of 10metres from the most undercut section of the cliff.

The west coast beaches are very flat, that is, they lead far inland for each vertical metre. In addition, the hard structures are built inland to improve the coastal zone. For example the drainage division has through the gully management division, undertaken a gully management study aimed at redesigning and constructing new gullies to ensure that sediment flow is significantly reduced. In addition, the building codes for critical buildings have been adjusted to take into account the need for ground elevation.

Table 6: Coastal Zone sub-areas Coastal Management Plan[83]

COASTAL ZONE SUB-AREAS	Region	Minimum Setback Plan
1a	Kitridge Point to Long Bay	10m from top of landward cliff or up to 100m from undercut of sea cliff
1a to 1b	Long Bay to Salt Cave Point	10m from undercut of sea cliff
1c	Salt Cave Point to Paragon	Minimum Setback - 50m from undercut of sea cliff
1d	Paragon to Inch Marlowe	Top of landward cliff inclusive of wetland, coastal vegetation and dune systems
1e	Inch Marlowe to South Point	Minimum Setback - 10m from undercut of sea cliff
2	Conset Point to Kitridge Point	50m from undercut of sea cliff
3a	Bathsheba to Tent Bay	30m from high-water mark or 10m from undercut of sea cliff
3b	Tent Bay to Bath Beach	30m from high-water mark or 30m from undercut of sea cliff
3c	Bath Beach to Conset Point	400m inland including coastal woodland, vegetation, dune and beach systems
4a	Chandler Bay to North Point	200m from undercut of sea cliff
4b	The Landlock to Chandler Bay	
5	North Point to Archer's Bay	200m from undercut of sea cliff
6	Maycock's Bay to Batts Rock	30m from high-water mark, 10m from undercut of sea cliff
7	Batts Rock to Needham 's Point	30m from high-water mark or 10m from undercut of sea cliff
8	Needham's Point to South Point	10m from undercut of sea cliff or 30m from high watermark

C. ENGINEERING STRUCTURES

Vulnerability within LECZ varies significantly; there exist locations with particularly high-adaptation costs. Cost estimates of infrastructure adaptation within the LECZ are constrained by:

1. Deficits in infrastructure provision varies significantly within the LECZ, the outcome of which is not only infrastructure adaptation but the provision of nonexistent infrastructure to standards that makes allowance for the direct and indirect impacts of climate change.

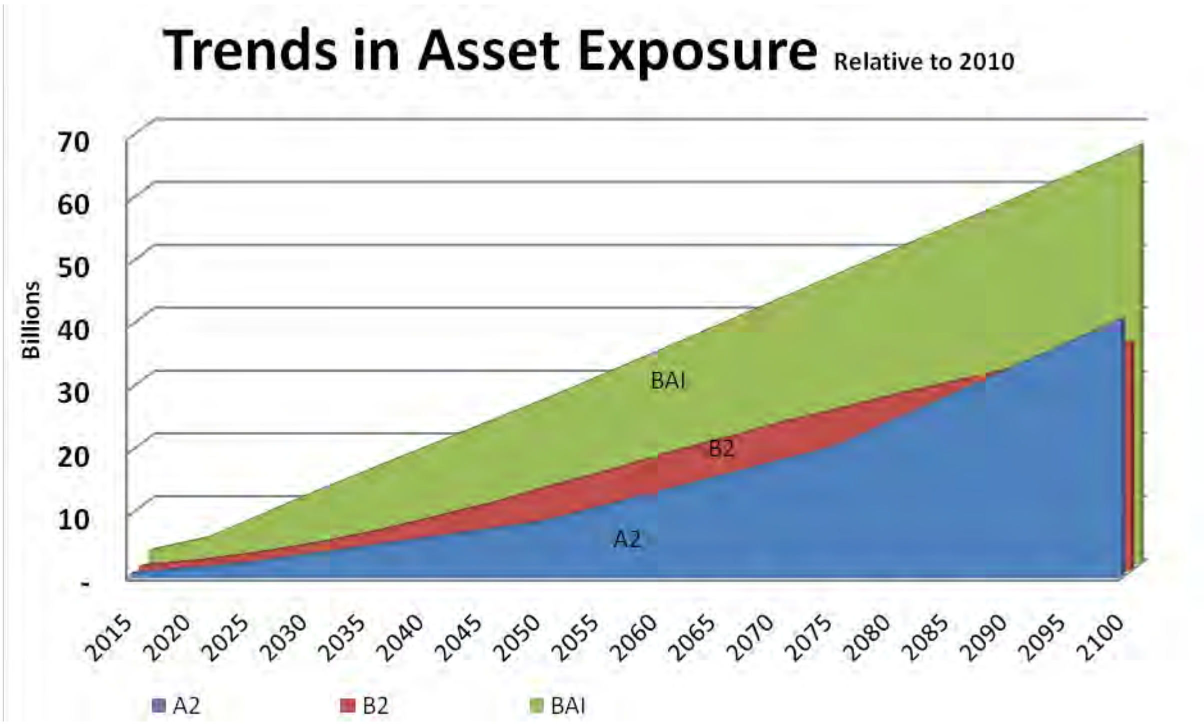
2. Data on location specific adaptation efforts as it relates to modifying existing climate-sensitive infrastructure and climate-resilient infrastructure are not available, hence the use of aggregates to provide elaboration of what it would cost to ensure effective adaptation.

The LECZ span the full 92 miles of Barbados coastline which is inclusive of 80 beaches; the direction of physical investment in Barbados geared towards a path of economic development that is geared towards beach tourism, as it is shown from the US$40billion exposure within LECZ to SLR in

[83]Barbados Coastal Zone Management Plan

the year 2100 relative to 2010. For the year 2010, there exists asset exposure in excess of US$3 billion for both the B2 and A2 scenario[84] (figure 31).

Figure 31: Trends in asset exposure relative to 2010



Source: Data compiled by author

This exposure could also see a supplementation of the current tourism product to include a golf course, health spas and recreational outdoor activities (hiking and camping) especially on the East and North Coast, all of which is within the LECZ.

Figure 32: Christ Church, Sea Defence at Rockley Beach[85]

The CZMU is charged with the development of an Integrated Coastal Management program that develops shore protection program against the impact of climate change manifestations such as sea level, ocean tides and currents, storms and hurricanes, coral reef ecosystems degradation in addition to the economic development trends in regards to commercial and housing development, drainage[86].

To adapt the 1.1 kilometer strip of beach on the southwestern coast, from Rockley to Coconut Grove, shoreline rehabilitation required the construction of five headlands, one major revetment and five spurs (figures 32 and 33). The revetment required 30,000 tons of granite boulders, beach nourishment 18,000 cubic meters of dredged sand. Along with the construction of board walk, this rehabilitation will cost $9 million.

The Government of Barbados focuses its adaption work on land preservation and protection. The strategies include:

- “do nothing” in underdeveloped locations on the east coast of the country. Allow the natural buffer action of the backshore areas to absorb much energy waves experienced on open coastal sections. Capital outlay is almost zero but the benefit is substantial
- 'Maintain' or 'hard options', inclusive of the building of revetments and sea walls, in highly developed coastal areas, for example Bridgetown.

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[85] http://www.superstock.com/stock-photos-images/1850-14337 (Feb 27, 2011)
[86] Adapted from http://www.iadb.org/idbamerica/index.cfm?thisid=4565 (Feb 24, 2011)

Figure 33 Rehabilitation of Rockley Beach[87].

- "control" or "soft options" which includes vegetation or re-vegetation of areas; vegetative matting on bluff faces to aid in bluff face stabilization; and enforcement of coastal related legislation specifically for the protection of some vegetation species and building setbacks, and the prevention beach sand mining." For example, the Coastal zone sub-areas draft coastal management plan, see table 6**.**The following outlines the areas covered by each sub-area, and describes the setbacks for the sub-areas.

As part of Barbados' adaptation to Sea Level Rise, there were 6 projects that were undertaken to lessen the impact of climate change on the exposed assets. These are[88]:

1. Rockley to Drill Hall – Waterfront Improvement (US$7.9 million)

The objective of the waterfront investment was to stabilize the beach to increase the capacity of the ecosystem services provided at the site. That is, increasing the regulatory amenities and provision services offered from the site; specifically for beach recreation, protection of physical infrastructure and beach nourishment. The actual investment included:

- Eight groynes comprising of four straight groynes and four fish-tailed /y-shaped groynes
- 70,000 $m^3$of beach re-charge
- Shoreline revetments
- Removal beach rubble

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[87]http://www.iadb.org/idbamerica/index.cfm?thisid=4565
[88]Taken from the CCPAC Strategy Document

- Steps to beaches

2. Woman's Bay (Silver Sands) – Headland protection – US$1.2 million

The engineering structure in the case was the rebuilding of a revetment that protects the headland between the Little Bay and Woman's Bay. This headland is important for the stabilization of sand at both beaches.

3. Crane Beach, St. Phillips – Restoration and Enhancement (US$ 2.5 million)

This structure consists of the rebuilding of a revetment that protects the headland that in turn protects the Crane Beach. The investment includes:

- Replacement of existing deteriorating revetment that stabilizes the headland;
- Construction of shore-parallel spurs south from the headland to hold and expand the beach adjacent to the headland for easier pedestrian access to the south beach. This included the construction of new steps to the beach also;
- Resurfacing of the headland along with the construction of a walkway at the top of the revetment to allow access to the north beach;
- Reconstruction of the access road to the headland.

4. Holetown Beach improvement (US$700,000)

This investment was geared towards protecting coastal infrastructure that was built close to the high water mark. The outcome of which was an enhanced beach and increase regulatory ecosystem capacity of the area. The actual investment included:

- Four rubble mount groynes
- Offshore dredging of sand
- Sand nourishing of foreshore between groynes.

5. Welches Beach improvement (US$2.5 million)

A critical infrastructure found on the west coast of the Island is Highway 7, the link between the north and south of the Island along the west coast. At the Welches area this critical infrastructure is at risk from being undermined by storm surges associated with hurricanes. The adaptation efforts at this site consist of

- Construction of a retaining wall along with a walkway along the seaward edge and access to the beach;
- Building of a revetment along the seaward edge of the roadway and fronting the retaining wall;
- Construction of three new groynes and refurbishing of one existing groynes;
- Placement of approximately 12,000 m^3 of sand recharge.

6. Walkers Savannah – Dune Restoration (US$0.5 million)

The restoration of the dune system included:

- Allowing natural processes to rebuild the dunes;
- Expediting and controlling natural dune formation by the planting of native dune vegetation and or the installation of sand fencing.

IX. CBA OF ADAPATATION STRATEGY

The IPCC (2007) defines adaptation benefits as those avoided damage costs or accrued benefits following the adoption and implementation of adaptation measures. While adaptation cost is defined as those costs of planning, preparing for, facilitating and implementing adaptation measures, including the transition costs.

For coastal defence structures the design life can be significant, being at least 50 years, and as long as 100 years in some cases. For the analysis two climate scenarios are explored, which reflects two contrasting pathways for climate change policy in Barbados. The scenarios for the analysis are the:

- Business-as-Usual (BAU) world with no climate policy based on the SRES A1 scenario;

- Adaptation Scenario with reductions in greenhouse emissions compared to the A1 scenario. In this the SRES B1 scenario 23 is used as a surrogate adaptation scenario

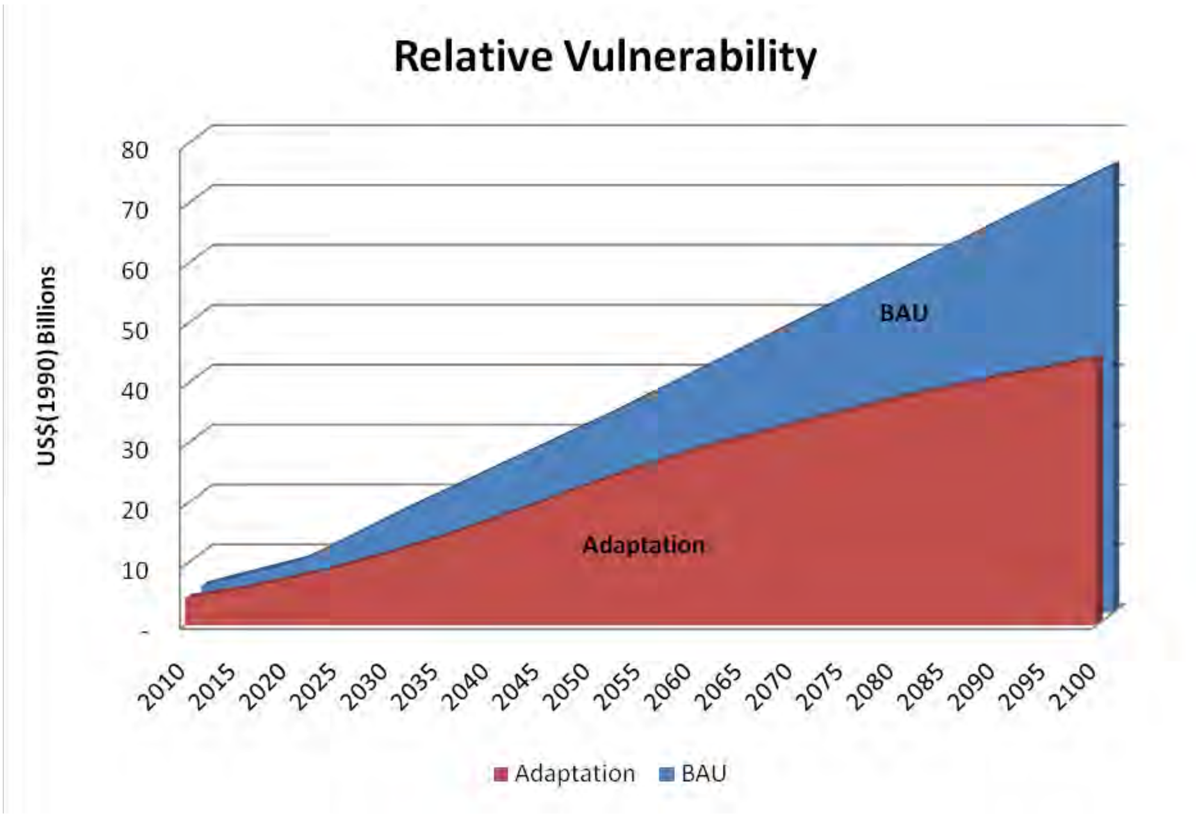
Given the lack of data for this analysis, it is assumed that adaptation strategies are designed to reduce the vulnerability associated with the BAU scenario, the outcome of which is a path change for the economy that is equivalent to that of the SRES B1 scenario.

A. BENEFIT OF ADAPTATION

The adaptation strategy for Barbados is a combination of policy, hard protection and active seaward advance via land claim. The adaptation benefits derived is an indicator of the reduced vulnerability associated with the measures and structures that the Government of Barbados has undertaken in regards to climate change.

With adaptation there is a residual vulnerability which cannot be adapted away. Even with the best of technology and optimal adaptation.

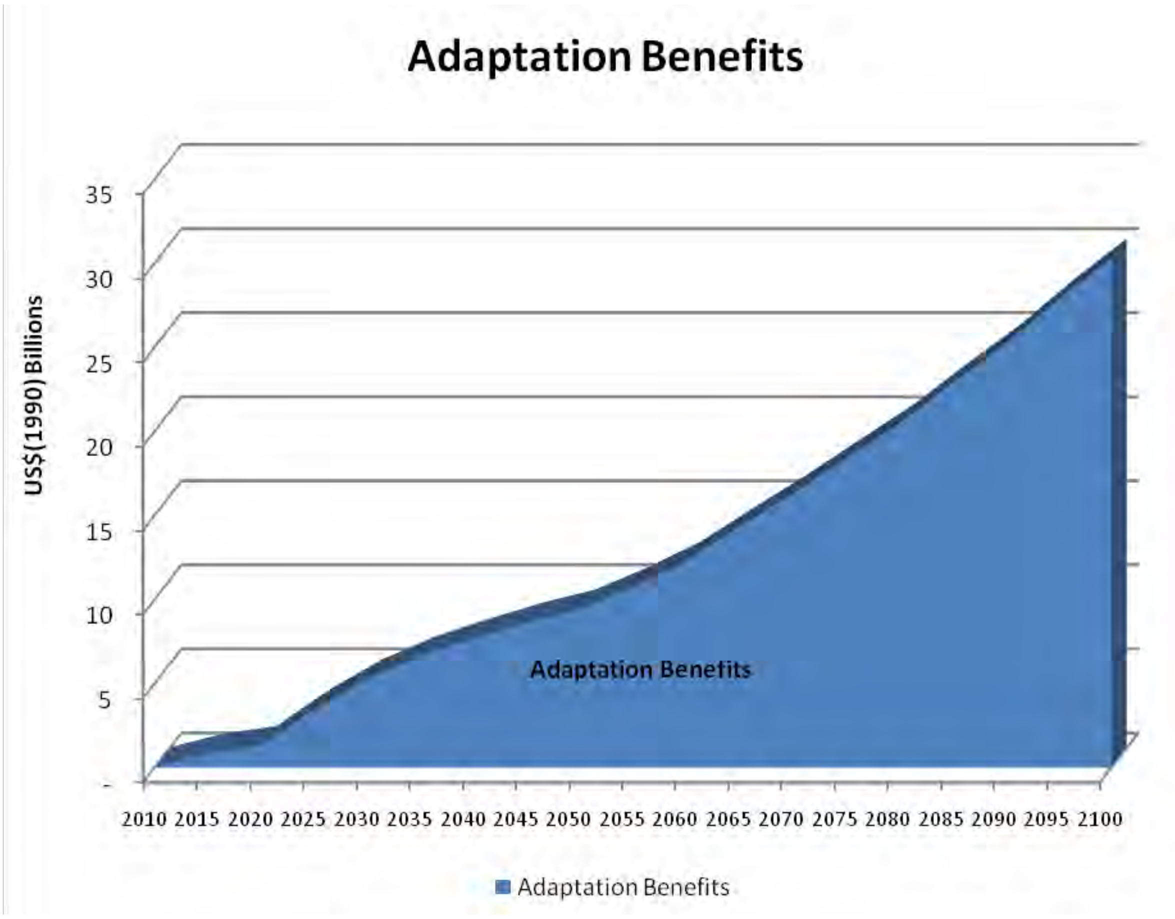
Figure 34: BAU vs. Adaptation



Source: Data compiled by author

With adaptation it has been shown that the vulnerability of the Barbados Economy, especially that within the LECZ, will decrease significantly (figure 35). Though with adaptation, the reduction in average annual vulnerability within the LECZ is approximately US$12.7 billion or approximately 270% of the estimated GDP for the year 2010. The residual vulnerability within the economy remains high (figure 36).

Figure 35: Adaptation benefits



Source: Data compiled by author

B. COST OF ADAPTATION

An investment in coastal adaptation is the outcome of government led research among the ministries and sometimes NGOs. The outcome of which is that the total cost of adaptation is spread across many ministries and therefore somewhat difficult to quantify the true cost of adaptation. There is a political and sufficient technical capacity in Barbados to identify the adaptation investment needs and the required funding, whether from the fiscal budget or grants, to make the investments in building new and or adapting existing infrastructure.

The costs of legislative measures are not systematically recorded. The legislative measures are implemented across several ministries within the Barbadian Government process. The outcome is an understated cost which does not reflect the true cost of developing the institutional/governance capacity to build and adapt needed infrastructure. Social infrastructure is also hard to value, in this case this cost is not factored into the analysis due to lack of data to substantial estimates.

The numbers of poor quality houses within the LECZ are indicative of the adaptation infrastructure deficit within the economy, especially as it relates to severe weather conditions. Significant capacity in post event responses as it is in relation to CDEMA and other local disaster response agencies has also significantly reduced the adaptation deficit within the economy.

From interviews with in-country government experts, it is plausible to assume that there are no single consolidated accounts of adaptation costs but only direct project costs associated with a particular adaptation strategy.

1. Major Project/Event estimates

For the adaptation infrastructure, fifty years of anticipation needs to sea-level rise is considered according to the BAU scenario. The costs of the major projects undertaken as Barbados climate change adaptation strategy are:

- Rockley to Drill Hall– Waterfront Improvement (US$7.9 million)
- Woman's Bay (Silver Sands) – Headland protection – US$1.2 million
- Crane Beach, St. Phillips – restoration and Enhancement (US$ 2.5 million)
- Holetown Beach improvement (US$700,000)
- Welches Beach Improvement (US$2.5 million)
- Walkers Savannah – Dune Restoration (US$0.5 million)

Capital cost for hard structures to adapt to climate change under the BAU in Barbados is estimated at US$15.3 million dollars.

C. BENEFIT COST ANALYSIS

From the analysis, it was shown that the benefit of adaptation far exceed the cost of adaptation. It was assumed that the B1 scenario represent the output that will occur with adaptation to climate change. The A1 scenario was used as the output for the BAU scenario; this is consistent with Nicholls (2007). It is argued that the use of A1 as BAU will tend to overstate the impact of climate change as it assumes that the impacts from the emission scenarios are the sole causes for the climate change impacts. However for this analysis and that which is consistent with the literature, Nicholls (2007) etc. it is adequate. It is a fact that infrastructure deficit does contribute to the impact of climate change on the economy. One of the main adaptation measures is to reduce the infrastructure deficit by increasingly investing protective infrastructure. This process is a gradual one. The lack of provision or inadequacies in provision for protective infrastructure does add to the vulnerability to climate change. However, the analysis is consistent with the literature as it has shown that the benefits from adaptation outweigh the costs.

X. POLICY RECOMMENDATIONS

A. OVERVIEW

The vulnerability associated with climate change can be reduced with the adaptation efforts within each state. The adaptation efforts via the redistribution of human settlements away from the coastline are technically possible but the feasibility of such action is another scenario that the planners need to consider. The trend in coastline development over the years in the Caribbean has been biased towards the coastline. The concentration of population in coastal settlements is true of Christ Church and Hastings in Barbados, where the most heavily densely populated areas are the coastline.

The damages and loss of life sustained during severe weather conditions that occur at a frequency that is currently acceptable to the current planners, but such frequency is increasing due to climate change. The latter manifest as acceptable risk as reflected to the tardiness of mitigating coastal vulnerabilities by the authorities. The vulnerabilities associated with coastal urbanization are not reflected in the economic incentives that drive coastal development at the moment. This is one of the reasons why this study is of such immense importance because of the need to show that climate change implies an increase in the frequency of severe weather conditions in addition to inundation. These increased frequencies are above the acceptable level, hence falling within the category that warrants attention by the Government.

Of importance to note is that settlement infrastructure is immobile and long lasting, making rapid spatial movement away from the coast to be very costly, hence, the need to pay special attention to the future scenarios of climate change. Given that climate change risk and vulnerability is not reflected in the pricing mechanism for houses along the coast, there will continue to be an increase in infrastructure along the coastline to continue to support existing coastal settlements. This also fuels the development of major socio-economic infrastructure along the coast to also support the existing infrastructure. The outcome of which is the path dependency of coastal settlements to prior coastal developments.

B. POLICY DIRECTION

As the manifestations of climate change become more evident, the socioeconomic vulnerability within the LECZ will increase, this represents infrastructure that facilitates the entire Barbadian economy. Strategies for coping with coastal erosion and flood damages associated with sea-level rise include defending the shoreline by means of protective structures, beach restoration, and the enforcement of setbacks. Even at present rates of sea-level rise and land subsidence, most of the shoreline of Barbados is eroding.

Accelerated sea-level rise, increase frequency of storm surges may intensify the rate and extent of coastal erosion. In response, existing hard engineering structures may need to be strengthened and elevated repeatedly over the next 100 years. For New York, it is estimated that by the 2080s adaptation for climate change costs will grow between 5 to 26% due to the manifestations of climate change. This rate of adaptation cost is far below the projected exposed asset, hence a justification for adaptation. As such the Government of Barbados should develop a system of collection and management of data that would monitor sea level rise and its impacts and would improve the modelling of the physical and economic impact of climate change.

Coastal adaptation to climate change in Barbados is a multistage and iterative process that should include the following adaptation strategies:

1) Improving building design, building codes and increase coastal planning
   a) Relocation of critical infrastructure to less vulnerable areas
   b) Enforcement of setbacks in vulnerable areas

2) Response strategy**:** Progressive abandonment of land and structures in highly vulnerable areas and resettlement of inhabitants where possible.
    a) no development in susceptible areas
    b) conditional phased-out development
    c) conservation of ecosystems harmonized with the continued occupancy and use of vulnerable areas and adaptive management responses
    d) advanced planning to avoid worst impacts along with the strict regulation of hazard zones

3) The main areas of high population and of high economic value, which has resulted in the coastline being protected with groynes. Hard structures such as groins are not the only protection measures to be used, beach nourishment is also viable. This not only stabilizes the coastlines but also provides protection for the mainland as well as sandy beaches for recreation and enhancement of the tourism product. Climate change will result in sea-level rise and increased storminess. This will mean that existing dikes will have to be strengthened and raised. Adherence to maintenance scheduled is a must.

4) Adaptation strategy will emphasize strict protection. There will be great emphasis on defending vulnerable areas, population centers, and economic activities and natural resources. The possible adaptation actions shall include but not limited to:
a) Possible options includes
    i) Hard structural options
    ii) Increase use of dykes, levees and floodwalls/flood gates and tidal barriers
    iii) Reinforcement of seawalls, revetments and bullhead

XI. CONCLUSION

Infrastructure deficit within the Barbados economy does contribute to the vulnerability of the Island to the manifestations of climate change. Evidence of the existence and size of the adaptation deficit can be seen in the trend in mounting vulnerability projection to extreme weather events such as floods and sea level rise. This is the outcome of the expansion of human populations, socio-economic activities, real property, and infrastructure of all kinds into the LECZ.

Physical capital in the ground is not as climate-proof as they could and arguably should be. The A2, B2, adaptation and BAU projections all show that the adaptation deficit will continue given the exponential growth of exposed assets within the LECZ.

The Barbados Government must be congratulated on the efforts currently underway to reduce the vulnerability of the economy. With current adaptation strategies, the vulnerability deficit has decrease significantly for 1in30 year event but this may not be the case larger events. The adaptation efforts comprised both hard engineering structure and policy to prevent infrastructure deficits in the pass to be continued in the future.

A. SUMMARY CONCLUSIONS

Natural catastrophes are classified as great if a region’s ability to help itself is distinctly overtaxed, making supra-regional or international assistance necessary. As a rule, this is the case when there are thousands of fatalities, hundreds of thousands are left homeless, and/or overall losses are of exceptional proportions given the economic circumstances of the country concerned.

The analysis has shown that base upon exposed assets and population, the sea level rise can be classified has having the potential to create potential catastrophe in Barbados. The main contributing factor is the concentration of socioeconomic infrastructure along the coastline in vulnerable areas.

The A2 and B2 projections has indicated that the number of catastrophes that can be classified as great, is likely to be increased for the country. This is based upon the possible impacts that the projected unscheduled impacts to the economy both in terms of loss of life and economic infrastructure can have.

Global changes have meant increased vulnerability nearly everywhere, however, the A2 and B2 projections represents mainly a change in population density and increase economic activity. These results arise from the A2 and B2 projections, thereby indicating that the growth in numbers and losses are largely due to socioeconomic changes over the projection period and hence the need for increase adaptation strategies. Climate change is probably playing an increasingly decisive role but the projected impact is purely anthropogenic.

The A2 and B2 projections have shown that the following aspects can turn events that are entirely natural into devastating catastrophes:

- Population growth: People will only be able to create the necessary settlement areas by making use of new sites, where natural hazard exposure can be very high.

- Settlement and industrialisation of highly exposed regions: Cities are spreading rapidly, frequently in highly exposed regions such as flood and coastal zones. Above all, the progressive settlement within coastal areas bring with it the risk of tropical-storms, tsunami or storm surge losses. The A2 and B2 projections indicate a rise in population density in coastal communities and increasing concentration of economic infrastructure along the coast.

- Concentration of population and values: The more conurbations there are in the coastal zones, the greater the probability that the manifestations of climate change will affect one of them.

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