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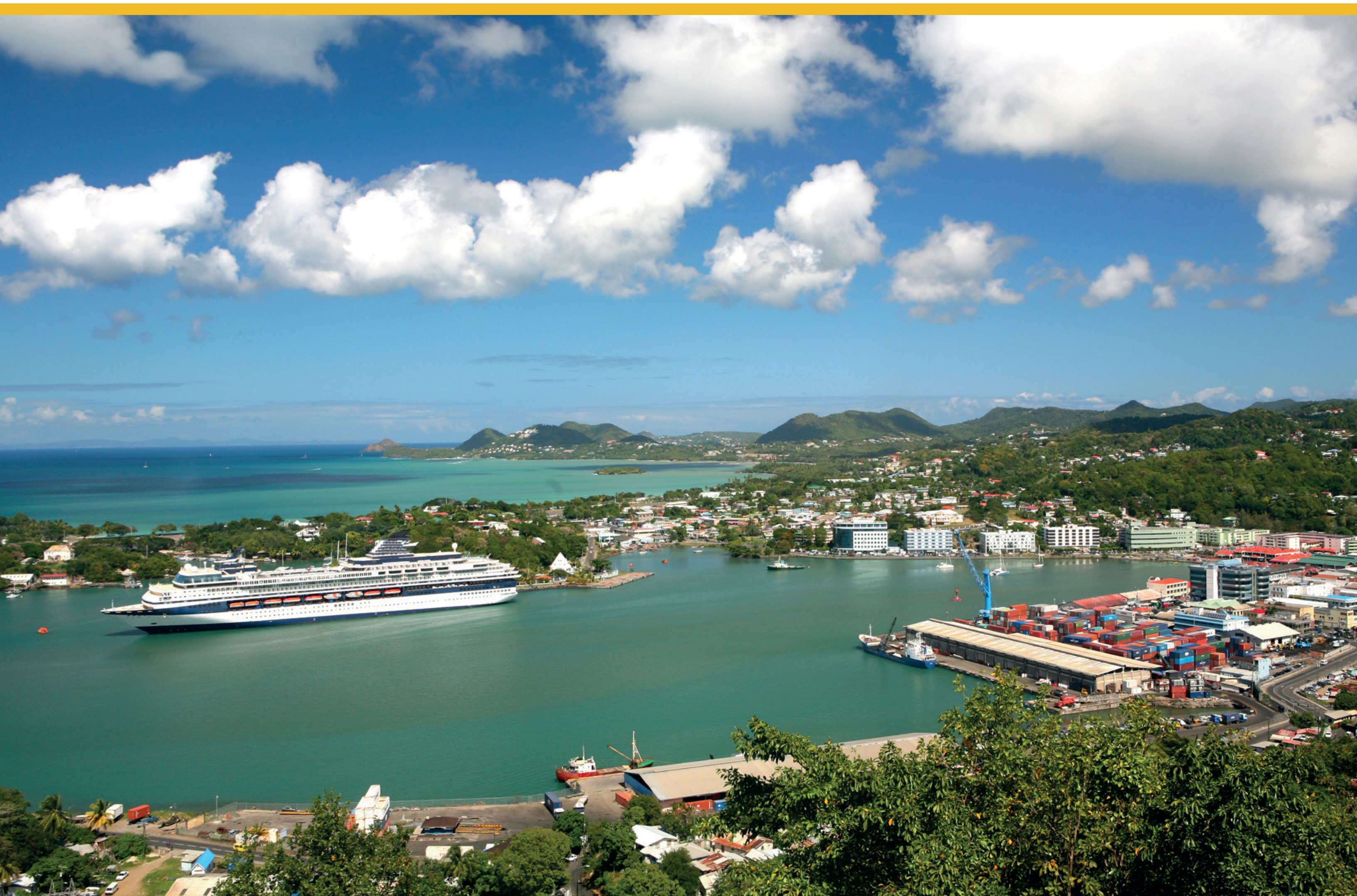
Climate Change Impacts on Coastal Transport Infrastructure in the Caribbean: Enhancing the Adaptive Capacity of Small Island Developing States (SIDS)

Saint Lucia: A case study



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NOTE

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For further information about the project and relevant documentation, see SIDSport-ClimateAdapt.unctad.org.

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EXECUTIVE SUMMARY

Background

Small Island Developing States (SIDS) share environmental and socio-economic vulnerabilities that can challenge their growth and development aspirations. Their geographical location and geomorphology dictate reliance on coastal transport infrastructure, particularly seaports and airports, a fact that can exacerbate vulnerabilities due to the increased exposure of such assets to the variability and change of several climate-related forcings. At the same time, SIDS' capacity for adaptation and resilience building with regard to the coastal transport infrastructure is constrained by unfavourable economies of scale and limited financial and human resources for the targeted vulnerability assessments necessary to identify requisite adaptation options.

Against this background, an UNCTAD UN Development Account project has been carried out with the objective to design/test a methodological framework for assessing climate impacts on the coastal transportation infrastructure of Small Island Developing States (SIDS), with an emphasis on the Caribbean region. Two Caribbean SIDS with different environmental and socio-economic characteristics were selected as case studies: Jamaica and Saint Lucia. Detailed assessments of the vulnerability of the islands' transportation assets were carried out to: (a) improve knowledge and understanding at the national level, and (b) test new approaches in order to develop an appropriate methodology for assessing climate-related impacts on coastal transportation in other SIDS. The present report presents the assessment of the criticality of Saint Lucia's major transportation assets (airports and seaports) and their potential vulnerabilities to Climate Variability and Change (CV & C).

Saint Lucia: Economic Background and Risks Related to Transportation

Saint Lucia is a Small Island Developing State located at the Lesser Antillean Arc of the Caribbean Archipelago with a total resident population of 185,000 in 2015. The island is of volcanic origin. This has resulted in a mountainous and rugged topography, characterized by steep slopes cut by fast-flowing water drainage networks, confined low-lying coastal areas and 'pocket' beaches. Saint Lucia is an open economy which has progressed within the context of a relatively stable social and political environment. The island's economy is vulnerable to global economic shocks (such as the global financial crisis in 2008), fossil fuel price hikes, and changes in international trade and tourism preferences. In addition, due to its geological and climatic characteristics is subject to natural disasters.

The tourism sector is St. Lucia's main economic driver, which has been estimated to contribute up to 41.5 % of GDP (direct and indirect contributions, 2015), being also the largest earner of foreign exchange. In Saint Lucia, tourism follows the *Sea-Sand-Sun* (*3S*) model and, thus, most tourism infrastructure and activities are concentrated along the coast. On the back of strong tourism inflows and depressed oil prices, Saint Lucia's economy showed measurable recovery in 2015 following a weak performance over the previous three years. GDP growth reached 0.5 % in 2014, with transportation and hotels contributing mostly to the economic recovery. Saint Lucia, for the first time, surpassed the one million mark in the combined number of stay-over and cruise ship passengers. Between 2012 and 2015, the island recorded an 11.1 % overall increase in stay-over tourist arrivals, from 306,801 to nearly 345,000. Total visitor expenditure increased to an estimated EC$2.08 billion, supported by a 3.1 % rise in spending by stay-over visitors. The growth was projected to continue in 2016, with early projections set at 2.8 %.

While Saint Lucia's small size and high degree of openness have made it vulnerable to external economic shocks, its geographic location, climate and geology have also made it susceptible to natural hazards. The island is vulnerable to hydro-meteorological (e.g. high winds, excess rainfall, hurricanes) and geophysical events (e.g. earthquakes, volcanic activity), the impacts of which can be severe and pronounced by the island's small economy; historical information indicates that storm-induced flooding and landslides have been the most likely hydro-meteorological impacts affecting Saint Lucia. Average annual economic losses associated with extreme hydro-meteorological events for the period 1992-2011 have been equivalent to roughly 2 % of GDP or about US$ 26.94 million PPP. However, singular high-impact events can be devastating: Hurricane Allen (1980) have resulted in damages/losses equivalent to about 60 % of GDP while the recent Hurricane Tomas (2010) resulted in damages/losses estimated at US$ 336.2 million (43.4 % of GDP).

Key economic and critical infrastructure assets in the country including the airports, seaports and fuel storages, are all located along the coast or on low-lying reclaimed coastal land. Thus, transport infrastructure is vulnerable to the impacts of climate change, as is exposed to both coastal and inland flooding, which is further exacerbated by Saint Lucia's topography.

Critical facilitators of the large tourism sector are the key transport assets (i.e. airports, seaports and the interconnecting road network) that are mostly located on low-lying coastal land. Thus, transport infrastructure and operations are vulnerable to CV & C, particularly to changes in the intensity/frequency of marine storms and high rainfall events that can increase exposure of the major assets to marine and/or riverine flooding (and landslides). Changes in other climatic factors (e.g. the frequency of heat waves) can also disrupt transport operations. Generally, there may be severe effects of the CV & C on the transport infrastructure and operations that, in turn, could cause major disruptions to related economic sectors such as tourism.

Climate: Trends and Projections

St. Lucia experiences a tropical maritime climate. The location, size and geomorphology of the island allow for weather that is affected by large scale weather systems such as the northeast Trades, the El Niño Southern Oscillation (ENSO), the Atlantic High Pressure System and the passage of tropical waves, depressions, storms and hurricanes. Saint Lucia may be already experiencing some of the effects of CV & C. There is increasing evidence to suggest that its climate is changing, with major climatic trends and projections being as follows:

- Minimum temperatures have increased since 1960's at a rate of about 0.16 °C per decade (maximum temperature increase rates of about 0.20 °C per decade).
- The warming trend is expected to continue. The island is projected to be warmer compared to the 1970-1999 average temperature by up to about 1.8 °C by the 2050s and 3 °C by the 2080s. The

frequency of very hot days/nights will increase significantly and that of very cool days/nights decrease.

- There is no statistically significant trend in the historical rainfall, which shows considerable inter-annual variability. Projections by both GCMs and RCM show a drier island by the end of the century (projected median decreases in annual rainfall of up to 22 % and 32 %, respectively). Also, projections suggest likely decreases in total heavy rainfall.
- Sea levels will rise considerably in the course of the century. Recent projections suggest a mean level rise at Saint Lucia of 0.13 - 0.14 m by 2030s, 0.31 - 0.35m by 2060 and 0.56 - 0.76 m by the end of the century, depending on the scenario.
- Recent studies on the regional storm surges and waves project that marine storm conditions may not be overwhelming in the course of the century; these studies project small/moderate increases in storm surge levels as well as mostly decreases in the wave power of the extreme storms (e.g. the 100-year events).
- Hurricane intensity is projected to increase, but not necessarily the hurricane frequency.
- Sea surface temperatures in St. Lucia are projected to increase by 0.8 °C - 3.0 °C by 2080s, with potential adverse effects on the island's coral reefs.

Criticality of Transport Infrastructure

The contribution of transportation to Saint Lucia's economy was estimated at EC$ 400,920,000 (13.45 %) in 2015, a figure that highlights the importance of seaports and airports and their intermodal connections in the social and economic development. The four major transport assets in Saint Lucia are the two airports (Hewanorra International Airport (HIA) and George F.L. Charles) and the two seaports (Castries and Port Vieux Fort). Their criticality is shown by their throughput:

- In 2015, 71,364 Twenty Foot Equivalent Units (TEUs) were transported through the two major seaports and about 2,965 tonnes through the airports with the incoming/outgoing cargo being also serviced by the road network;
- Visitor arrivals (stayovers and cruise passengers) totalled 1,073,017 in 2015;
- Saint Lucia is a major destination for cruise ships, with up to 677,394 arrivals in 2015, has direct connectivity to major US gateways and the UK and is visited by major cruise liners such as Celebrity, Carnival, Norwegian, and Royal Caribbean; and
- The HIA facilitates approximately 80 % of all air traffic into and out of the island, serving as the gateway to the international long-haul airlines that connect the island to the United States, Canada, Europe and the rest of the world, whereas George F.L. Charles airport handles passengers mainly for regional flights to/from Caribbean destinations (e.g. St Vincent, Martinique, Grenada, Trinidad and Barbados). The airports handled 840,696 passengers in 2016.

Given the importance of airports and seaports and their land interconnections to tourism and the movement of goods, the vulnerability of their infrastructure and operations to CV & C is a most important factor for consideration.

Assessment of Asset Vulnerability to CV & C: Methodology

In order to assess asset vulnerability to CV & C, historical hydro-meteorological impacts and disruptions were summarized and the direct and indirect impacts on the 4 critical coastal transport assets of St. Lucia (i.e. the 2 seaports and 2 airports) were assessed.

Regarding the former, information available from previous impact assessments regarding extreme events is summarized. Concerning the latter, the approach adopted to assess the direct impacts of CV & C on the coastal transport infrastructure/assets consists of the following tasks: (i) assessment of direct impacts on transport operations, using the '*thresholds*' method; and (ii) assessment of the direct impacts on coastal infrastructure through modelling of the flood/inundation due to extreme sea levels (ESLs) under the present and future climate. In the first task, impacts on operations are assessed on the basis of comparisons between current transport operational thresholds (where available) for different climatic factors such as temperature and precipitation, and climatic factor projections. In the second task (contributed to the study by the EC-JRC), extreme sea levels (ESLs) for different periods in the 21st century have been estimated using projections for the regional Mean Sea Level Rise (MSLR), as well as dynamic simulations (DFLOW FM model and wave model WW3) for storm surges and waves forced by atmospheric conditions (ERA-INTERIM). In addition, in order to assess hurricane impacts, the effect of cyclones on coastal sea levels are taken into consideration on the above projections. The projected total ESLs were then used to predict marine coastal flood/inundation on the basis of dynamic simulations using the open-access model LISFLOOD-ACC (LFP) and a digital elevation model (DEM).

In addition to the direct climate impacts on the infrastructure of the major transport assets there are also indirect impacts. Transport is a demand-driven industry. As international air passenger volumes to St. Lucia are mostly controlled by international tourism, potential CV & C impacts on tourism are also assessed. Since St. Lucia tourism has developed according to the *3S* tourism model and most of the tourist infrastructure/assets are concentrated along the island beaches, potential CV & C impacts on St. Lucia's tourism (and thus the demand for air transport) are projected through the 'proxy' of the decrease in the carrying capacity of St. Lucia beaches due to beach erosion under different climatic forcings. In addition, other indirect impacts on tourism/transport are related to the connectivity between the major gateways of international tourism and the major tourist destinations of the island, i.e. the coastal resorts/beaches. This connectivity is under increased risk of disruption due to landslides that have been recorded during (and following) extreme rainfall events; thus, an assessment of this connectivity has been also carried out.

Historical and Future Climatic Direct Impacts on the Major Transportation Assets

Historical information suggests that storm-related flooding and landslides are the most likely impacts of CV & C affecting transport. Both airports and Port Castries have suffered damages/losses from hydro-meteorological events. In comparison, Port Vieux Fort appears to have been resilient to storm surges and there have been no reported incidents of flooding. The connecting road transportation network (including roads and bridges) has been frequently disrupted by landslides. The landslide risk, which was already high due to both terrain and climate, has been exacerbated by construction on steep hillsides and loss of natural vegetation. Generally, many of the island's roads traverse areas of high/extreme landslide hazard risk.

Regarding future disruptions due to climatic factors, operational thresholds for each facility were identified in order to determine the climatic conditions under which the facility might be damaged and/or operation disrupted. The analysis was focused on climatic factors likely to be affected by CV & C, such as, precipitation/flooding, temperature, sea level and tropical storms, with the objective being to project future threshold exceedance. Results of the approach with regard to the effects of rising temperatures are shown in Table 1. Extreme temperatures can affect aircraft operations and the ability of employees to work safely outdoors as well as increase energy costs. According to projections, the annual mean temperature of Saint Lucia is to increase by 0.3 - 1.2 °C by the 2030s and 0.5 - 2.1 °C by the 2060s in compared with the end of the 20th century, with an accompanying increase in the frequency of very hot days. It is shown that there will likely be future disruptions in both airports and seaports which are set to increase over the years. Some of the aircrafts currently using HIA are projected to face reductions in take-off payloads during the extreme heat days if the runway is not extended; down-time days for employees is projected to increase together with energy costs (Table 1).

Table 1 Days of disruptions for the airports and seaports

Climate Stressor	Sensitivity	Threshold	Disruptions (average days/year)		
			2000-2019	2040- 2059	2080 - 2099
Airports					
Extreme Heat	Employee ability to work safely outdoors	Heat Index (NOAA) over 39.4 °C (103 °F), resulting from 30.6 °C (87.1 °F) and 80 % relative humidity presents 'high' risk	2.05	13.2	53.7
		Heat Index (NOAA) over 46 °C (115 °F), resulting from 32.5 °C (90.5 °F) and 80 % relative humidity presents 'very high risk'	0	1.05	11.8
		Boeing 737-500 aircraft would not be able to take off from HIA if the temperature exceeds 31.2°C without reducing aircraft loads	1.1	12.1	67.5
		Boeing 737-400 aircraft would not be able to take off from HIA if the temperature exceeds 31°C without reducing aircraft loads	1.7	12.25	67.9
Ports					
Extreme Heat	Energy costs	1°C warming = 5% increase in energy costs if temperature exceeds 27.8°C (mean temperature for the period 1986-2005: 26.8 °C)	N/A	221	351.5
		3°C warming = 15% increase in energy costs if temperature exceeds 29.8°C (mean temperature for the period 1986-2005: 26.8 °C)	N/A	47.6	179
		6°C warming = 30% increase in energy costs if temperature exceeds 32.8°C (mean temperature for the period 1986-2005: 26.8 °C)	N/A	1	15.4

In the following sections, summaries of the past and projected future CV & C disruptions are presented for each facility.

Hewanorra International Airport (HIA)

Past damages/losses have been mostly associated with intense precipitation events which resulted in overflowing of the (re-directed) La Tourney River. Increases in flood-inducing extreme precipitation can have very significant impacts on the operations of the HIA and, by extension, to the economy. However, recent projections suggest likelihood of milder precipitation events (with the exception of hurricanes), which suggest that, assuming proper management of the current (recognized) terrestrial flooding vulnerabilities, there will be no significant increase of the current risk. There has been, to date, no significant damage caused by storm surges and waves.

The results of the inundation risk modelling suggest that, under the projected extreme sea levels (ESLs) and taking into consideration the effects of cyclones, the eastern edge of the runway will be affected; a 50-year ESL by 2050 under RCP 4.5 superimposed by the effects of a hurricane will inundate a length of about 130 m (Figure 1) and a 100-year ESL by the year 2100 under RCP 8.5 will inundate a length of about 380 m.

Finally, the operational threshold method (detailed above) suggests that CV & C may have significant effects on the airport operations and energy costs. For example, assuming no major technological advances in aircraft design, decreasing the take-off payload will be necessary for much more days per year by 2050 (by an order of magnitude) than is currently the case.

George Charles International Airport (GCIA)

The flooding of the runway reported previously by airport officials was probably due to poor drainage into Ganters Bay rather than the impact of storm surges and waves. Storm surge/waves at the fronting Vigie Beach have resulted only in sand being swept across the road and onto the perimeter of the runway, where the walkway is located. However, previous research has indicated that marine flooding levels exceeding 1.8-2.4 m might result in (at least) partial inundation of the airport runway. In any case, potential erosion of fronting Vigie beach in response to extreme storm events may increase substantially the exposure of the backshore elements of the airport.

The inundation modelling carried out within the framework of the present project (courtesy of EC-JRC) has shown that Vigie beach will be flooded by the year 2050, under a 50-year ESL (under RCP 4.5) superimposed by a hurricane (Figure 1). Under a 100-year ESL by 2100 (under RCP 8.5) water will flow on the runway from the Vigie beach. The inundation of the beach will make the airport very vulnerable to the incident waves.

Castries Seaport (CSP)

Port Castries facilities are located at approximately 1.5 m above MSL. The Castries docks have withstood past storm events and ESLs without sustained damage, although floating debris reaching the port from the land have presented problems to berthing vessels. According to SLASPA officials, effects of ESLs in the Ganters Bay have significantly worsened, since the mangroves were removed and replaced with a concrete wall. Previous research has shown that a 100-year event may generate water levels well and above the elevation of parts of the port, suggesting increased risk of inundation particularly close to the entrance. The results of the present study suggest that the effects of a hurricane superimposed on the projected ESLs will raise the sea level by ~1 - 2.4 m (according to all tested scenarios from baseline to 2100), causing significant damages/flooding to the port facilities even if the mildest of the tested scenarios is considered.

It must be also noted that projections regarding the wave power of extreme events for Saint Lucia in the course of the 21st century are generally optimistic (in the absence of 'freak' hurricanes), although the projected changes in the direction of wave approach may necessitate some rearrangement/upgrading of the structural elements of the port.

Vieux Fort Seaport (VFSP)

Port Vieux Fort appears to have been resilient to storm surges and there have been no reported incidents of flooding: the Christmas Eve trough, which caused significant flooding in the area with many houses and roads damaged/flooded, did not cause significant damages to the port. Previous studies have shown that a SLR of about 1m (the mid-century MSLR plus a storm surge of 0.6 m) will not cause any damages to the port to speak of, although the seaward side of the Town of Vieux Fort will be likely flooded. It should be also noted, that flooding of the Mankote mangrove may result in its degradation as it is already under stress from anthropogenic factors.

Model results of the present study suggest that cyclone effects superimposed on anticipated ESLs will result to SLR of ~1-2.4 m (according to all tested scenarios from baseline to 2100). Given that Port Vieux Fort is approximately 1.5 m above mean sea level, all the examined SLR scenarios will cause damages/flooding to the port facilities and the surrounding area, affecting houses as well.

Finally, the operational threshold method (detailed above) suggests that CV & C may have significant effects on the energy costs of both seaports due to the projected increase in extreme temperatures.

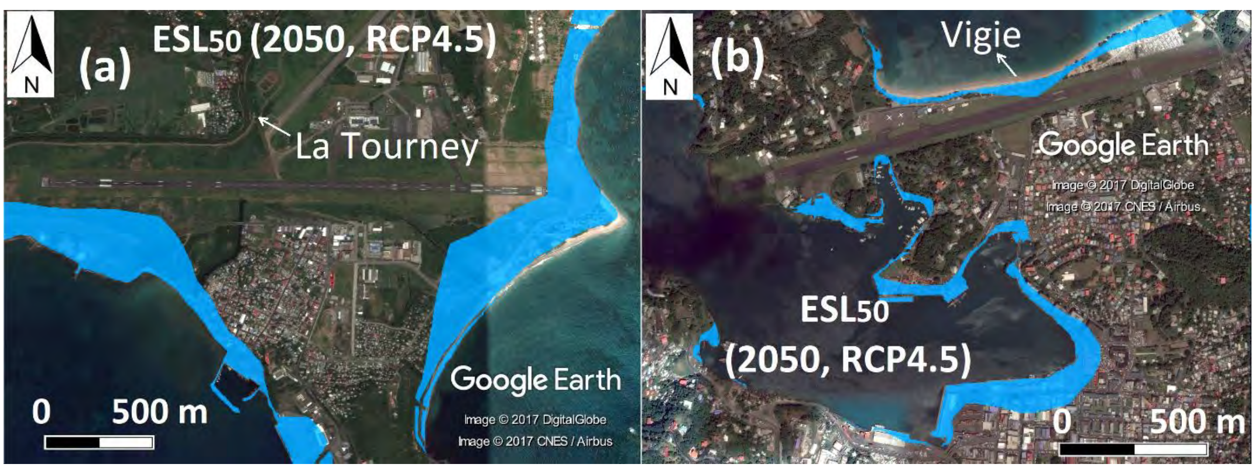

Figure 1 Inundation maps of (a) Hewanorra Airport and Port Vieux Fort and (b) the George Charles Airport and Port Castries under 50-year ESL (cyclone effects are included) projected for the year 2050 according to RCP4.5 scenario

Indirect Impacts of CV & C on the Major Transportation Assets

CV & C Impacts on Tourism

Transport is a demand-driven industry. International air passenger volumes to St. Lucia are mostly controlled by international tourism and, thus, potential CV & C impacts on tourism should be considered.

Since St. Lucia tourism follows the *3S* (*Sea-Sand-Sun*) tourism model and most of the tourist infrastructure/assets are concentrated along the island beaches, CV & C impacts on St. Lucia's tourism (and thus indirect impacts on air transport) should be also assessed. In the present study an assessment has been carried out through the 'proxy' of projected decreases in the carrying capacity of St. Lucia beaches due to beach erosion under different climatic forcings. Previous research has also suggested that sea level rises of 1 m and 2 m could place about 7 % and 10 % of the major tourism coastal infrastructures/assets at risk.

In the present study, the geo-spatial characteristics (e.g. beach width maxima) and other attributes (e.g. backshore development) of all ('dry') beaches of Saint Lucia have been recorded, on the basis of the images and other related optical information available in the Google Earth Pro application. Seven cross-shore analytical and numerical morphodynamic models were used in appropriate ensembles to project the response of the Saint Lucia's 'pocket' beaches to long and short-term SLR. Outputs include: (i) potential ranges of beach erosion and temporary inundation/flooding and corresponding ranges of decreases in beach carrying capacity ('dry' beach widths); (ii) ranges in beach short-term (temporary) inundation; and (iii) assessment of backshore infrastructure/assets likely to be affected by beach retreat/erosion and flooding.

It was found that there will be significant impacts on the Saint Lucia beaches. In 2040, storm-induced ESLs of about 1 m combined with a moderate MSLR of about 0.2 m will result in the complete erosion and flooding of <u>at least</u> 11 % and 24 % of all island beaches, respectively. In 2100, superimposition of storm levels on the projected MSLRs could have devastating effects. A combined ESL of 1.56 m (e.g. a storm-induced extreme level of +1 m superimposed on a MSLR of 0.56 m -RCP4.5) could result in the complete erosion of <u>at least</u> 20 % and the complete flooding of <u>at least</u> 31 % of all beaches. It must be stressed that the above projections represent the absolute minimum beach erosion and flooding.

These results, although being on the better side of similar projections for other island tourism destinations, show that there may be significant challenges ahead. There may be significant CV & C impacts on Saint Lucia's tourism which, in turn, may affect negatively the demand for transportation services.

Connectivity of major assets

Indirect impacts on tourism/transport are also related to the connectivity of the major gateways of international tourism/arrivals to the major tourist destinations and urban centres of the island, i.e. to the coastal resorts/beaches and to Castries. This connectivity is under increased disruption risk due to the many landslides along the road network that have been recorded during and following extreme precipitation events. These disruptions, in addition to human losses and asset/infrastructure damages also present challenges to the smooth operation of the tourism and transportation industry. In the present study, related impacts have been assessed on the basis of the landslide density recorded after Hurricane Tomas at the connecting road network between the 2 international airports and the 30 most touristic beaches of the island. It was found that during such events, and in the absence of major cliff armouring engineering works, the connectivity between the major touristic beach resorts (mostly located along the northern island coast) and the HIA (located at the southern tip of the island) is at much higher disruption risk than that between the resorts and the George F.L. Charles international airport. Similarly, cargo distribution from Port Vieux Fort (also located at the south) to the major urban centre of the island and the tourist resorts in the north is also likely to be impeded.

Potential approaches to adaptation

A variety of adaptation measures might be employed (following detailed risk assessments), some examples are presented on table below (see also Chapter 6).

Table 2 Examples of adaptation measures differentiated into action areas

Action Area	Adaptation Action
Engineering	Enhance the structural integrity and efficiency of critical facility components
	Future procurement of mechanical components for the assets against future operating environment requirements
	Assess and develop new design standards for hydraulic structures
	Ongoing hydrographical monitoring
	Construction of storm retention basins for flash flooding
Technology	Investment in more climate-resilient technologies and equipment in planned expansion and upgrade programmes
	Refrigerated storage specifications should be upgraded and seek less energy intensive alternatives
	Automation of logistics procedures
Planning, design and development	Internal capacity-building and retraining building of redundancy into critical operations
	proactive infrastructure and management plan
	Re-examine land use planning in flood prone areas
Management	operational systems need to mainstream climate-change considerations
Insurance	Some risks cannot be avoided; therefore, they must be insured by third parties

Conclusions

The assessment of the impacts of Climate Variability and Change (CV & C) carried out for the major coastal transportation assets of Saint Lucia within the framework of UNCTAD's Development Account Project has shown the following.

The most critical transportation assets (seaports and airports) are all located along the coast and have small elevations; this makes them vulnerable to a number of climatic factors and their projected changes. There is also a strong nexus between these transportation assets and tourism, the main driver of Saint Lucia's economy. Therefore, the 'well-being' and smooth operation of these assets is extremely important for Saint Lucia's economy (and generally for SIDS).

Both historical information and future projections suggest that these assets (and their interconnecting road network) will be vulnerable to a number of CV & C impacts. There will be an increasing inundation flooding risk of the assets (particularly during hurricanes), mostly related to marine flooding as terrestrial floods are not projected to increase significantly. At the same time, results from the 'operational thresholds' approach suggest that air transport operations will be also affected by CV & C, as the projected increases in the frequency of very hot days will likely require reductions in aircraft payloads and increased energy costs.

Finally, there can be significant indirect impacts on transportation, as the dominant 3S tourism of Saint Lucia (and all other island tourist destinations) will be challenged by increasing beach erosion. Although beach erosion projections for Saint Lucia appear to be on the better side of similar projections for other island destinations, the problem will still need careful consideration, as it has potential to affect (amongst others) the demand for transportation services.

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Chapter 1: INTRODUCTION

1.1 Project Background

Small Island Developing States (SIDS) share a number of socio-economic and environmental vulnerabilities that challenge their growth and development aspirations. Their climate, location and geomorphology, as well as their reliance on coastal transport infrastructure, in particular seaports and airports, exacerbate these vulnerabilities, including their susceptibility to climate variability and change (CV & C) factors, such as sea-level rise and extreme weather events (UNCTAD, 2014). At the same time, SIDS' capacity to adapt and to build resilience of their coastal transport infrastructure is constrained. SIDS have limited financial and human resources to conduct targeted vulnerability studies, carry out cost assessments, and identify and prioritize requisite adaptation options.

Three issues are pervasive:

1. The lack of information/data at a downscaled local level
2. Insufficient cooperation and coordination of action at all levels
3. The urgent need for targeted capacity-building in order to develop effective adaptation measures that ensure the resilience of transport infrastructure, services and operation.

Building on UNCTAD's related research and consensus building work, a project on "Climate change impacts on coastal transport infrastructure in the Caribbean: enhancing the adaptive capacity of Small Island Developing States (SIDS)" is currently being implemented by UNCTAD. The project aims to strengthen the capacity of policy makers, transport planners and transport infrastructure managers in SIDS to:

a. Understand climatic impacts on coastal transport infrastructure - in particular seaports and airports; and
b. Take appropriate adaptation response measures.

The project is expected to significantly improve the understanding of relevant issues in Jamaica and Saint Lucia and assist in the development of appropriate national adaptation capacity with measurable and durable impact. In addition, significant multiplier effects are expected in respect of the methodology for assessing adaptation needs and priorities in coastal transport infrastructure which will be developed, tested, refined and applied in a controlled way as part of the case-study-approach.

Thus, the project objectives can be described as:

i. Enhanced knowledge/understanding among policy makers, transport planners and transport infrastructure managers in SIDS of climate change impacts on port and airport infrastructure as well as associated implications for services and operations.
ii. Strengthened capacity of policy makers, transport planners and transport infrastructure managers in SIDS to effectively plan and develop requisite adaptation measures that enhance the resilience of coastal transport infrastructure.

iii. Increased collaboration, dialogue, information-sharing and partnerships among relevant public and private sector stakeholders, as well as scientists and engineers; creation of synergies, building also on existing networks for collaboration.

There has been significant collaboration, in the implementation of this project, with other entities and stakeholders, including with UNEP; regional commissions, in particular UNECLAC; UNDP; the World Bank; and the Caribbean Community Climate Change Centre. Close cooperation and collaboration was also sought from private sector partners and, importantly, with local stakeholders, including relevant seaport/airport and planning authorities and local academic institutions.

1.2 Approach

Case-studies focusing on two vulnerable SIDS in the Caribbean region (Jamaica and Saint Lucia) were carried out to enhance the knowledge and understanding at the national level; and to develop a methodology for assessing climate-related impacts and adaptation options in other SIDS. The case-studies involve three main components:

1. An assessment of the potential climate change impacts on ports and airports in Jamaica and Saint Lucia, their direct costs and broader economic impacts.
2. An assessment of options for adaptation in response to the potential impacts.
3. The development of a methodology/tool to assist transport infrastructure managers and other relevant entities in SIDS in assessing climate-related impacts and adaptation options regarding coastal transport infrastructure.

The methodology has been designed with a view to its transferability and replication in other jurisdictions across SIDS regions, subject to location-specific modifications. The results of the study, including the methodology, were reviewed and refined at an Expert Group meeting and, following the development of guidance/training material, were presented at two national workshops for stakeholders in Jamaica and Saint Lucia.

The national workshops also served to solicit further input, including on the methodology for assessing adaptation needs and priorities. So as to ensure significant multiplier effects, a regional workshop was convened to present the insights gained as a result of the study, provide training in the methodology for assessing climate-related impacts and adaptation options and consider best practices/experiences.

Chapter 2: COUNTRY PROFILE

2.1 Geography

Saint Lucia is a Small Island Developing State (SIDS) within the Lesser Antillean Arc of the Caribbean Archipelago and located between 13° 43' and 14° 07' North and 60° 05' West (Figure 2-1). The island state is the second largest of the Windward Islands and situated on a volcanic ridge between Martinique to the North and St. Vincent and the Grenadines to the south. It is 42 km long, 22 km wide at its longest and widest points, with a land area of 616 km^2, and is characterized by mountainous and rugged topography, with steep slopes cut by fast-flowing rivers.

Figure 2-1 Map of Saint Lucia

The Island is of volcanic origin as evidenced by its mountainous terrain, with a central north-south oriented ridge of mountains rising to Mount Gimie at 950 m. In the southwest coast are the Gros and Petit Pitons (797 m and 750 m respectively), two immense towering volcanic cones rising sharply from the sea and enclosing a small bay which together form the Piton Management Area, a UNESCO World Heritage Site. Near Petit Piton, in the crater of an ancient volcano, are the boiling sulphur springs from which the nearby town of Soufrière takes its name. A choice tourist site, the springs also contain substantial energy potential.[1] There are flat areas near the northern and southern tips of the island and broad flat valleys run between offshoots off the main central valleys to the sea. A significant portion of Saint Lucia is covered in natural forests, although land continues to be cleared for agriculture and construction. It has numerous fertile valleys that are made up of alluvial soils and are generally where the larger agricultural production is undertaken. As shown in the land use map in Figure 2-2, the majority of urban settlements and tourism

[1] With initial studies on environmental and social impact assessment and pre-feasibility studies to be concluded in 2017, the government of Saint Lucia expects drilling for the geothermal project on the island state to start by 2018. In 2014, Saint Lucia committed to achieving a national target of meeting 35% of its energy requirements from renewable sources by the year 2020. The Government envisages that developing the country's geothermal resource is a key strategy to reduce Saint Lucia's dependence on fossil fuels and to meet its sustainable energy target.

development are located in the narrow coastal zone of the island while much of the farming activities are situated on slopes and in the interior, just below the areas demarcated as natural forests.

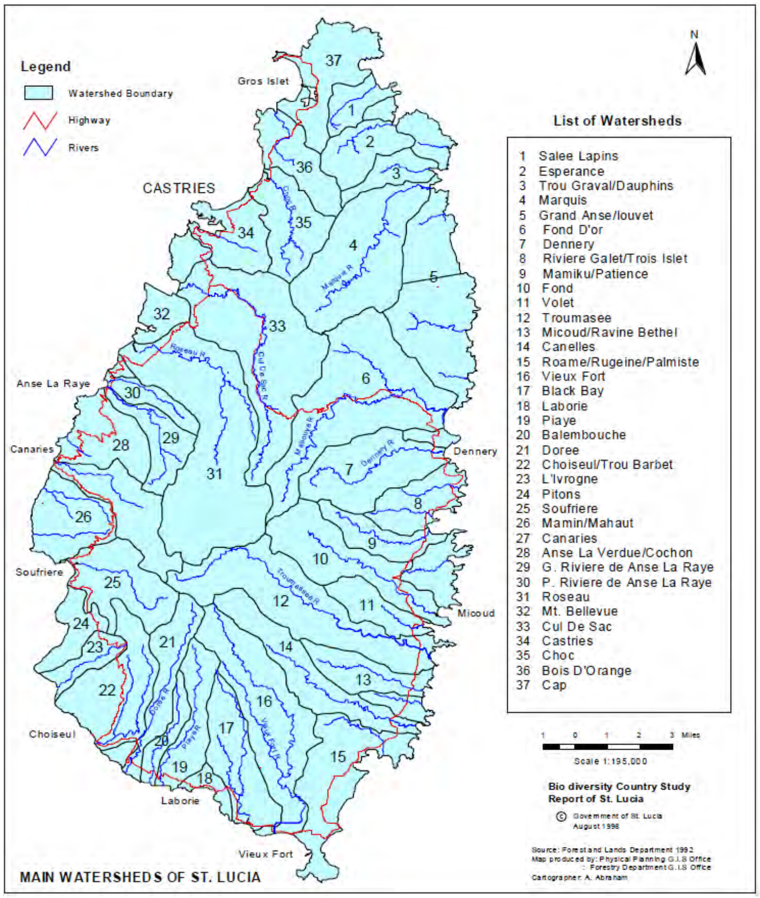


Figure 2-2 Saint Lucia: Watersheds and Rivers

The island comprises 37 main watersheds that radiate from the central mountain ranges of the interior towards the coast (Figure 2-3a). Within these watersheds, 10 are small multiple drainage basin complexes while 25 water catchments are harnessed for domestic water supply. Most of the water consumed or used on the island coming from 7 catchment areas which have their headwaters mainly in the mountainous south-central area of the island (Thomas-Louisy, 2014).

Its coast measures 158 km, with the capital town, Castries, located in a bay on the northwest coast of the island. The population of St. Lucia is concentrated in the north of the island, particularly the north-western and north-eastern part which includes Castries, Gros Islet, and Babonneau. As the population has increased, the settlement pattern has sprawled from the low lying urban areas into the surrounding hillsides creating expanding suburban settlements (World Bank, 2013). The rapid urbanization of the former rural areas of the island, with denser populations living in unplanned or informal settlements has led to increased risks with regard to natural and man induced climate change (Thomas-Louisy, 2014).

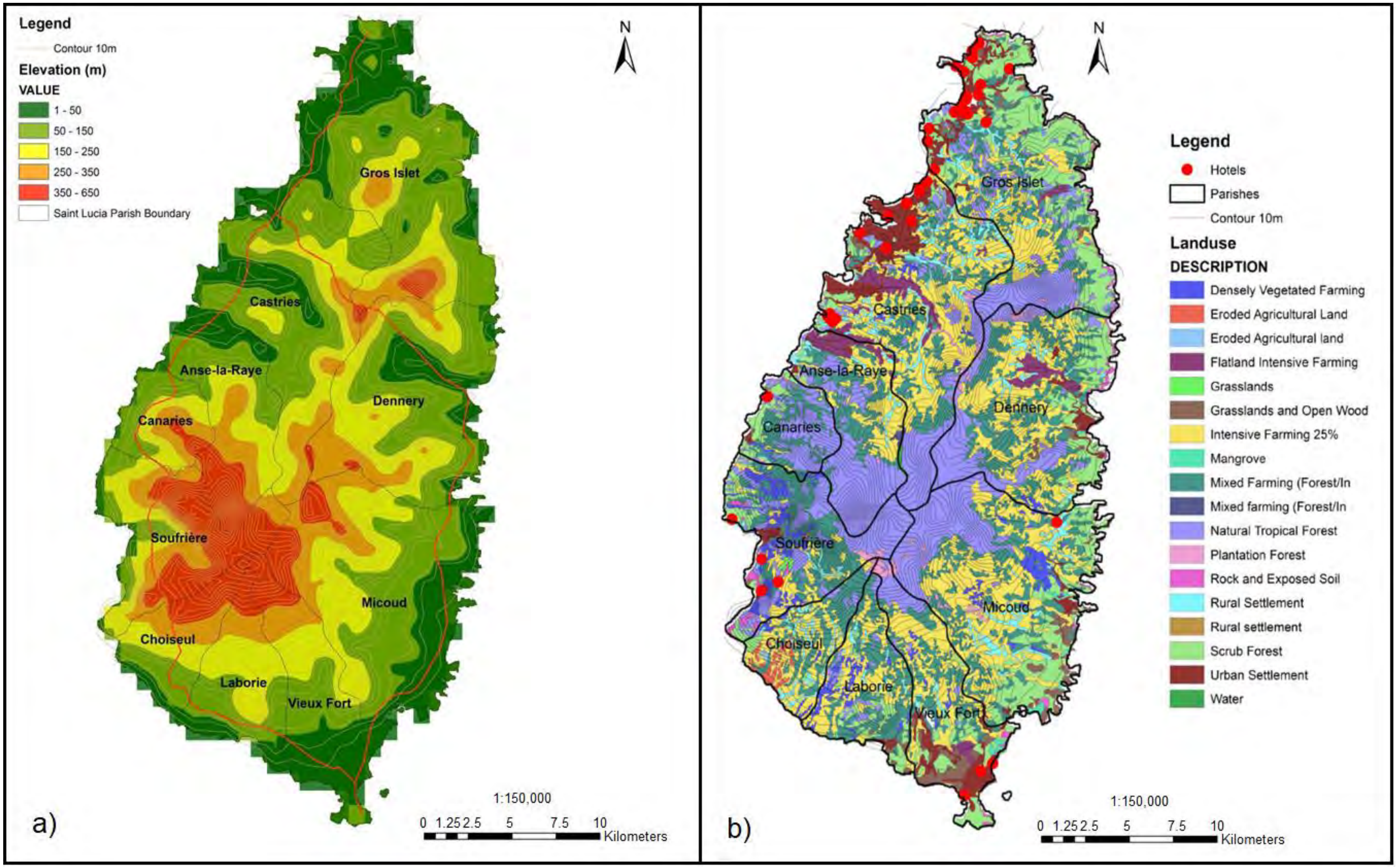


Figure 2-3 Saint Lucia: a) Topography (Source: ESL, 2015); b) Land Use (Source: ESL, 2015)

Figure 2-4 Reefs off Anse Chastanet on the West Coast (left), the Pitons (right)

Saint Lucia has a relatively high level of biological and ecosystem diversity. A total of over 1,300 known species of plants (including seven endemics), over 150 species of birds (including five endemics), approximately 250 reef fish species and 50 coral species have been identified for the island (GoSL – Government of Saint Lucia, 2000). The high biodiversity in the coastal marine environment was corroborated by P. Hawkins and C. M. Roberts who collected fish counts and coral cover measurements (as cited in Barker, 2003). They counted fish using an adaptation of the stationary point visual census technique at 5 and 10m depths. During 15-minute intervals, they estimated size (total length to nearest cm) and number of non-cryptic reef species (Table 2-1) at nine of the dived sites (Site # 1,3,4,6,7,8,9,11 and 12) and two of the snorkelled sites (Site # 13 and 14). Hawkins and Roberts also measured percentages over of hard corals and live substrate (this included hard and soft corals, fans, sponges, gorgonians, octocorals, zoanthids, tunicates, algae, anemones and hydroids).

Table 2-1 List of sites and fish species identified during counts (Source: Barker, 2003)

Latin name		Common name
A.	*Abudefduf saxatilis*	Sergeant major
	Chromis multilineata	Brown chromis
	Chromis cyanea	Blue chromis
	Stegastes partitus	Bicolor damselfish
	Thalassoma bifasciatum	Bluehead wrasse
	Myripristis jacobus	Blackbar soldierfish
	Clepticus parrae	Creole wrasse
B.	*Lactophrys polygonia*	Honeycomb cowfish
	Gymnothorax miliaris	Goldentail moray
	Gymnothorax funebris	Green moray
	Gymnothorax moringa	Spotted moray
	Echidna catenata	Chain moray
	Enchelycore nigricans	Viper moray
	Myrichthys breviceps	Sharptail eel
	Myrichthys ocellatus	Goldspotted eel
	Synodus intermedius	Sand diver (lizardfish)
	Bothus ocellatus	Eyed flounder
	Bothus lunatus	Peacock flounder
	Equetus punctatus	Spotted drum
	Narcine brasiliensis	Lesser electric ray
	Diodon holacanthus	Balloonfish (puffer)
	Diodon hystrix	Porcupinefish
	Malacanthus plumieri	Sand tilefish
	Scorpaena plumieri	Spotted scorpionfish
	Rypticus saponaceus	Greater soapfish
	Sphoeroides spengleri	Bandtail puffer
	Aluterus scriptus	Scrawled filefish
	Gerres cinereus	Yellowfin mojarra
	Calamus calamus	Saucereye porgy
	Chaetodipterus faber	Atlantic spadefish
	Aulostomus maculatus	Trumpetfish
	Halichoeres radiatus	Puddingwife
	Balistes vetula	Queen triggerfish
	Bodianus rufus	Spanish hogfish
	Kyphosus sectatrix	Chub
	Pomacanthus paru	French angelfish
	Holocanthus ciliaris	Queen angelfish
	Cantherhines macrocerus	Whitespotted filefish

A= species identified in the 'small fish' (<25cm long) category, B= species identified in the 'big fish' (≥25cm long) category.

Site No.	Site Name
1	Anse la raye wall (D)
2	Lesleen M (D)
3	Turtle reef (D)
4	Anse Chastanet reef (D, S)
5	Fairyland (D)
6	Grand Caille (D, S)
7	Trou Diable (D, S)
8	Pinnacles (D)
9	Superman's Flight (D)
10	Piton wall (D)
11	Jalousie (D, S)
12	Coral Gardens (D, S)
13	Anse Cochon (S)
14	Jalousie-Hilton reserve (S)

D= sites used for dive trips,
S= sites used for snorkel trips.

The importance of this biological diversity is reflected to the fact that population centres and economic activities, including tourism, are concentrated along the coast. Saint Lucia is one of the largest tourism destinations in the Caribbean, which has emerged as the main engine of economic growth since the decline of the banana industry on the island. Tourism has been increasingly associated with beach recreational activities according to the dominant 'Sea, Sand and Sun-3S' tourism model (Phillips and Jones, 2006). Consequently, beaches have become very important economic resources (Ghermandi and Nunes, 2013), forming one of the pillars of tourism, an economic sector that contributes more than 23 % of the Gross Domestic Product - GDP in many Caribbean Small Island States – SIDS (UNECLAC, 2011b). With 19,000 acres of rainforest acting as a habitat for rare birds and plants, 2.4 km^2 of mangroves and 37 km^2 of seagrass, the island also provides numerous activities for more adventurous tourists. Also the 7 km^2 of coral reefs are one of the most important components of the regional tourism product; there are a number of dive sites dotted around the island (Figure 2-5). The island also benefits from marketing the island as a leading destination for weddings and honeymoons. During the shoulder periods, the tourist industry also receives a significant boost from the Saint Lucia Jazz festival in May and the Saint Lucian Carnival in July (UNECLAC, 2011a).

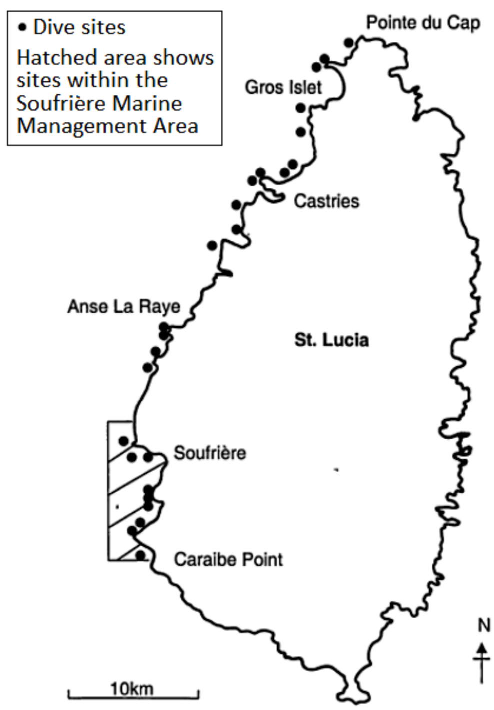


Figure 2-5 Location of sites used by dive businesses in 2001

However, the variety of activities that take place in Saint Lucia's coastal zone points to interventions being necessary to address environmental imperatives (potential or realised) related to a plethora of issues including air and marine pollution control, waste management, physical planning and flood mitigation. For those reasons, the Government of Saint Lucia has established a Coastal Zone Management – CZM policy, approved and adopted by Cabinet in 2004, with concurrent guidelines, strategies and actions that allow for an integrated approach to coastal zone planning, management and development (Walker, 2005).

2.2 Socio-economic Profile

Saint Lucia is characterized as a small open economy and has progressed within the context of a relatively stable social and political environment. St. Lucia's economy is particularly vulnerable to economic shocks, including the global economic and financial crisis, capricious tourism receipts, dependence on fossil fuel imports, financial instability from the weak banking sector, adverse effects of global warming, the spread of the ZIKA virus, local labour market issues, the collapse of European trade preferences that supported the traditional banana crop and relatively frequent natural disasters.

St. Lucia has experienced anemic growth since the onset of the global financial crisis in 2008. Favourable international conditions have contributed to improved demand for tourism, St. Lucia's main economic sector, the external current account deficit has reduced and the authorities have made some progress in addressing the weak fiscal state by implementing additional revenue measures over the past few years, negotiating a wage freeze with labour unions, enacting under-execution of budgeted capital expenditures, implementing a VAT in 2012 and launching the Citizenship by Investment Program in 2016 (Review of the Economy 2015; IMF, 2016). The island nation has also been able to attract foreign business and investment, especially in its offshore banking and tourism industries (CIA, 2016). In addition to the prospects of growth, capital expenditure is expected to increase, as work on a number of on-going projects may be fast-tracked while European Union (EU) funding has been identified for a new bridge along with other road works (EFR, 2016). Notwithstanding the improvement in the fiscal position, the financial sector continues to be impaired by nonperforming loans, rising public debt (75.4 % of GDP) and unemployment rates (24.1 %) while external sector competitiveness continues to be weakened by an overvalued exchange rate, economies of scale disadvantages and structural bottlenecks (Review of the Economy 2015).

The authorities are committed to the Eastern Caribbean Currency Union (ECCU) debt target of 60 % of GDP by 2030. In recent budget addresses, GoSL identified the key sectoral priorities as consisting of tourism, public utilities and the financial sector while other focus areas include assistance in exporting, support for the creative industries and interventions in agriculture and fisheries. Albeit slow, economic activity in Saint Lucia is projected to promote growth towards 2 % in the medium-term, driven primarily by developments in the construction sector, additional FDI-financed touristic and public infrastructure projects, such as upgrading Hewanorra International Airport (IMF, 2016).

2.2.1 Economic Indicators

St. Lucia's economy grew moderately in the last three decades, averaging around 3.5 % annually between 1981 and 2013 (PSAR, 2014). However, the onset of the global financial crisis in 2008, together with several natural disasters, has had a significant impact on the country's economic growth. In 2009, the economy contracted by 2.7 % due to a sharp decline in visitor arrivals (PSAR, 2014), while in 2010 the country was struck by Hurricane Tomas which led to loss of life and significant damage to infrastructure and agriculture; total damage was estimated at 43.4 % of Gross Domestic Product (GDP) (UNECLAC, 2011c). Although its fragile state, Saint Lucia's economy showed measurable signs of recovery in 2015 after a weak performance over the previous three years; a recession in 2012 and close to zero growth in 2013 (IMF, 2016). This growth has been spurred on by strong tourism inflows and lower oil prices, resulting in an increase in GDP by 0.5 % in 2014, with transportation and hotels mostly contributing to the economic recovery (IMF, 2016). The current account deficit is estimated to have narrowed from 11.2 % to 6.7 % of GDP in 2014, while inflation increased to 3.5 %, mainly owing to higher food prices. For the first time since fiscal year 2008-2009, the primary balance switched to a small surplus of 0.1 % of GDP in fiscal year 2014-2015, reflecting somewhat higher revenues, including from policy measures, restraint on current spending, and cuts to capital expenditures (IMF, 2016). In 2015, the GDP in St. Lucia was worth 1.43 billion US dollars, reaching an all-time high, while it represented less than 0.01 % of the world economy (World Bank, 2016). According to World Bank data, GDP per capita for the year under review was 7,735.91 US$. The main service sectors (real estate and business activities; transport and communications; hotels and restaurants; financial intermediation; and wholesale and retail trade) account for 60 % of GDP, with wholesale and retail trade and accommodation and food service activities accounting for 53 % of enterprises in the economy (Figure 2-6a) (PSAR, 2014). In 2015, real GDP growth was estimated at 2.4 % (World Bank, 2016), fuelled by improved performances mainly in the construction, transport and agriculture sectors (Figure 2-6b). However, according to Prime the country's Minister, a 7 % growth is needed in order to just maintain the current debt levels.

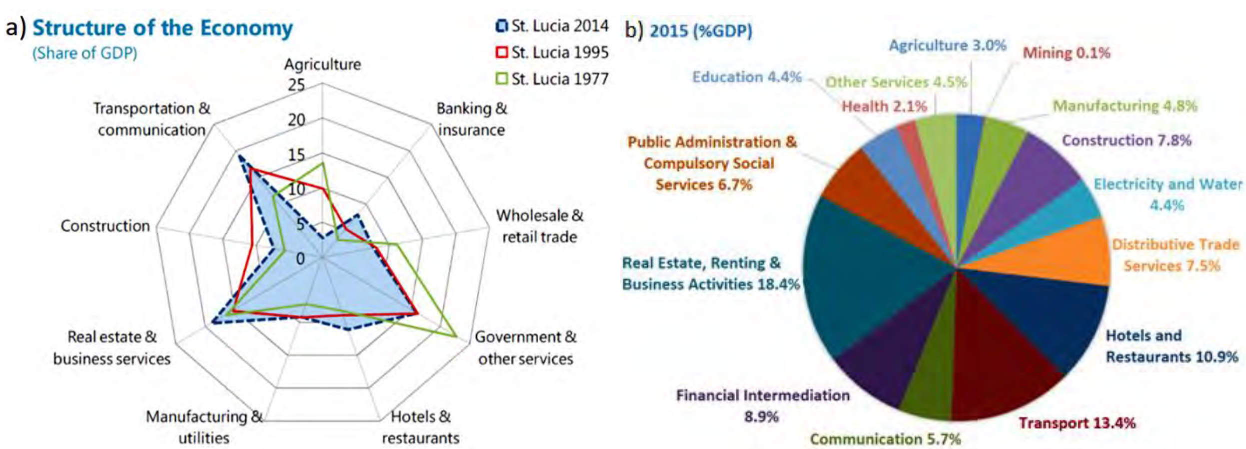


Figure 2-6 Main Economic Sectors (% GDP) a) 1977-2014 (Source: IMF, 2016) and b) 2015 (Source: SLTB, 2016)

a. Tourism

The tourism sector, St. Lucia's main economic driver, is estimated to contribute up to 41.5 % of GDP (direct and indirect contributions, 2015) and is the largest earner of foreign exchange. Saint Lucia, for the first time, surpassed the one million mark in the combined number of stay-over and cruise ship passengers (Review of the Economy, 2015). Between 2012 and 2015, the island recorded an 11.1 % overall increase in arrivals, from 306,801 to nearly 345,000 (SLTB, 2016). The encouraging increase is mainly a result of the continued economic recovery in source markets and additional airlift, particularly from the US. For 2015, stop over arrivals to St. Lucia increased 6.1 % thanks to a 11 % increase from the United States (the largest source market) coupled with the largest rate of increase from the Caribbean market (6.6 %) (Figure 2-7). Mitigating the sector's positive performance was an 8.7 % decline in the number of arrivals from the European market, as well as a reduce in the average length of stay (8.7 days compared to 9.0 days in 2014) (SLTB, 2016).

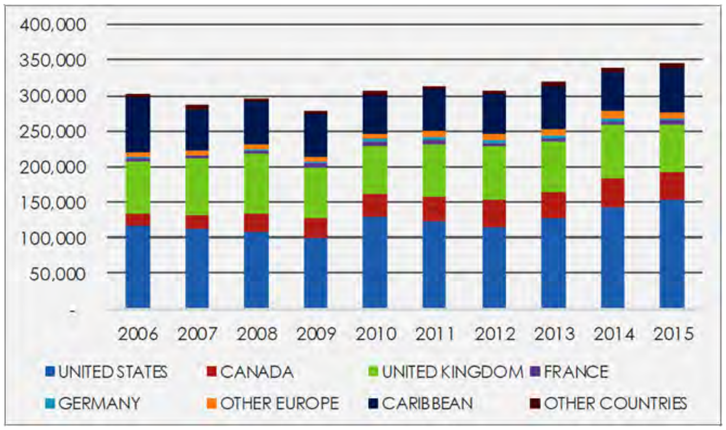


Figure 2-7 Tourist arrivals by market (Source: SLTB, 2016)

The hotels & restaurant sector experienced a 3 % improvement in activity while cruise ship passengers increased 5.6 % to 677,394 visitors. Total visitor expenditure increased by 3.2 % to an estimated EC$ 2.08 billion, supported by a 3.1 % rise in spending by stay-over visitors (Review of the Economy, 2015). That impressive growth trend looks set to continue in 2016 with early projections set at 2.8 % (SLTB, 2016). However, activity in the tourism industry is estimated to have declined in the first quarter of 2016, relative to the corresponding period of 2015. Total visitor arrivals fell by 10.1 % to 366,322, stay-over arrivals decreased marginally 0.9 % to 97,367 while a decline in the number of cruise passengers is reported mainly due to a reduction in cruise ship calls (Figure 2-8). The outturn in stay-over arrivals sub-category mainly reflected weak outturns in the Canadian and European markets. On the contrary, yacht visitor arrivals are estimated to have grown by 35.0 % (5,220) and the number of excursionists almost doubled to 3,392 for the period under review (EFR, 2016).

The growth in the tourism sector had a positive impact in the labour market; according to the World Travel & Tourism Council's report for St. Lucia (WTTC, 2015), travel & tourism directly supported 16,500 jobs (21.5 % of total employment). Furthermore, travel and tourism contributed to 36,000 jobs indirectly supported by the industry (46.3 % of total employment).

Activity in the tourism industry is projected to remain challenged by the prospects for the advanced economies and the ZIKA advisory alert issued for Saint Lucia as the number of infected cases increase. Nevertheless, factors including positive ratings and awards that the country has been receiving, marketing initiatives by the Saint Lucia Hotel and Tourism Association, increased airlift from the USA, the main source for stay-over visitors, and the resilience of the US economy as well as the fact that Saint Lucia becoming a home port for P & O Cruises, are likely to contribute to continued improvement in the performance of the tourism industry, with consequent expansion of other ancillary sectors like wholesale and retail, transport and distributive trades (EFR, 2016).

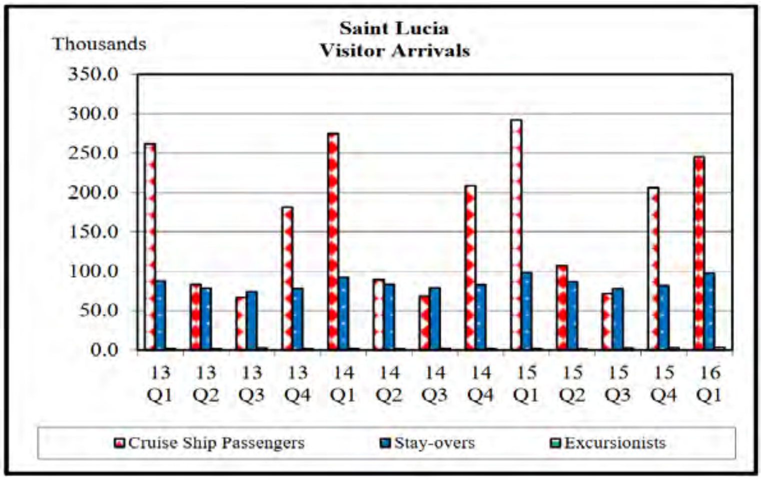
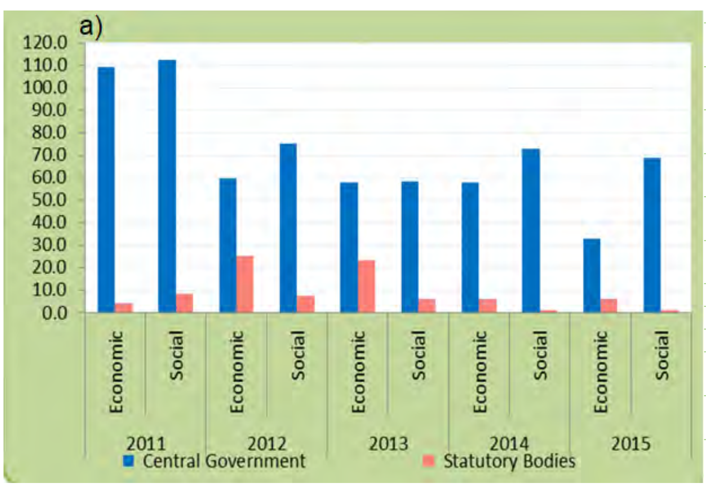


Figure 2-8 Visitor arrivals (Source: EFR, 2016)

b. Construction

After declining for three consecutive years, value added in the construction sector expanded by 7.4 % in 2015. Consequently, the sector's contribution to total GDP increased from 7.4 % in 2014 to 7.8 % in 2015 (Review of the Economy, 2015).



b)	2013	2014	2015
Central Government, of which:	**$116.1**	**$130.9**	**$101.8**
Constituency Development Program	19.5	24.5	23.7
St. Jude Hospital Reconstruction Project	6.5	15.1	23.5
Disaster vulnerability Reduction Project (DVRP)	0.0	0.7	4.7
Reconstruction & Rehabilitation of Roads	4.0	4.6	4.7
Community Infrastructural Development	1.3	1.7	4.7
Bridges & Culverts	8.0	8.0	3.5
New National Hospital	17.0	7.9	3.2
Choiseul Road rehabilitation	0	0	2.2
Desilting of Rivers and Drains	2.6	4.4	2.0
Shelter Development Programme	0.4	8.7	1.9
La dig (MOCHA) and Deville bridge reconstruction	0	0.7	1.7

Figure 2-9 a) Public sector construction expenditure on infrastructure by category and b) Selected Central Government construction expenditure (EC$ in millions, Source: Review of the Economy, 2015)

This improved performance was mainly fuelled by investments in the private sector which was evidenced by increased construction activity and upgrading of commercial and tourism related plants. Mitigating the positive trend, total expenditure on construction activity by the public sector declined in 2015 by 20.4 % to $109.8 million (Figure 2-9a), while central's government construction spending on all major functional classifications fell by 22.3 % to $101.8 million (except water, community works, education and sports)

(Figure 2-9b). The heightened activity in the sector is partially reflected by the increase in imports of all major construction materials and commercial banks credit for home construction and renovation (EFR, 2016). Tangible evidence of the strong recovery in the sector was supported by a net increase of 3,039 jobs created in the sector in the fourth quarter of 2015 (Review of the Economy, 2015).

c. Agriculture

The agriculture sector remains a significant contributor to St. Lucia's economic and social development in terms of employment and income creation, and food and nutrition security. The sector showed signs of recovery in 2015, contributing 2.8 % to GDP (EC$920.40 million); a 25 % increase over 2014 (IICA, 2015). Crop and livestock production were the most productive sub-sectors generating 2.47 % and 4.9 % increases in contribution to the sector, respectively (Figure 2-10). The positive performance of crops was mainly the result of an estimated increase in the purchases by hotels and supermarkets as they continue to support local production along with the post-Hurricane Tomas vegetable crop rehabilitation programme aimed at boosting cultivation and enhancing disaster risk management in order to increase the resilience of the sector (UNEP, 2016).

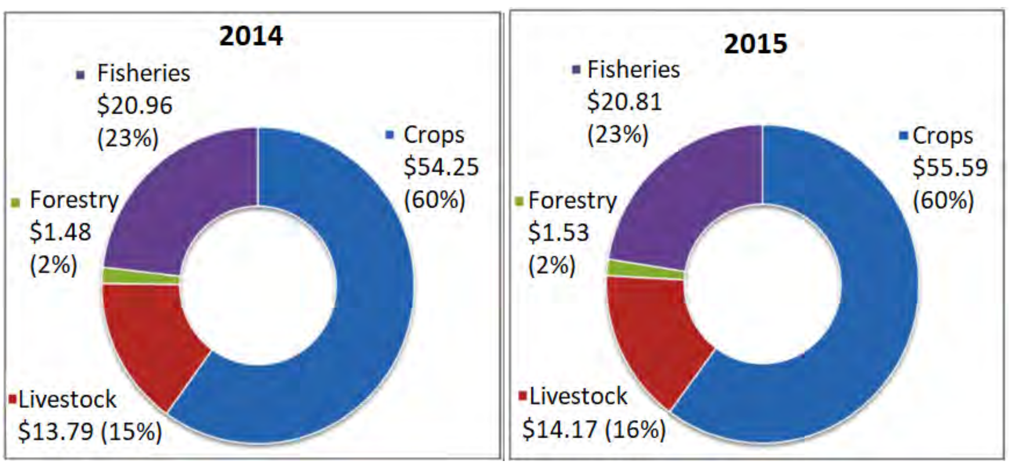


Figure 2-10 GDP Contribution of Major Agricultural Sub-Sectors (Current Prices, EC$ Millions; Source: IICA, 2015)

Banana production remains central to the sector, occupying ~48 % of the cultivated land and accounting for 41.4 % of gross agricultural output. After several years of decline, banana exports increased by 35.3 % in 2015 compared to a 24.1 % fall in 2014 and earnings from banana exports increased by 26.2 % to $22.4 million. While exports to the United Kingdom market fell by 5.0 %, the volume of exports to the Caribbean region more than doubled to 6,337 tonnes. Evidence of the resurgence in the sector was also supported by a net increase of 871 persons employed during 2015 (Review of the Economy, 2015). Sector performance, however, continues to be constrained by several challenges, inter alia, limited access to financing, natural phenomena like hurricanes, the conversion of agricultural land for housing and commercial enterprises, an increase in the emergence of trans-boundary pest and diseases, droughts and invasive species, under-investment in production infrastructure and support systems (access roads, water management, improved production technology etc.), rising costs of inputs and other structural and cultural constraints (rural unemployment, age of farmers etc.) (CDB – Caribbean Development Bank, 2012; IICA, 2015).

d. Manufacturing

Despite the limited contribution of the sector to the economy, at 4.7 %, manufacturing firms account for 9 % of all enterprises on the island and provide 10 % of all employment (PSAR, 2014). Value added in the manufacturing sector is estimated to have grown in 2015 following five consecutive years of contraction; the output of the total value of manufactured products is estimated to have grown in 2015 by 2.4 % to an estimated $280.2 million. This development is consistent with the sector being positively influenced by increased level of manufactured exports (1.9 %; particularly for food-based products) in the US market and the positive domestic economic growth. The growth of manufactured exports was however tempered by export declines to Trinidad and Tobago and Guyana which were consistent with a deceleration of economic activity in those markets. The manufacturing sector recorded the highest increase (8.1 %) in commercial banks' lending to the economic sectors in the January to March 2016 period (EFR, 2016). Government's interventions in the manufacturing sector are in the area of export facilitation, which is supported by the Trade Export Promotion Agency (TEPA), and investment facilitation, which is carried out by Invest St. Lucia.

e. Transportation

With Saint Lucia being sea locked, a resilient and reliable transportation network, in particular maritime and air transport sub-systems, is vital for the country's socio-economic prosperity, especially since it is highly dependent on transport-intensive imports for much of the nation's consumption needs. Transport network in St. Lucia consists of a main ring road that intersects the island connecting all major urban communities, the two main airports and the country's two main ports. This system is connected to the interior rural communities through a network of secondary roads as well as unpaved minor roads and footpaths that are vital for communications, economic livelihoods and social connections. In addition to the road transport, Saint Lucia has two airports: George F.L. Charles Airport and Hewanorra International Airport.

George F. L. Charles Airport is situated in the north of the island, it plays host to a number of general aviation and commuter airlines linking Saint Lucia to the other territories of the Eastern Caribbean. Hewanorra International Airport is situated in the south of the island, where jet flights from Europe and North America are regularly scheduled, serving more than 90 % of the tourists. Additionally, Saint Lucia has five sea ports two of which are major harbours; Port Castries and Port Vieux Fort. Most of the cargo is imported through Port Castries and is then transported by the road network to the rest of the island. The road network system therefore plays a vital role to Saint Lucians being the only form of transportation within the island; there is no marine transportation between the towns and villages although there has been an increase in water taxis, used mainly for recreation purposes.

The direct contribution of transportation to the GDP is provided in Table 2-2. Over a 10 years' period, between 2005 and 2015, more than 60 % of the contribution was from road transport while air transport contributed the smallest percentage.

Table 2-2 Contribution of transportation to the economy (Source: CSO, 2016a)

	GDP Official Levels (in EC$ millions)		Rate of Growth (%)		Contribution to the Economy (%)	
	2014	*2015*	*2014*	*2015*	*2014*	*2015*
Transport	**325.56**	**335.99**	**9.99**	**3.21**	**13.20**	**13.45**
Road Transport	187.14	192.93	7.75	3.09	7.59	7.72
Air Transport	14.03	14.28	1.32	1.74	0.57	0.57
Sea Transport	51.92	54.35	7.44	4.68	2.11	2.18
Auxiliary Transport Activities	72.46	74.44	20.53	2.72	2.94	2.98

In particular, road transport contributes the highest percentage to GDP as all products (imported, exported and locally produced and consumed) flow through the road network. In 2015, the volume of agricultural products sold to Supermarkets, Hotels and local consumers was estimated at about 10,000 tonnes, accounting for about EC$ 30 million. Additionally, 30,648 Twenty Foot Equivalent Unit (TEU) of cargo arrived at Port Castries and Port Vieux Fort and 1,535,777 kg arrived through both airports (Table 2-3) which was transported by road to the various destinations throughout the country. It is estimated that 1,073,017 tourists (stayovers and cruise passengers) arrived at St. Lucia in 2015 and that total tourist expenditure increased by an estimated 3.2 % to EC $2.08 billion (Review of the Economy, 2015), further reinforcing the importance of transportation to the St. Lucian economy.

*Table 2-3 Seaport and Airport 2015 statistics (Source: Saint Lucia Air and Sea Ports Authority; *Source: The World Bank; **Source: Review of the Economy, 2015)*

Cargo Throughput (landed & loaded)	Seaports: 71,364 TEUS* Airports: 2,965,010 kg
Aircraft movement (arrivals & departures)	32,453
Airline passengers (embarked & disembarked, excl transit)	823,928
Cruise Calls	388
Cruise Passengers	677,394
Yacht Calls (Rodney Bay and Marigot Bay Marinas)	8,442**
Yacht Passengers (Rodney Bay and Marigot Bay Marinas)	41,635**

2.2.2 Socio-demographic Indicators

a. Population and Demography

St. Lucia's total resident population was estimated at 184,999 in 2015, an increase of 0.7 % from the previous year (Table 2-4). The population is almost evenly divided between males and females (49.1 % and 50.9 % respectively) and the age distribution is as follows: 22.8 % of population is under 15, 67.5 % of population is 15 -64 and 9.7 % of population is over 65 years old (World Bank, 2016).

Table 2-4 Population statistics (Source: World Bank, 2016)

	2008	2009	2010	2011	2012	2013	2014
Population total	172,729	175,196	177,397	179,278	180,890	182,305	183,645
Population growth rate	0.44	0.42	0.4	0.39	0.38	0.36	0.35
Birth rate	15.4	15.1	14.81	14.63	14.42	14.19	13.94
Death rate	6.71	6.8	6.9	7	7.1	7.21	7.32
Net migration rate	-4.33	-4.14	-3.93	-3.73	-3.54	-3.34	-3.13

b. Education, Labour Force and Employment

Approximately 14 % of the annual budget is allocated to the financing of education and educational services in St. Lucia and ~6 % of GDP is invested in education; a commendable investment for a young developing country, with very few natural resources. The education sector has grown on average by 3.6 % between 2008 and 2012, and in recent years it has been the only segment of the economy that seems not to have been significantly affected by the global economic downturn. Most of this growth has been due to the activities of offshore medical universities, which train people for medical careers in the US. Since 1980 the island has attracted a number of offshore medical schools: in 2010 there were five offshore medical schools registered, with around 420 students in total (PSAR, 2014). In addition, plans like Basic Education Enhancement Project (BEEP), the EU funded Education Enhancement Through Information and Communications Technology Programme (EETICT) and the Secondary Education program (USE), contribute to the enhancement of the education system and the delivery of more effective education services. The implementation of the later that was introduced in 2006 resulted in a significant increase in enrolment and government expenditure in secondary education, with the gross enrolment ratios of primary and secondary education being above 90 %. As a result, teachers in secondary education have increased from around 300 in 1980s to more than 1000 in 2013. At the same time, enrolment in tertiary education has stayed relatively flat. As shown in Figure 2-11, while the shares of labour force participants with either a secondary or a tertiary diploma have both increased, the share of tertiary education is much lower.

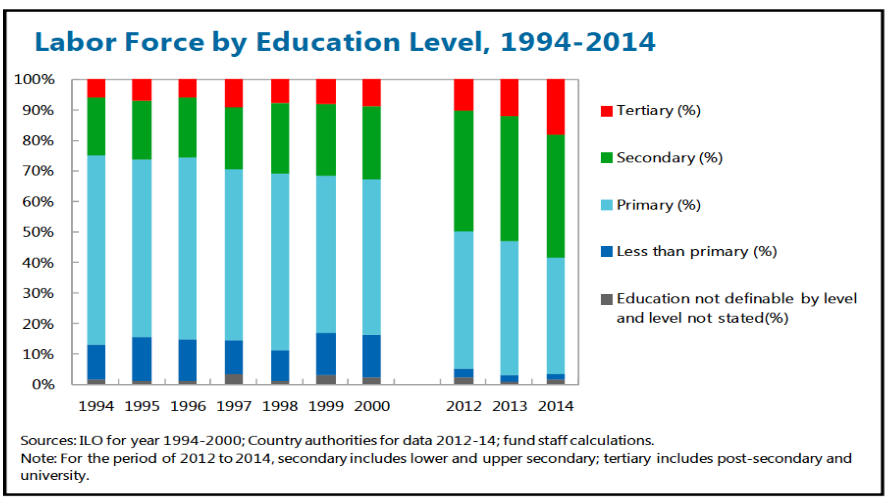


Figure 2-11 Labour Force by Education Level, 1994-2014 (Source: IMF, 2016)

Following the favourable performance of education as well as the incipient economic recovery in 2015, the labour market has also been positively impacted. As shown in Table 2-5 below, during 2015, the total labour force of St. Lucia was ~102,000 and the overall labour force participation was 72.2 %, with higher participation by males (76 %) than females (65 %). The employed labour force increased by 3.8 % to 77,131 with a net increase of 2,802 persons employed as at 2015 compared to 2014. However, structural shifts in employment (especially from labour intensive agriculture and manufacturing industries to services) have displaced a large number of unskilled workers. Partly reflecting weaknesses in the education system, labour supply did not adjust to this shift and unemployment rates have remained high since 1990s, and increased further with the recent economic recession. Whereas the rate of unemployment fell to 24.1 % in 2015 from 24.4 % in 2014, the unemployment situation still remains difficult with over 24,000 unemployed persons in 2015, particularly females, young people and rural population (Review of the Economy, 2015). Over the past two decades, the youth unemployment rate was 37 % on average, and 22 % for females as opposed to 16 % for males (IMF, 2016).

Table 2-5 Labour market summary table (Source: CSO, 2016b)

Annual Labour Market 2015	
Working-age population ('000s)	**141**
Labour force ('000s)	**102**
Labour force participation rate (%)	**72.2**
Employment ('000s)	**77**
Employment-to-population ratio (%)	**54.8**
Unemployment ('000s)	**24.5**
Unemployment rate (%)	**24.1**
Time-related underemployed ('000s)	**8.5**
Time-related underemployment as a share of labour force (%)	**8.4**
Youth unemployment ('000s)	**12.1**
Youth unemployment rate (%)	**41.0**
Share of vulnerable employment in total	**6.4**
Earnings (local currency units)	**937.0**
Social security coverage rate (%)	**65.1**

The skills mismatch is likely one of the key reasons for high unemployment. As shown in Figure 2-12, the percentage of job seekers with below secondary level education was 60 % as opposed to an only 25 % of employer requests. In addition, migration trends show a significant drain of highly educated labour force, which has worsened the aforementioned mismatch. According to U.S. Census data, 53 % of the labour force with tertiary education had migrated to the US during the period 1965-2000 (Mishra, 2006) while the national census data in 2010 showed that 20 % of all migrants hold tertiary degrees and 8 % university degrees.

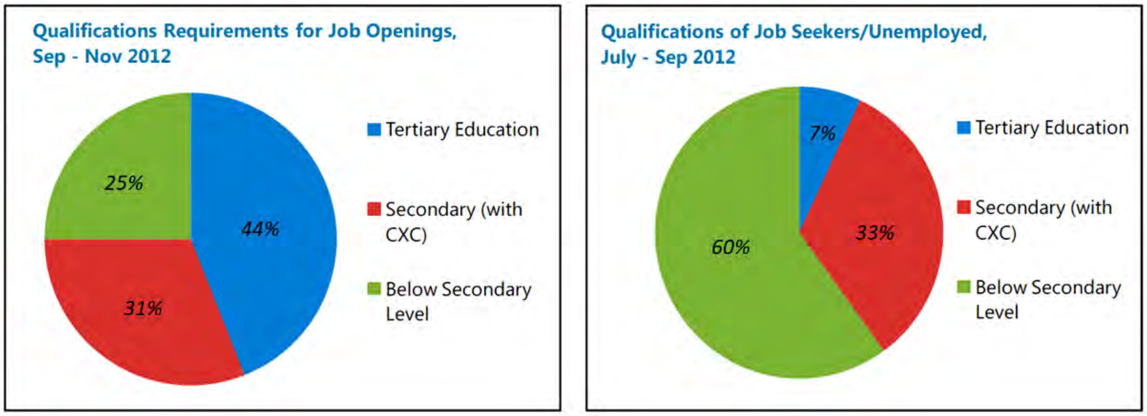


Figure 2-12 Difference between qualifications required and offered (Source: Catherine, 2013)

c. Social issues

Saint Lucia has been able to improve its ranking in the UNDP Human Development Report (HDR, 2015) from the medium level attained four years prior, to "high"; in 2014, the country scored 0.729 on Human Development Index (HDI) and is currently ranked 89 out of 188 countries. Closely associated with the HDI is the country's performance in achieving the Millennium Development Goals (MDGs). The standard of living in Saint Lucia has increased, with many households now having access to basic amenities. Many demographic indicators have also improved: life expectancy has increased, fertility rates have decreased and adult literacy is quite high at 94.5 % (UNDP, 2010). While some of the indicators associated with the HDR and the MDGs have improved, Saint Lucia has witnessed social problems such as rising incidence of poverty, crime, informal settlements and underground economy. Closely associated with rising poverty levels is the increasing incidence of crime, which is also correlated with feelings of social exclusion and alienation; drug activities and concomitant "turf battles".

The Country's Poverty Assessment revealed that the proportion of the population living below the poverty line increased from 25 % in 1995 to 29 % in 2006 (Kairi Consultants, 2007). However, indigence or extreme poverty fell from 7.1 % in 1995 to 1.6 % over the same period reflecting the use of informal systems and more focused targeting by GoSL. An additional 11.5 % of the population was determined to be vulnerable to poverty in the event of an economic shock or natural hazard event.

Social vulnerability in Saint Lucia was found to correlate with: low per capita household consumption; low levels of education; insufficient or no employment; a high wage dependency ratio; and a low asset base. A UNDP financed Poverty and Social Impact Assessment (UNDP, 2010) confirmed that the recession has exacerbated the poverty and vulnerability situation of poorer households. Indeed, there is a high probability that vulnerability indicators have not improved for female-headed households with high dependency ratios, the elderly (particularly males and females living alone), unemployed youth, persons with disabilities and rural households.

2.2.3 Natural Hazards and Economy

Saint Lucia is vulnerable to numerous natural disasters arising from meteorological events (high wind, excess rainfall, hurricanes and drought) and geophysical events (earthquake, volcanic activity and tsunami), the impacts of which are especially pronounced given the country's already tenuous economic situation. Development pressures and systemic deficiencies have resulted in substantial damage of critical infrastructure, housing, and livelihoods, during disasters. Poor land use planning and associated squatter developments, deforestation and developments in disaster prone areas have exacerbated vulnerabilities to climate change impacts and in particular climate related disasters. Most of the island's major human settlements, and associated infrastructure (telecommunications, roads, airports and seaports), are located along the narrow coastal belt and are at direct risk from extreme weather activity, sea level rise and storm surges, rain-induced landslides on steep slopes, and flooding and inundation, posing threats to the population's socioeconomic well-being and the country's general economic and fiscal stability.

Particularly damaging are events associated with excessive or prolonged rainfall, which provoke flooding and landslide activity. The highest elevations are located centrally, in the island's interior, and (due to orographic rainfall effects) these areas typically receive the highest rainfall. As river systems drain radially from the island's center to the coast, transit time for rainfall runoff is relatively short. This effect, coupled with the steeply sloping topography, creates the potential for flash floods. Steep slopes dominate the island's landscape, and tilted volcanic deposits define the geology and soils. A combination of high slope angles and rainfall leads to slope instabilities and a high potential for landslides. The most common type of landslide in Saint Lucia is debris flow, which is defined as the rapid movement of a mass of soil, water, and air. Debris flows pose a significant threat to human lives because they (a) may travel long distances, (b) approach fast, and (c) exhibit a considerable destructive force.

The island's mountainous landscape presents significant engineering challenges, particularly for road construction. Many roadways are bordered by high-relief vertical cuts in the landscape, which increase the vulnerability of the transportation network to landslides, debris flows, and cut failures (Figure 2-13). In addition to the island's steep topography, underdeveloped and dilapidated infrastructure—such as roads, bridges, and water supply systems as well as health and education facilities—remains vulnerable to flooding and landslides.

Key economic and critical infrastructure networks in the country including roads, the airports, the seaports, and the fuel storage, are all located along the coast or on low-lying reclaimed coastal land (ICF GHK, 2012). Thus, transport infrastructure is vulnerable to the impacts of climate change, particularly to storm and high rainfall events and is exposed to coastal as well as inland flooding, which is further exacerbated by Saint Lucia's topography. Impacts include (but not be limited to) greater inundation/erosion/threat/loss of low-lying/coastal development and communities; loss of recreational value and carrying capacity of beaches; poor operational performance of inundated municipal and household septic systems, contaminating drainage and water supplies; reduced capacity/ performance of drainage infrastructure and bridges, increasing risk of flooding in low-lying coastal areas; interruptions in local, regional and international communication resulting from damage to and/or destruction of critical infrastructure; loss of access (temporary/permanent) to, damage or destruction of, critical infrastructure such as coastal roads and bridges, disruptive to several types of economic, social and cultural activities.

Data from the literature corroborate that historically, hurricanes, storms and flooding have been the most likely hazards to affect Saint Lucia (Thomas-Louisy, 2014). Landslide potential is particularly great in Saint Lucia and they occur primarily as a secondary effect of heavy storms, floods or seismic activity while the vulnerability to landslides and rock falls has been exacerbated by building construction over hillside areas and loss of natural vegetation. Much of the island's road infrastructure traverses areas of high or extreme landslide hazard risk (Thomas-Louisy, 2014).

Figure 2-13 Landslide inventory map of Saint Lucia (Source: Van Westen, 2016)

The impacts identified in the transport sector largely relate to damage and loss incurred to the main roads and bridges as well as impacts resulting from compromised riverbanks. Furthermore, communities with limited road access are particularly vulnerable to isolation following landslide events, while landslides and rock falls can severely impact traffic flows between the north and south of the island. Historically, during major storm events the road network in Saint Lucia suffered damage causing them to be impassable. That could have catastrophic impacts in case of a disaster, as the effectiveness of all emergency procedures that have to be followed relies on a well-functioning and reliable transportation system, with roads cleared and airports/seaports open.

Saint Lucia has a history of severe storm events and landslides that have resulted in fatalities, damage to critical infrastructure, agricultural crop losses, and other economic impacts. Table 2-6 summarises some of the most significant storm events that affected the island and the associated impacts.

Table 2-6 Storm events that have impacted Saint Lucia

Storm	Impacts
1938 Nov 21st	Ravine Poisson and Ravine Ecivisse landslides created a "sea of mud" that killed 62 and injured 32 people.
1960 July 10th – 16th	Hurricane Abby. Damage to roads and bridges; 6 deaths; US$ 435,000 damage. (Hurricane Disaster (n.d.); U.S. Weather Bureau, 1960).
1980 Aug 4th	Hurricane Allen. The Barre de L'Isle landslide caused by the storm caused road damage estimated at half a million dollars, severely disrupted transportation between Castries and Dennery, and negatively impacted the tourism industry. Six reported killed with US$ 87 million in total damage. (UWI, 2005; ICF GHK, 2012).
1994 Sept 10th	Tropical Storm Debby destroys 60 % of Banana crops. Landslides initiated by the storm caused widespread debris flows that cleared vast amounts of forest and agricultural land. Total damage was estimated at over US$ 103 million. (Saint Lucia Meteorological Service, 1994; Rappaport E, 1994).
1996 Oct 26th	The Tropical Wave incurred an estimated EC$ 12 million in damages to property and infrastructure.
1999 Nov 13th – 23rd	Hurricane Lenny. Storm surge/waves had major coastal impacts, including beach erosion at the NW coast; roads, coastal defences and walkways washed away; $6.6 million infrastructure damages. (USAID/J-CAR, 2000).
2002 Sept 21st	Tropical Storm Lilly. Damages estimated at US$ 20 million. 4 persons died.
2004 Sept 2nd	Hurricane Ivan. Damage totalled US$ 2.6 million (2004 US$); three serious injuries were reported.
2007 Aug 17th	Hurricane Dean. Damage was estimated at US$ 18.8 million. One death reported. (UNECLAC, 2007).
2010 Oct 30th	Hurricane Tomas. Storm surge and waves (1 in 15-year event) had relatively small direct damages; roads/bridges severely impacted, mostly from landslides and floods; HIA and GCIA were closed; HIA runway flooded and silted; total impact on transport infrastructure US$ 52.8 million; The total cost of the damage and losses to the different sectors amounted to US$ 336 million (43.4 % of GDP). Seven persons were reported to have lost their lives, while 5,952 people were severely affected. (UNECLAC, 2011c).
2013 Dec 24th - 25th	Outside the normal hurricane season, a tropical trough system (Christmas Eve Trough) passed over Saint Lucia and produced extraordinarily heavy rains and rapid flash flooding. Total damage and loss of US$ 99.9 million, equivalent to 8.3 % of Saint Lucia's GDP. Transport infrastructure sustained the majority of damages (72 %), followed by infrastructure for agriculture (13 %), water and sanitation (6 %), and housing (4 %). Six persons were confirmed dead, over 550 were displaced, and approximately 19,984 were directly impacted by the event. (GoSL and World Bank, 2014).
2016 Sept	Landslides and floods; several roads blocked; both GCIA and HIA airports closed during the storm. (Next Steps in Saint Lucia Recovery After Tropical Storm Matthew, 2016).

While the figures provided above are proxies, they provide evidence of the significance of the transportation system to the Saint Lucian economy. Any damage to the system caused by climate change and climate variability will therefore impact on the economy, contributing to the increasing debt to GDP ratio.

Figure 2-14 Left: Debris flow at Fond St. Jacques during Hurricane Tomas; Right: Landslide adjacent to main North-South high way at Barre de l'Isle

The average annual economic losses associated with extreme hydro-meteorological events for the period 1992-2011 are equivalent to roughly 2 % percent of GDP or US$ 26.94 million PPP (Harmeling and Eckstein, 2012). Singular high-impact events such as Hurricane Allen (1980) have resulted in damages and losses equivalent to about 60 % of annual GDP while the more recent Hurricane Tomas (2010) resulted in damages and losses estimated to be US$ 336.2 million which accounts for 43.4 % of St. Lucia's GDP. The road infrastructure in particular suffered badly as result of landslide action; the subsector has incurred a total damage of EC$ 141.66 million (~ US$ 52.47 million - 2011 exchange rate) (UNECLAC, 2011c). Droughts have also placed tremendous strain on the limited national water supply for local communities and productive sectors of the economy.

Up until the late 1990s, the conventional approach to adverse natural events in Saint Lucia has been primarily response and recovery post-disaster, with very limited focus on disaster preparedness, risk mitigation, or prevention. Large fiscal deficits and debt accumulations (many of them the result of previous disasters) have required the government to rely on ad hoc budget reallocations and emergency assistance from donors, and to delay the replacement/repair of damaged capital stock. However, implementation of several plans like the World Bank's Disaster Vulnerability Reduction Project (DVRP) (World Bank, 2014), the Pilot Program for Climate Resilience (PPCR), updating Saint Lucia's Country Document for Disaster Risk Reduction (SLU DRR - CD) and joining the Caribbean Catastrophe Risk Insurance Facility (CCRIF) in 2007, has successfully reduced Saint Lucia's vulnerability to adverse natural events.

2.3 Country Profile Overview

Recent financial indicators (2015) suggest a positive economic environment, with most sectors showing a better economic performance relative to the previous year (2014). In particular:

- Total value added at constant prices for the Saint Lucian economy increased by 1.3 % during 2015 when compared to a decrease of 0.65 % in 2014.

- The construction sector accounted for the largest share of the total increase in 2015. The sector is estimated to have expanded by 7.4 %, an increase mainly driven by private sector investment related to the construction/upgrading of hotels and commercial buildings.

- The tourism sector continued to perform well; there has been a 2 % increase in the number of stayover visitors to a record 344,908. The sector benefited from appreciable increases in arrivals from the US, the largest and most lucrative source market; total visitor expenditure increased by 3.2 % to EC $2.08 billion. Mitigating the sector's positive performance was (a) an 8.7 % decline in the European arrivals; and (b) a reduction in the average length of stay.

- Following a decline in activity in 2014, manufacturing production was estimated to have risen in 2015 on account of improved outputs in food and paper products.

- The agriculture sector showed signs of recovery in 2015, contributing a 2.8 % to the GDP, a 25 % increase over 2014. Purchases of crops by hotels/supermarkets both recorded double digit increases reflecting both an increase in the local demand and favourable weather conditions.

- The direct contribution of transportation to GDP in 2015 was 13.45 %, an increase of 3.21 % in relation to 2014.

- The performance of the economic sectors was also reflected in the labour market. The average rate of unemployment in 2015 fell to 24.1 % compared to 24.4 % in 2014.

- Reflecting the improved economic fundamentals, GoSL's fiscal operations continued to improve, evidenced by a further reduction in the overall fiscal deficit, which was estimated to have narrowed from 11.2 % in 2015 to 6.7 % of GDP in 2014, mainly associated with increases in revenue, driven mainly by increases in VAT collections, service charges and excise taxes on imports.

- Notwithstanding the lower fiscal deficit, total public debt continued to rise in 2015. The ratio of debt to GDP in 2015 increased to 75.4 % compared to 74.5 % in 2014.

- Annual damages associated with natural disaster recovery have averaged about 1.3 % of GDP since 1990. Given the elevated debt levels and fiscal and external current account deficits, calibration of fiscal adjustments should be considered in anticipation of future natural disasters arising from meteorological/geophysical events. This is required in order to maintain/improve the performance of the aforementioned economic sectors as well as to build resilience to future weather events by an appropriate selection/design of key infrastructure projects.

Chapter 3: CLIMATE

St. Lucia experiences a tropical maritime climate with the year-round warm, humid conditions associated with the tropics. The location, size and topography of the island allow for weather that is affected by large scale weather systems such as the northeast trades, El Niño Southern Oscillation (ENSO), the Atlantic High Pressure System and the passage of tropical waves, depressions, storms and hurricanes. The result is climate that is typical of a tropical island, with temperatures kept uniform by the surrounding waters and distinct rainfall cycles.

Inter-annual variability in the southern Caribbean climate is influenced strongly by the El Niño Southern Oscillation (ENSO). El Niño episodes bring warmer and drier than average conditions between June and August and La Niña episodes bring colder and wetter conditions at this time. St. Lucia lies on the southern edge of the Atlantic hurricane belt and is rarely, but occasionally, affected by hurricanes which occur throughout August, September and October.

3.1 Existing Climate and historical trends

a. Temperature

St. Lucia's climate is typical of a tropical island with temperatures that remain relatively consistent throughout the year. The island's location in the Atlantic Ocean/Caribbean Sea means that the ambient sea surface temperature average is about 26.7 °C at any time. Located within the north-east Trade Wind belt the island is normally under an easterly flow of moist, warm air with an average temperature of 27 °C (790 F) and relative humidity of 75 %. Mean daily temperatures vary between 23.3 °C and 30.9 °C with the coolest months between December and March and the warmest months between May and September. Figure 3-1 shows mean maximum and minimum monthly temperatures from 1985-2015 at George Charles Airport and Hewanorra Airport.

According to UNPD Climate Change country profile report (McSweeney et al., 2010) mean annual temperature in St. Lucia has increased by around 0.7 °C since 1960, at an average rate of 0.16 °C per decade. Monthly mean maximum and minimum temperatures have been increasing at a rate of 0.025 °C/month and 0.026 °C/year, respectively while there has been an increase in the annual frequency of warm days and nights accompanied by a decrease in cool days and nights (ESL, 2015). There is however insufficient daily observational data to identify trends in daily temperature extremes.

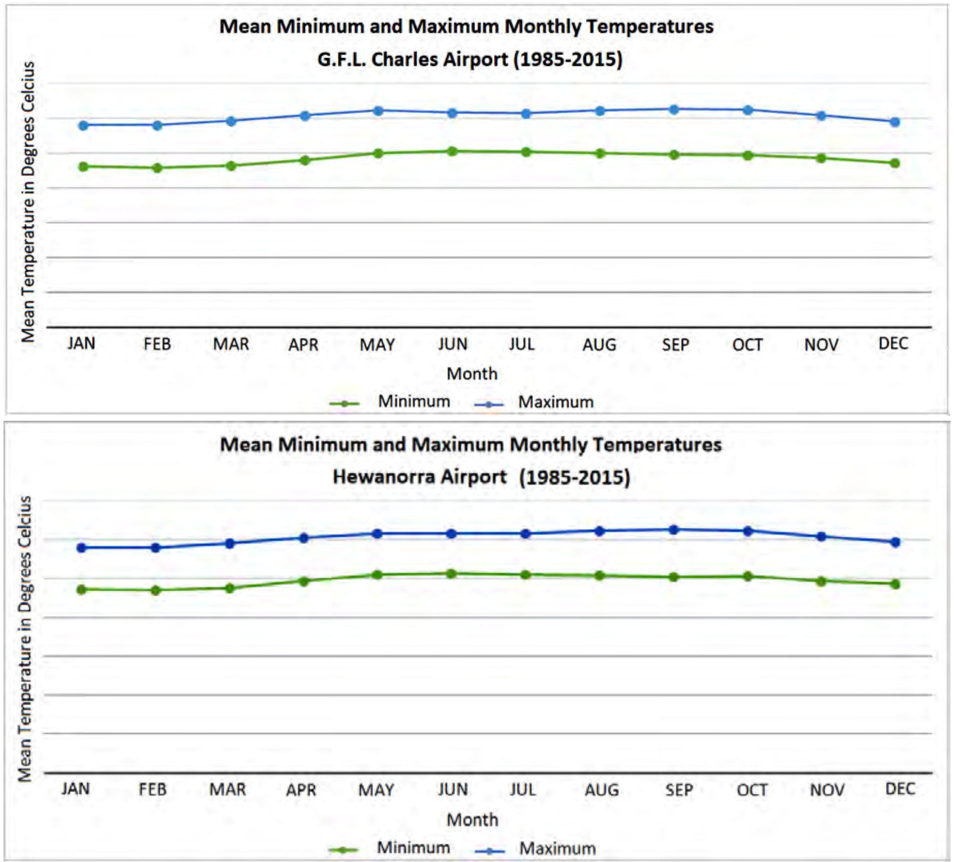


Figure 3-1 Mean Maximum and Minimum Temperatures (1985 – 2015) at George Charles Airport and Hewanorra Airport

b. Precipitation

Though there is not significant fluctuation in intra-annual temperature, Saint Lucia's precipitation climatology is characterized by a unimodal pattern of monthly variation with two distinct precipitation periods (Figure 3-2). The rainy season is usually between June and November when the island is influenced by the northerly migration of the Inter-Tropical Convergence Zone (ITCZ) and other tropical weather disturbances, such as waves, depressions, storms and hurricanes. These systems account for the majority of the rainfall during this period which can be as high as 256 mm[2] in a month. The drier period occurs between December and May when rainfall typically averages about 103 mm per month (Figure 3-2). The 30-year mean shows that the lowest rainfall is received in February (mean of 75.5mm) and March (mean of 72.7 mm). Rainfall amounts show annual and spatial variation with the orographic effects quite pronounced as illustrated in Figure 3-3. Total annual rainfall ranges from about 1,265 mm in the relatively flat coastal regions to about 3,420 mm in the elevated interior region (Simpson et al., 2012). The driest part of the island is Vieux Fort at the southern end where the rainfall is less than 947 mm per year.

There has been about a 1 % increase in rainfall per decade from 1960 to 2006 for both seasons (McSweeney et al., 2010). Since the 1970s, the wet season has begun earlier in the year and has displayed

[2] An analysis of 30 years of precipitation data shows a mean of 256.1mm for October, although since 2013 the mean rainfall for October was less than 200 mm while for 2015, it was 67.8mm (CAMI, monthly bulletins).

an increase in the number of peaks in rainfall, resulting in a shift in the rainfall climatology of Saint Lucia across decades. In addition, an increase in rainfall extremes has been noted at the Hewanorra International Airport, with increased number of days with rainfall above 10 mm, maximum number of consecutive dry days, maximum number of consecutive wet days, maximum 5-day rainfall and annual total precipitation when rainfall is above the 95th percentile (ESL, 2015). Although the precipitation pattern of the island has become decreasingly unimodal, the distinct periods of dry early months and wet late months has been retained.

Overall, gridded observations of rainfall over Saint Lucia do not show statistically significant trends over the period 1955 to 2015 while long-term trends are difficult to identify due to the large inter-annual variability in rainfall in the island (Simpson et al., 2012).

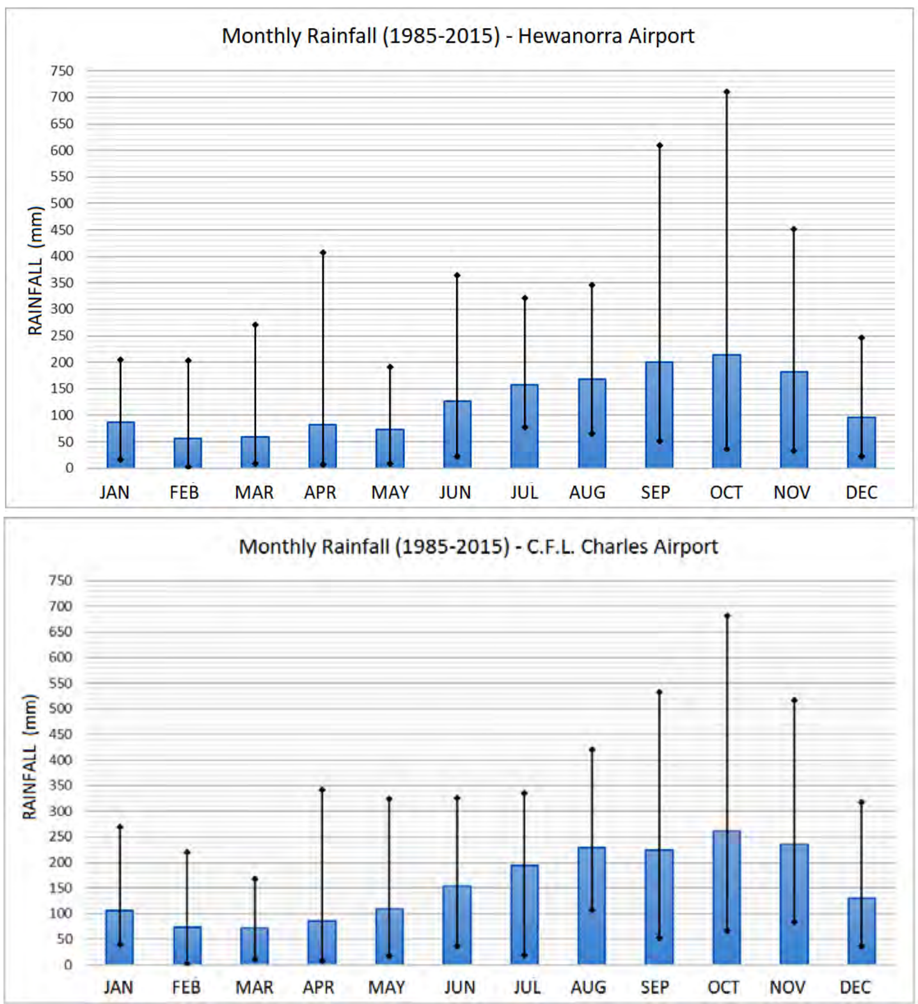


Figure 3-2 Average monthly precipitation (mm) from 1985 to 2015 with bars and points indicating the mean and the lowest and highest monthly values recorded respectively

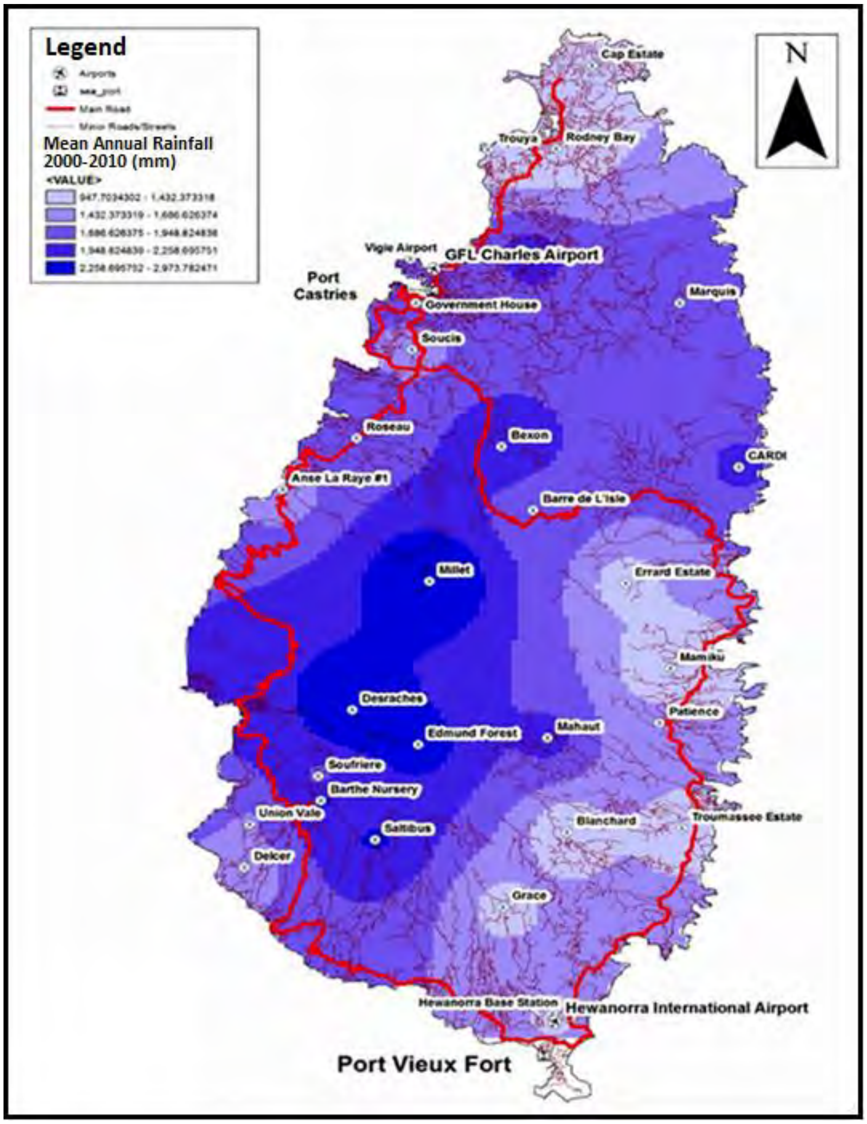
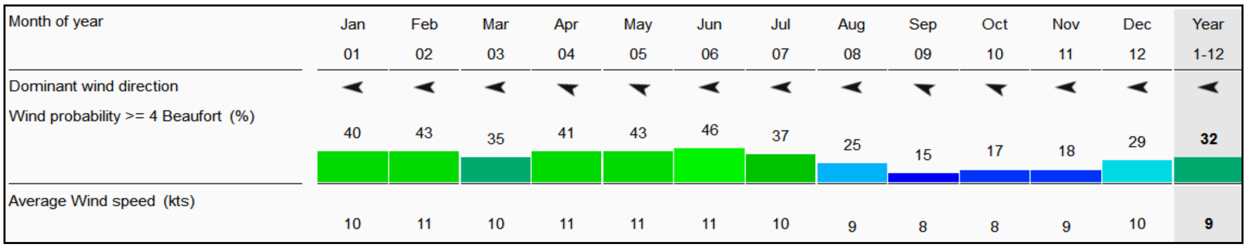


Figure 3-3 Rainfall distribution for the period 2000-2012

The Caribbean region also faces significant challenges in terms of drought. During the past decades, Saint Lucia has experienced several drought events, and particularly so in years with El Nino events (FAO, 2016). Two of the most recent drought periods were the severe 2009-2010 drought and the ongoing 2015-2016 drought, placing tremendous strain on the limited national water supply and exerting downward pressures on key sectors, including tourism, agriculture, industry and health. The 2009/2010 major drought preceded the unusually high rainfall event experienced during Hurricane Tomas. Whereas the return period of the rainfall was of the order of 180 years, the likelihood of a drought to be followed by a storm event of this magnitude is even more unusual, probably with a return period of over 1000 years (UNECLAC, 2011c). The drought conditions in Saint Lucia, therefore, set the stage for extremely high potential for surface erosion and mass movements on slopes in the event of a normal rainy period. Even if the rainy season were to be of normal levels, the effect of the drought on the soil/rock regime would have resulted in a severe hazard condition in respect of mass movements on slopes (a state that landslide hazard maps could not adequately represent).

c. Wind Speed

St. Lucia falls within the northeast Trade Wind belt and is normally under an easterly flow of moist warm air. Winds are typically from the east-north-east (67.5°) to east-south-east (112.5°) directional sector. Wind speeds are highest during the months of January to July, corresponding roughly with the dry season and they drop during August to December (Figure 3-4 & 3-5). Higher gusts are occasionally experienced with the passage of tropical disturbances and cyclones (SNC, 2011).



Month of year	Jan 01	Feb 02	Mar 03	Apr 04	May 05	Jun 06	Jul 07	Aug 08	Sep 09	Oct 10	Nov 11	Dec 12	Year 1-12
Dominant wind direction													
Wind probability >= 4 Beaufort (%)	40	43	35	41	43	46	37	25	15	17	18	29	32
Average Wind speed (kts)	10	11	10	11	11	11	10	9	8	8	9	10	9

Figure 3-4 Wind statistics for Castries based on observations taken between 01/2002 - 10/2016 daily from 7am to 7pm local time (https://www.windfinder.com/windstatistics/castries)

Observed mean wind speeds from the ICOADS (International Comprehensive Ocean-Atmosphere Data Set) mean monthly marine surface wind dataset demonstrate increasing trends around Saint Lucia in all seasons over the period 1960-2006. The increasing trend in mean annual wind speed is 0.3 ms^{-1} per decade and it is greatest in December, January and February at a rate of 0.51 ms^{-1} per decade (Simpson et al., 2012).

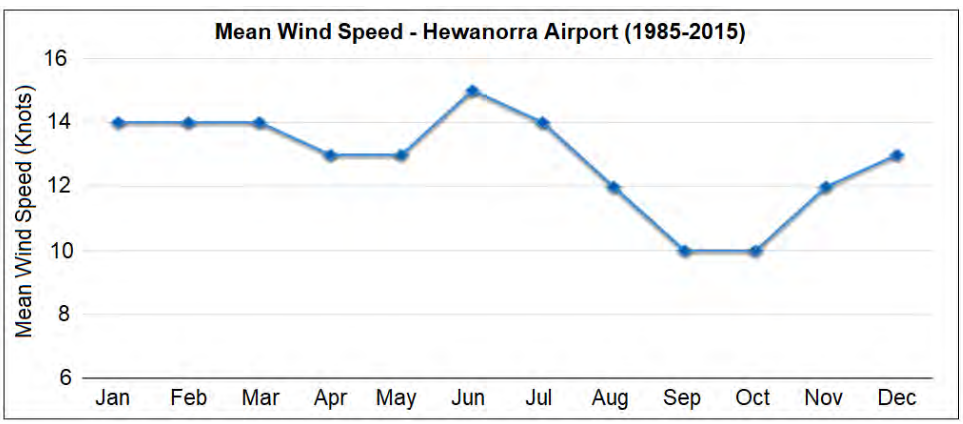


Figure 3-5 Mean wind speed for Hewanorra Airport for 1985-2015 (Data Source: Met Office)

d. Hurricanes

Saint Lucia lies on the southern edge of the Atlantic hurricane belt and is rarely, but occasionally, affected by hurricanes which occur throughout August, September and October, when the Atlantic Basin experiences its peak water temperatures, fuelling storm formation. Between 1951 and 2010, Saint Lucia has been hit by several tropical storms and hurricanes, which caused significant damage in terms of death, injuries to persons, property damage and loss of crops, livestock and infrastructure. A recent landmark event in the country has been Hurricane Tomas (see Box 1) in October 2010 which has exposed critical vulnerabilities as well as the impacts these may have on sustainable national and human development.

As presented in the 2017 Germanwatch report (Kreft et al., 2016), St. Lucia was ranked 49 out of 180 countries in the Global Climate Risk Index (CRI) (Table 3-1). The Index analyses the quantified impacts of extreme weather events like hurricanes – both in terms of fatalities as well as economic losses that occurred based on the assessment of four weighted relative indicators. It should be noted that the ranking reflects the direct impacts (direct losses and fatalities) and does not include the total number of affected people.

Table 3-1 Climate Risk Index for 1992-2011 (Source: Kreft et al., 2016)

Rank CRI	Country	Overall CRI Score	Fatalities (annual average)		Fatalities per 100,000 Inhabitants (annual average)		Losses in million US$ PPP*		Losses per GDP (%)	
			Avg	Rank	Avg	Rank	Avg	Rank	Avg	Rank
49	**St. Lucia**	60.67	1.10	145	0.68	27	16.740	129	1.0622	18

* Purchasing Power Parity

Several analyses of global (e.g. Webster et al., 2005) and more specifically North Atlantic (e.g. Holland and Webster, 2007; Elsner et al., 2008; Kossin et al., 2013; Holland and Bruyere, 2014) hurricanes have indicated increases in the observed record of tropical storms over the last 30 years. More recent assessments indicate that it is *unlikely* that annual numbers of tropical storms and hurricanes have increased over the past 100 years in the North Atlantic basin, while a *virtually certain* increase is evident in the frequency and intensity of the strongest tropical cyclones since the 1970s in the region (Christensen et al., 2013). However, argument reigns over the cause of these trends and the contribution of anthropogenic climate change.

Modelling studies (e.g. Klotzbach, 2006; Landsea et al., 2010) suggest that the aforementioned increases are mainly due to technological improvements, improved observational capabilities and more homogeneous database during recent decades and it remains uncertain whether those changes have exceeded the interdecadal and longer variability expected from natural causes. Klotzbach and Landsea (2015) found that when 10 more recent years of hurricane data (1970–2014) were added to the dataset, the analysis showed reduced trends in the frequency and percentage of category 4–5 hurricanes globally. Moreover, when the most recent 25 years (1990–2014) with the most reliable and homogeneous records were analysed, the trend showed insignificant decreases in the frequency and insignificant increases in the percentage of category 4–5 hurricanes in the Northern Hemisphere, while significant downward trends were present in accumulated cyclone energy globally.

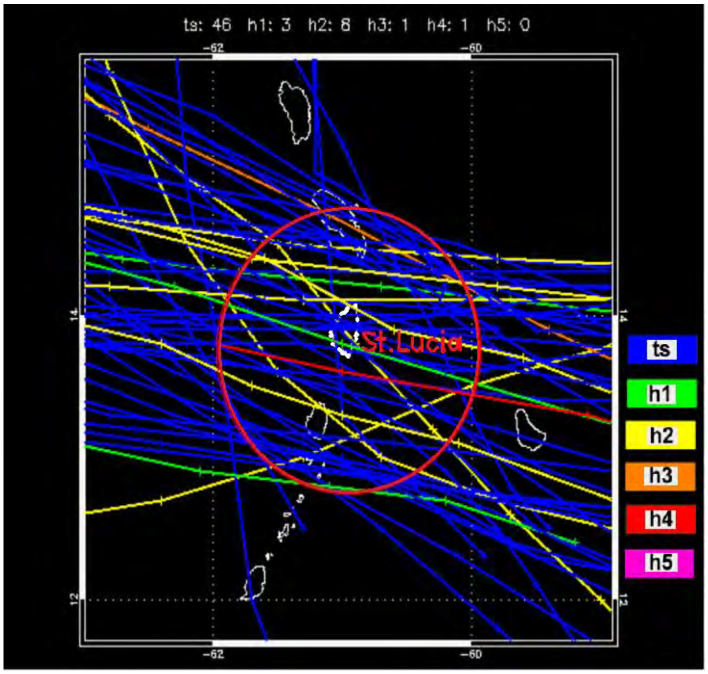


Figure 3-6 Map of all stormtracks since 1851 for St. Lucia (http://stormcarib.com/climatology/TLPC_all_isl.htm)

Table 3-2 Tropical Storms (ts) and hurricanes that passed by St. Lucia from 1951-2010 (http://stormcarib.com/climatology/TLPC_all_isl.htm)

Date	name	Wind	Cat.
Sep 1951	Dog	109	**h2**
Oct 1954	Hazel	81	**h1**
Aug 1958	Ella	40	**ts**
Jul 1960	Abby	63	**ts**
Sep 1963	Edith	98	**h2**
Sep 1967	Beulah	63	**ts**
Aug 1970	Dorothy	69	**ts**
Aug 1980	Allen	130	**h4**
Sep 1987	Emily	52	**ts**
Sep 1988	Gilbert	40	**ts**
Aug 1993	Cindy	40	**ts**
Sep 1994	Debby	63	**ts**
Aug 1995	Iris	58	**ts**
Aug 2001	Chantal	40	**ts**
Oct 2001	Jerry	52	**ts**
Jul 2003	Claudette	40	**ts**
Sep 2004	Ivan	120	**h3**
Aug 2007	Dean	104	**h2**
Oct 2010	Tomas	98	**h2**
Sept 2016	Matthew	60	**ts**

Box 1: Hurricane Tomas, 2010

On 31 October 2010, Hurricane Tomas passed just 29 miles (46.7 km) south of the island, as an intensifying cyclone, producing 92 mph (148 km/h) winds on the island. Later in the day, it became increasingly better organized, and reports indicated that the winds increased to 98 mph (158 km/h), a Category 2 hurricane.

Hurricane Tomas left a footprint of destruction and death as it swept across Saint Lucia. Deaths were estimated at 7 persons, with 825 houses affected and 136 houses completely destroyed by the hurricane. The data, as collected by the National Emergency Management Organization (NEMO), the Red Cross and the Ministry of Housing, suggest that some 5,952 persons, or 3.5 % of the national population were severely affected as a result of Hurricane Tomas.

The total cost of the damage and losses to the different sectors amounted to EC$907.7 million. The scale of the event can be gleaned from comparing the total impact with key economic indicators. The total impact represents 43.4 % of GDP, nine times agricultural GDP, three times tourism GDP, 62 % of exports of goods and services, 19 % of gross domestic investment and 47 % of public external debt.

e. Sea Level Rise

According to IPCC's Fifth Assessment Report, the rate of sea level rise since the 1850s has been larger than the average rate during the previous 2,000 years (high confidence) at a rate of 1.3–1.7 mm per year over much of the 20th century but increasing to 2.8–3.6 mm per year since 1993 (Nurse et al, 2014). In the Caribbean, an observed average rate of sea level rise over the past 60 years is broadly consistent with the global trend (approximately 1.8 mm per year) (Palanisamy et al., 2012). However, spatial and temporal variability dominates the rate of sea level rise in the Caribbean Sea which is forced by several parameters including wind and steric changes. Interannual variability (in both altimetry and tide gauges) accounts for over 30 % of the total sea-level variability in the region and to a large extent it is coherent and can partly be explained by the influence of ENSO while decadal sea level variability can partly be explained by steric and wind variability (Torres, 2013).

Long-term sea level monitoring data are not available for Saint Lucia. The collection of sea level data for the island only commenced in 1998, and therefore, future sea level rise in Saint Lucia must be based on predictions from data recorded elsewhere in the region. Like most recording stations around the world indicate that the mean sea level rise has steadily increased over the past century, data from nearby Fort-de-France tide gage station on Martinique demonstrate that sea levels have been rising since the data were first collected in 1976. This dataset has several gaps, and monthly average tide data are available only for 1976 – 1979, 1983 – 1985 and 2005 – 2016. The data show that from 2005 to 2016, sea levels at the station have raised an average of 7 mm per year. Averaging across the full available time series, sea levels at the station have raised an average of 2.7 mm per year (Figure 3-7).

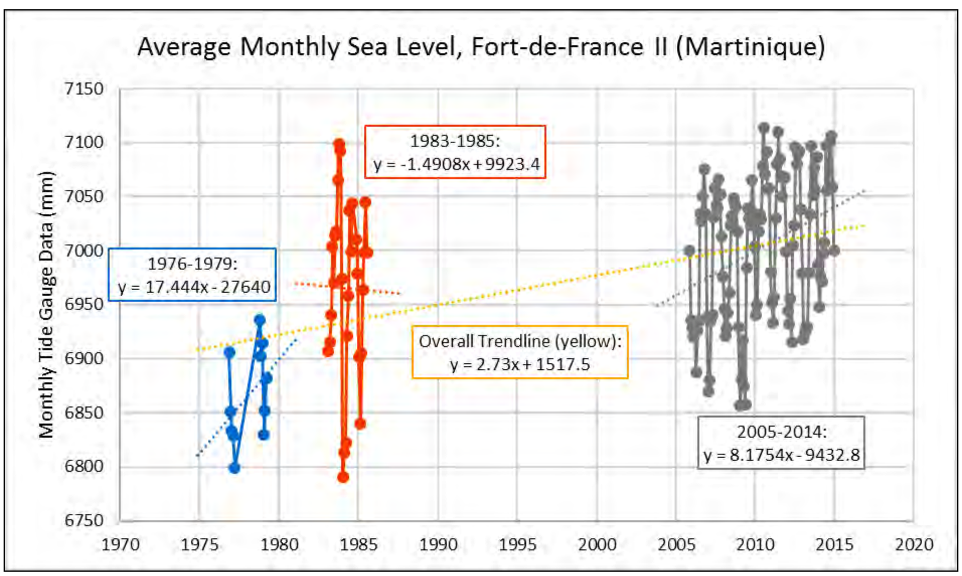


Figure 3-7 Monthly mean sea level data from Fort-de-France tide gage station on Martinique. Dataset available from: http://www.psmsl.org/data/obtaining/stations/1942.php

f. Storm Surge

Storm surges pose a major threat to coastal areas putting at risk coastal populations, economies and ecosystems and when coincide with the seasonal expansion in sea level and spring tides, extreme sea levels occur. Sea level extremes can cause flooding over large areas producing significant economic losses, threatening human welfare, enhancing erosion and causing changes to coastal morphodynamics. Largest meteorological surges from August to October occur due to the peak of the Atlantic hurricane season affecting the region. In addition, storm surges in the basin are due to stationary cold-fronts that enter the basin in the winter season.

Torres and Tsimplis (2014) investigated sea level extremes in the Caribbean Sea using data from 13 stations with hourly records available. In their study, the non-tidal component (which includes the contribution of the seasonal sea level cycle, storm surges and mesoscale eddies) of extreme sea levels was segregated and the assessment showed that in nearly 300 years of analysed sea level data from 13-time series together, non-tidal extremes range from 76 cm in Magueyes to 20 cm in Le Robert (Figure 3-8). The largest value in Magueyes is due to large storm surge forced by hurricane (class 5) David in 1979. That is consistent with the general trend that most sea level extremes in the Caribbean occur from September to November, linked to the Atlantic hurricane season (peak from August to October) combined with the peak of the seasonal cycle mainly in September and October.

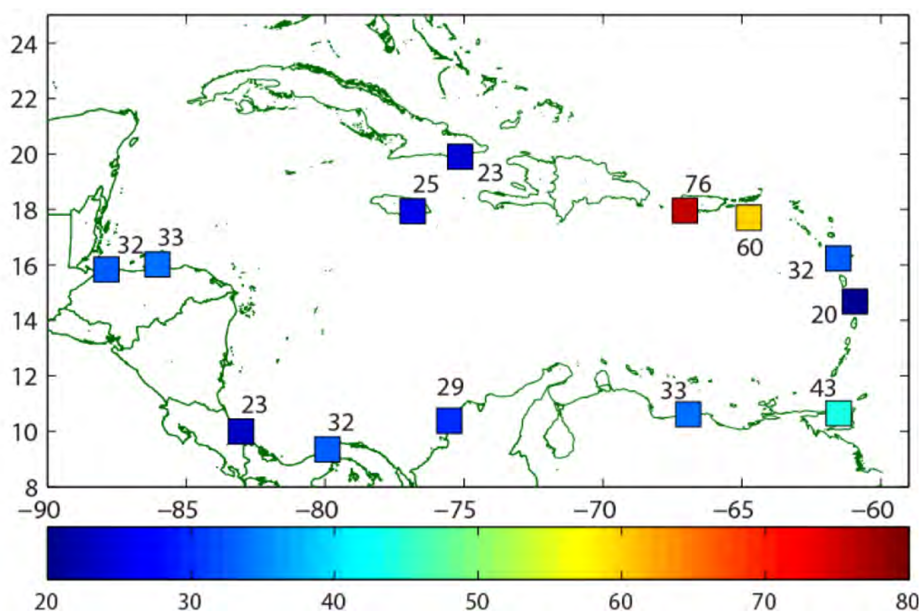


Figure 3-8 Maximum sea level observations (non-tidal residual) referenced to the mean sea level of the first year of the time series (in cm). The annual mean sea level has been removed (Source: Torres and Tsimplis, 2014)

For Saint Lucia, there have been no recorded long sea level data. However, there have been reports for marine flooding due to much higher extreme sea levels during the recent years including:

- Hurricane Lenny in 1999 that produced an estimated 6 m storm surge that caused damages to at least 70 houses (ICF GHK, 2012).
- Hurricane Dean in 2007 generated a strong storm surge during high tide which damaged marine equipment and infrastructure in Castries Harbour and the northern tourism resort area. Hourly sea level data from a weather buoy located 4 miles North of Saint Lucia recorded the maximum height at 10.2 m (Auguste, 2007).

- Hurricane Tomas in 2010 produced waves that were equivalent to a 15-year event (UNECLAC, 2011c). To point out the significance of the event, it should be mentioned that current civil engineering practices involve infrastructure and flood mitigation designs typically for 25-year to 50-year return periods.

3.2 Climate Projections

The evidence for rapid climate change is compelling; the warming trend – which most of it is very likely human-induced - is of particular significance and is proceeding at a rate that is unprecedented in the past 1,300 years (IPCC, 2007). Climate models are the primary tools available for assessing the response of the climate system to various forcings and for projecting future climate over various time scales. However, it is important to highlight the uncertainty lying in the resulted projections because of the uncertain nature of future anthropogenic and natural forcings, the incomplete understanding of natural processes, the gaps and possible systematic biases that may be included in the models, as well as the internal climate variability (IPCC, 2007).

Global Climate Models (GCM) provide global simulations of the climate system's response to increasing greenhouse gas concentrations. These models are proficient in simulating the large scale circulation patterns and seasonal cycles of the world's climate, but operate at coarse spatial resolution (grid boxes are typically around 2.5 degrees latitude and longitude). GCMs limited resolution hinders the ability to provide representative description of a regions local climate, as the finer scale characteristics of small regions like the Caribbean islands, may not be captured in a GCM grid mess. The traditional approach to address the horizontal scale limitations of the GCM is through statistical downscaling, which finds the statistical relationship between large-scale atmospheric structures and a region's local climate characteristics. The output of the GCMs downscaling are Regional Climate Models (RCM) which simulate the climate at a finer spatial scale over a small region of the world, represent climate processes comparable to those in the atmospheric and land surface components of AOGCMs (Atmosphere-Ocean General Circulation Models), though typically run without interactive ocean and sea ice.

As part of the process of getting model analyses for a range of alternative assumptions about how the future may unfold, IPCC generated scenarios for future emissions of important gases and aerosols. The Socio-Economic Driven SRES Scenarios were developed using Integrated Assessment Models (IAMs) that combine key elements of biophysical and economic systems (including future demographic and economic development, regionalization, energy production and use, technology, agriculture, forestry and land use) which were broken into 4 suites of storylines:

- A1 describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. This scenario family develops into three groups that describe alternative directions of technological change in the energy system: A1F1 (fossil intensive), A1T (non-fossil energy sources) and A1B (balance across all sources).
- A2 assumes a population that continuously increases and regional economic development with technology change more fragmented than other scenarios.
- B1 describes a global population that peaks in mid-century and declines thereafter, and an emphasis on global solutions to economic, social, and environmental sustainability.

- B2 corresponds to intermediate population and economic growth with less rapid introduction of new technologies than in the B1 and A1 storylines. It assumes an emphasis on local and regional solution.

The latest evidence suggests that so far measured global emissions are similar to, if not higher than, the worst-case A1B and A2 scenarios (Simpson et al., 2010).

In the IPCC AR5, four new Representative Concentration Pathway (RCP) scenarios were introduced that specify concentrations and corresponding emissions, but are not directly based on socio-economic storylines like the SRES scenarios. The pathways are named according to their 2100 radiative forcing level and are based on a different approach that includes land use changes, more consistent harmonized GHG emissions and concentrations, gridded reactive gas and aerosol emissions, as well as ozone and aerosol abundance fields. They include one mitigation scenario leading to a very low forcing level (RCP2.6), two medium stabilisation scenarios (RCP4.5 and RCP6) and one very high baseline emission scenario (RCP8.5) (see Table 3-3).

However, they have not been used broadly by the scientific community for projecting climate change in regional level yet so projections derived from the RCPs will be limited to certain indicators.

Table 3-3 The four global Radiative Forcing Pathways from greenhouse gas emissions from human activities

Name	CO_2 equivalent (ppm)	Pathway	Comparable SRES scenario
RCP 8.5	>1370	Increasing greenhouse gas emissions over time, leading to high greenhouse gas concentration levels	A1 F1
RCP 6	850	Radiative forcing is stabilized shortly after 2100 at 6 W/m^2 consistent with the application of a range of technologies and strategies for reducing greenhouse gas emissions	B2
RCP 4.5	650	Total radiative forcing is stabilized shortly after 2100 at 4.5 W/m^2 without overshooting the long-run radiative forcing target level	B1
RCP 2.6	490	Radiative forcing level first reaches 3.1 W/m2 by mid-century and returns to 2.6 W/m2 by 2100; greenhouse gas emissions are reduced substantially, over time	None

Climate model projections presented in this report are based on the results of future scenarios using both a General Circulation Model (GCM) ensemble of 15 models under 3 scenarios (A2, A1B and B2) and the Regional Climate Model (RCM), PRECIS. For SLR, projections that derived from RCP4.5 and RCP8.5 are presented as well.

a. Temperature

GCMs projections from a 15-model ensemble indicate that temperature in Saint Lucia is expected to rise from 0.6 °C to 1.8 °C by the 2050s and 0.9 °C to 3 °C by the 2080s, relative to the 1970-1999 mean. The range of projections across the ensemble for all 3 scenarios spans around 1 - 1.5 °C, with the mean temperature rise projected uniform throughout the year (CARIBSAVE, 2012). In the UNDP report for the island (McSweeney et al., 2010), the range of projections are similar, with an estimated increase by 0.5 to 2.1 °C by the 2060s, and 1.0 to 3.6 °C by the 2090s (Figure 3-9). The range of projections by 2090 is around

1 - 2 °C, with a uniform warming rate throughout the year, but a little more rapid in the colder seasons, from September to November and from December to February (McSweeney et al., 2010).

Moreover, all GCM projections indicate substantial increases in the frequency of days and nights that are considered 'hot'[3] in current climate: by the 2060s, 28 - 68 % of all days and nights in a given year would be classified as very hot by present day standards, with this rising to 37 - 100 % by the end of the century. On the contrary, days and nights that are considered 'cold'[4] in current climate show decrease in projections from most of the models and are almost non-existent by the 2060s (McSweeney et al., 2010).

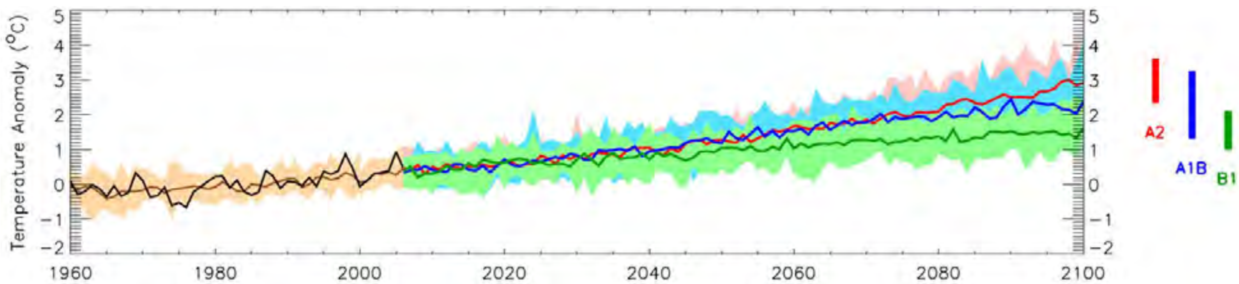


Figure 3-9 Trends in annual mean temperature for Saint Lucia. All values shown are anomalies, relative to the 1970-1999 mean climate. From 1960 to 2006 black curves show the mean of observed data, while brown curves and shading show median and range of model simulations of recent climate respectively across an ensemble of 15 models. From 2006-2100 coloured lines show the median (solid line) and range (shading) of the ensemble projections of climate under three emissions scenarios. Coloured bars on the right-hand side of the projections summarise the range of mean 2090-2100 climates simulated by the 15 models for each emissions scenario (Source: McSweeney et al., 2010).

According to the CARIBSAVE Risk Atlas, RCM simulations driven by ECHAM4 model indicate temperature increases that are higher than any of the models in the GCM ensemble in all seasons under A2 scenario. Notably, RCM projections indicate increases of 3.3 °C and 2.4 °C in mean annual temperatures by the 2080s, when driven by the ECHAM4 and HadCM3 model respectively, compared with GCM ensemble projections of 1.8 - 3.1 °C for that period. The difference in the rate of warming between RCM and GCM projections is attributed to the improved spatial resolution in the RCM that allows the land mass (which warms more rapidly than ocean) to be represented in the grid boxes.

The near term projections (2030s) of maximum temperature from the RCM PRESIS model suggest an increase of approximately 1.0 °C to 1.4 °C in maximum temperature. Minimum temperatures are expected to increase by 0.9 °C to 1.7 °C by the 2030s on average across the island. The projected changes in maximum and minimum temperature indicate a difference in warming rates in the north and south, with the north projected to be warmer than the south (ESL, 2015).

[3] The temperature threshold for a 'hot' day or night is defined by the daily temperature which is exceeded on the 10% of days or nights in the standard climate period (1970-99).
[4] The temperature threshold for a 'cold' day or night is defined by the daily maximum temperature below which the 10% coldest days or nights in the standard climate period (1970-99) fall.

b. Precipitation

GCM projections of future mean annual rainfall for Saint Lucia from the 15-model ensemble are broadly consistent in indicating decreases. Annual precipitation projections vary from -25 % to +18 % in the 2030s, -40 % to +10 % in the 2060s and -56 % to +15 % by the 2090s, with negative median values for all seasons ranging from -10 % to -22 % (Figure 3-10, McSweeney et al., 2010; SNC, 2011). In addition, total rainfall in 'heavy'[5] events decreases by -26 % to +6 % by the 2090s in most model projections. In the CARIBSAVE study, results are broadly similar, with projected annual rainfall changes ranging from -37 mm to +7 mm per month (-66 % to +14 %) by the 2080s across three emission scenarios.

RCM rainfall projections are strongly influenced by the driving GCM providing boundary conditions. Changes projected by the RCM driven by HadCM3 and ECHAM4 simulations are between -32 % and -11 % in total annual rainfall respectively (expect for months September to November when driven by HadCM3) (CARIBSAVE, 2012). Generally, for both GCMs and the RCM, largest seasonal changes are seen in June, July, August and March, April, May (SNC, 2011).

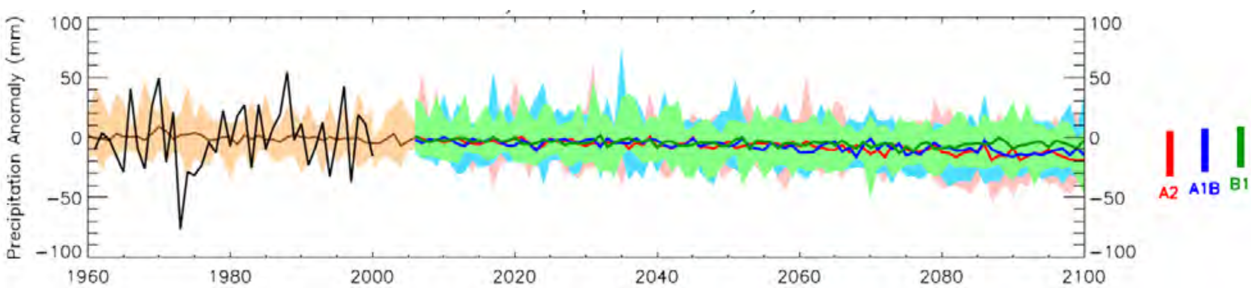


Figure 3-10 Trends in monthly precipitation for the recent past and projected future. All values shown are anomalies, relative to the 1970-1999 mean climate. See Figure 16 for details (Source: UNDP, 2010)

c. Wind speed

In GCM projections, mean wind speeds over Saint Lucia generally show either a very small increase or no change. Across the 15-model ensemble and under all three emission scenarios, projected changes in annual average wind speed range between -0.4 and +0.1 ms^{-1} by 2020s, -0.22 and 0.3 ms^{-1} by 2050s and -0.2 and +0.5 ms^{-1} by the 2080s.

Comparatively, RCM projections based on two driving GCMs are similar to changes indicated by the GCM ensemble. Small changes in wind speed are indicated for all seasons when driven by ECHAM4, while relatively large increases are projected from June to August (+1.1 ms^{-1}) and from September to November (+1.0 ms^{-1}) by the 2080s when driven by HadCM3 (CARIBSAVE, 2012).

In the Atlas of Probable Storm Effects in the Caribbean Sea (Nurse, 2013), projected wind speeds for Castries as 10-year event, 28-29 ms^{-1}; 25-year event 37 ms^{-1}; 50-year event 43 ms^{-1}; and 100-year event 49 ms^{-1}.

[5] A 'heavy' rainfall event is defined by daily rainfall amount exceeded by the 5% of heaviest events in a given region or season.

d. Hurricanes

Tropical storms and hurricanes form from pre-existing weather disturbances where Sea Surface Temperature (SST) exceeds 26 °C. SSTs are a key factor in determining the formation, development and intensity of tropical storms. GCM projections for Saint Lucia indicate increases in SSTs throughout the year that range between +0.8 °C and +3.0 °C by the 2080s across all three emissions scenarios (CARIBSAVE, 2012). Although observed and projected increases in SSTs under a warmer climate potentially expand the regions and periods of time when tropical storms may form, they may not necessarily be accompanied by an increase in the frequency or intensity of such events, as other factors including subsidence, wind shear and static stability determine the critical conditions for storm formation.

Similar to the uncertainty lying in observational analyses as mentioned in paragraph 3.1 d., confidence is also low in numerical simulation of hurricane activity, and is further decreasing as downscaling from global to regional spatial domains. Both GCMs and RCMs do not explicitly model hurricanes as they are still relatively primitive with respect to the complex atmospheric processes that are involved in hurricane formation and development, thus the ability to project future changes in frequency or intensity is restricted. In addition, inter-model differences in regional projections for all cyclone parameters lead to lower confidence in projections within individual basins.

Globally, the consensus projection is for decreases in the frequency of tropical cyclones by 5-30 %, increases in the intensity of category 4 and 5 hurricanes by 0-25 %, a minor increase in typical lifetime maximum intensity, and increases in tropical cyclone rainfall amounts by 5-20 % (Knutson et al., 2010; Christensen et al., 2013). The assessment provided by Knutson et al. (2010) of projections based on the SRES A1B scenario concluded that it is likely that the global frequency of hurricanes will either decrease or remain essentially unchanged due to greenhouse warming. They also suggested a likely increase in mean tropical cyclone maximum wind speed (+2 to +11 % globally) with projected 21st century warming, although increases may not occur in all tropical regions. Several modelling studies also project substantial increases in the frequency of the most intense cyclones and it is more likely than not (>50-100 % probability) that this increase will be larger than 10 % in some basins (e.g. Emanuel et al., 2008; Knutson et al., 2010; Murakami et al., 2012). Figure 3-11 below, shows the expected percent change in four hurricane metrics in the average over the period 2081–2100 relative to 2000–2019, under an A1B-like scenario for the North Atlantic. The projected trends are broadly consistent with the global estimates, although the frequency of very intense storms presents a substantial increase in relation to the global average.

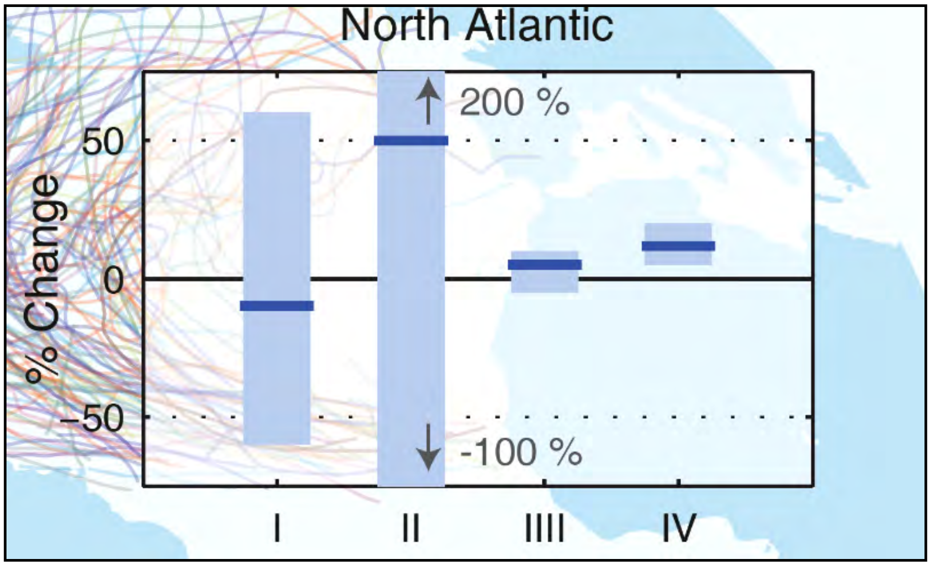


Figure 3-11 General consensus assessment of the numerical experiments about hurricane expected percent change in the average over period 2081–2100 relative to 2000–2019, under an A1B-like scenario. The four metrics considered are: (I) the total annual frequency of tropical storms, (II) the annual frequency of Category 4 and 5 storms, (III) the mean Lifetime Maximum Intensity (LMI; the maximum intensity achieved during a storm's lifetime) and (IV) the precipitation rate within 200 km of storm centre at the time of LMI. The solid blue line is the best guess of the expected percent change, and the coloured bar provides the 67 % (likely) confidence interval for this value (Source: Christensen et al., 2013)

e. Sea Level Rise

Globally, sea levels have risen faster than at any time during the previous two millennia and it is virtually certain that the rate of global average SLR is accelerating (Nurse et al., 2014). According to the IPCC Fifth Assessment Report, while there remains considerable uncertainty related to the magnitude and timing of both climate change and SLR, there has been significant improvement in understanding and projection of sea level change since the previous AR4 report. As stated in AR5:

> "*Under all RCP scenarios, the rate of sea level rise will very likely exceed the observed rate of 2.0 [1.7–2.3] mm/yr during 1971–2010, with the rate of rise for RCP8.5 during 2081–2100 of 8 to 16 mm/yr (medium confidence). For the period 2081–2100 relative to 1986–2005, the rise will likely be in the ranges of 0.26 to 0.55 m for RCP2.6, 0.32 to 0.63 m for RCP4.5, 0.33 to 0.63 m for RCP6.0, and of 0.45 to 0.82 m for RCP8.5 (medium confidence).*"

Sea level rise will not be uniform across regions. By 2100, about 70 % of the coastlines globally are projected to experience a sea level change within ±20 % of the global mean, while it is very likely that sea level will rise in more than about 95 % of the ocean area (Church et al., 2013).

Sea level rise projections in the Caribbean under the intermediate low-emissions scenario RCP4.5 for 2081–2100 (relative to 1986–2005) are between 0.5-0.6 m and similar to global projections (Nurse et al., 2014). Small islands in the basin will not have uniform SLR risk profiles and they will be impacted in varying scales. For instance, Saint Lucia is a tectonically active volcanic island so land movement may increase or decrease the local sea level rise (Simpson et al., 2010). However, the SIDS economies can be more vulnerable to SLR in comparison to other regions since most of their population and infrastructure are in their narrow coastal zone. In the assessment of the vulnerability of Caribbean coastal tourism to scenarios of sea level rise, Scott et al. (2012) estimated that the elevation equivalent of a projected sea level rise of 1 m would damage 49-60 % of tourist resort properties, with indirect impacts on the sustainability of coastal tourism destinations in the region. For Saint Lucia, the Climate Change Risk Atlas, states that: 1 m SLR would place 7 % of the major tourism properties at risk, along with 50 % of airports and 100 % of the ports, and 2 m SLR would place 10 % of major tourism resorts at risk.

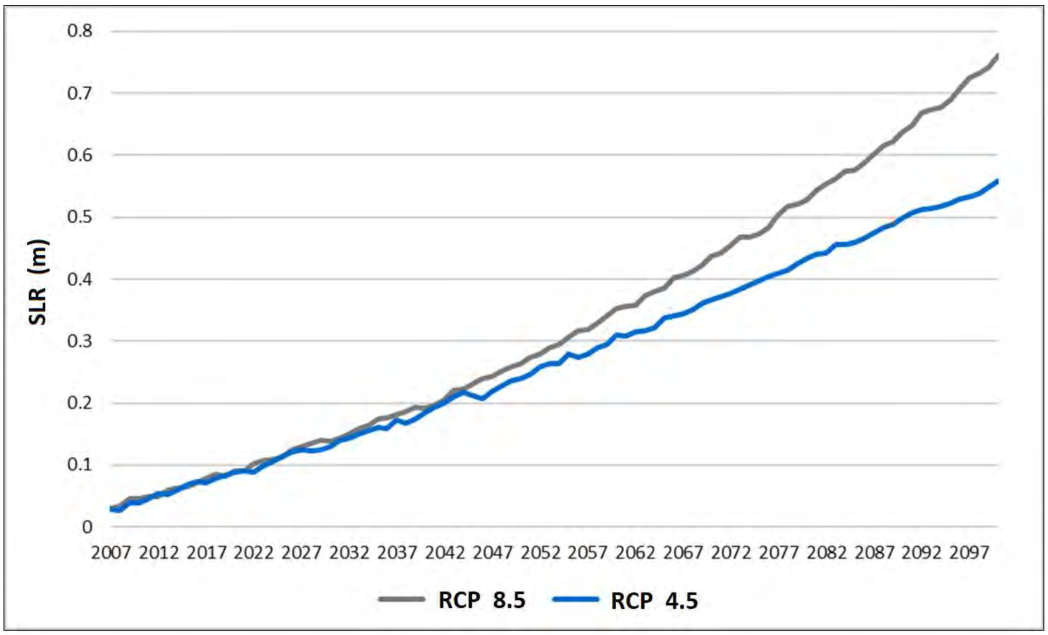


Figure 3-12 Sea level Rise projections for Saint Lucia (Graphed using data from: http://icdc.cen.uni-hamburg.de/1/daten/ocean/ar5-slr.html)

The near term projections (2030s) of sea level rise in Saint Lucia from RCP 4.5 and RCP 8.5 scenarios suggest an increase of 0.13 m and 0.14 m respectively. By 2060 an increase of approximately 0.31 m for the RCP 4.5 and 0.35 m for the RCP 8.5 is projected while sea level is expected to rise 0.56 m and 0.76 m respectively, by the end of the century (Figure 3-12).

f. Storm Surge

Small island states in the Caribbean Sea are especially vulnerable to storm surges for several reasons, inter alia, the location of human communities and infrastructure on lowlands along the coastal fringe, the constraints on adaptive capacity, the generally inexistent coastal protection against sea flooding, the projected SLR (over which a given storm surge height will be superimposed) and the probable increase in the severity or frequency of storms. In addition, population growth is considered as a major contributor to the increased vulnerability to storm surges (Pielke et al., 2003). Projections for future change in storm surge height or frequency of occurrence remain difficult due to the high degree of uncertainty associated with estimations of potential changes in sea level and hurricane activity.

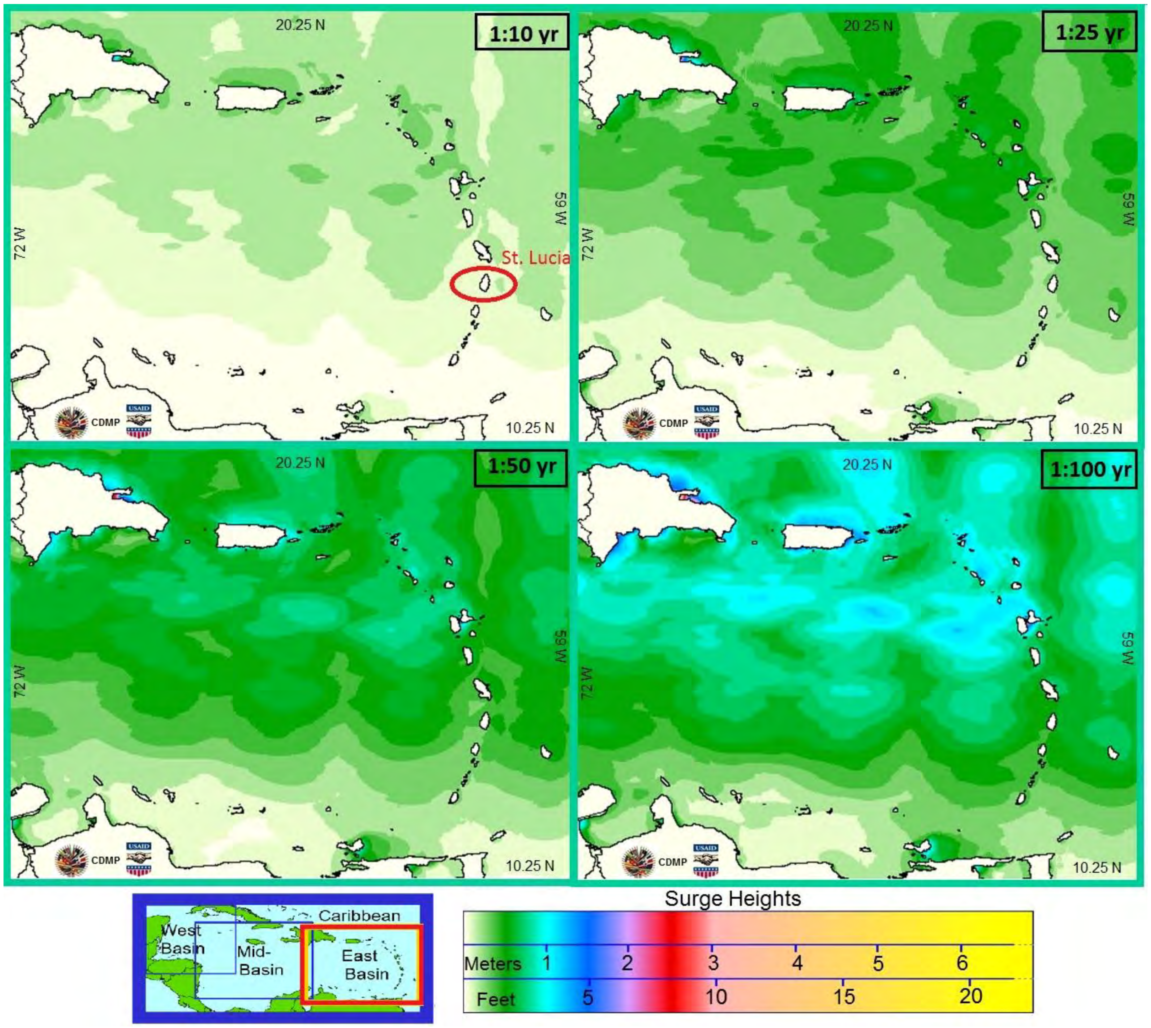


Figure 3-13 Maps of East Caribbean basin showing maximum storm surges which are most likely to occur (Maximum Likelihood Estimates, or MLEs) over four return periods: 10, 25, 50 and 100 years (Source: Nurse, 2013)

Nurse (2013) estimated the eights associated with the return periods of storm surges for Castries to be: i) 1:25-yr - 0.3 m, ii) 1:50-yr - 0.4 m and iii) 1:100-yr - 0.6 m (Figure 3-13).

g. Waves

In literature, coastal hazard is mainly assessed through predictions of relative sea level rise in view of climate change. However, increased flooding and erosion can be an effect of waves, which contribute to the water level rise through wave run-up and wave setup. There are few global studies discussing large-scale projections of waves that either focus on average wave conditions, or explore extreme wave conditions by focusing on high percentile values or on low return levels.

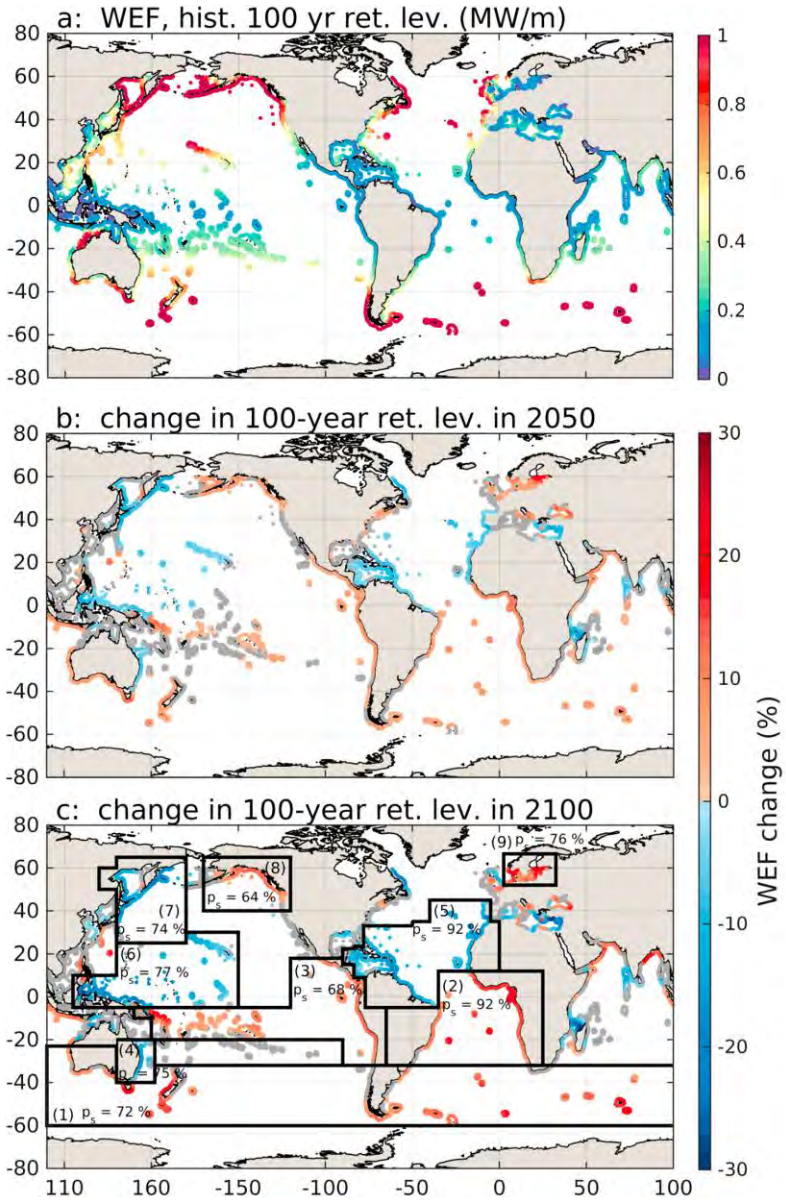


Figure 3-14 Ensemble relative change of the 100 year WEF for the year (b) 2050, and (c) 2100 in relation to baseline (a). The grey dots correspond to locations where no significant change was projected. In Figure c the areas of significant change are reported together with the percentage p_s of points where the increase is significant (Mentaschi et al., 2017)

Mentaschi et al. (2017) conducted a modelling analysis to identify global trends in extreme wave energy flux (WEF) along coastlines in the 21st century under RCPs 8.5, and investigated their correlation with long-term trends of teleconnection patterns such as the Antarctic Oscillation, El Niño–Southern Oscillation, and North Atlantic Oscillation.

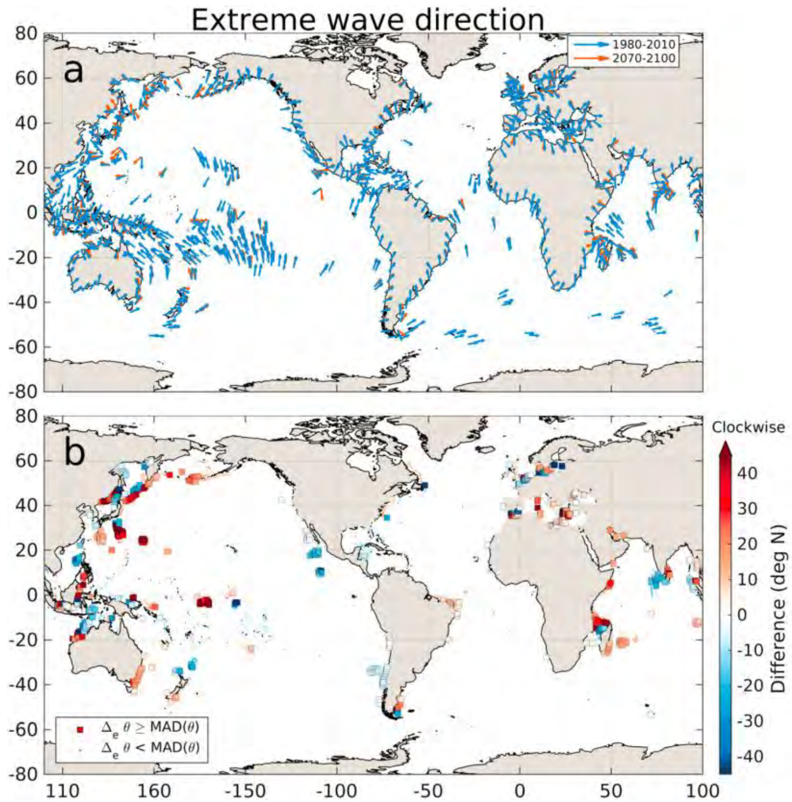


Figure 3-15 Ensemble mean change of extreme WEF direction: (a) quiver plots showing the direction of propagation for the baseline and 2070–2100. (b) Scatter plot showing the direction change between the start and end of the century, expressed by the box colour; the box type indicates that the change in direction exceeds the intermodel mean absolute deviation MAD(ϑ) of the change (Mentaschi et al., 2017)

The simulations of the WEF with a global wave model driven by an ensemble of GCMs for the northern tropical Atlantic are characterized by a clear negative trend (Figure 3-14). The average change of the 100 year return level at regions that showed decrease (including the Caribbean) is of about -13 %, while the average change of the mean WEF is -6.83 %. Moreover, it was found that the projected decrease in WEF translates into a more than 50% reduction in frequency by the end of the century. In addition to the WEF and return periods, the extreme wave direction was investigated, where insignificant changes were projected for Saint Lucia (Figure 3-15). Finally, the link between the long-term variations of the climatic indices and the change of extreme WEF for the region was found to be strong for all the models of the ensemble, where the correlation with the ENSO index is -0.91. The results indicate that all coastal components should be addressed in the assessment of future coastal hazard, as they could act cumulatively or counterbalance regional sea level rise and associated impacts.

3.3 Climate Change Overview

Saint Lucia is already experiencing some of the effects of climate variability and change through damages from severe weather systems and other extreme events, as well as subtler changes in temperatures and rainfall patterns. Detailed climate modelling projections for Saint Lucia predict:

i. An increase in average atmospheric temperature;

ii. Reduced average annual rainfall;

iii. Increased Sea Surface Temperatures (SST);

iv. The potential for an increase in the intensity of tropical storms; and

v. The accelerating rate of sea level rise.

There is evidence to suggest that the climate of Saint Lucia is changing. Climate trends described in this Chapter are as follows:

- Minimum temperatures have increased at a rate of ~0.16 °C per decade, and maximum temperatures at ~0.20 °C per decade.
- The warming trend is expected to continue. The country is projected to be warmer by up to 1 °C by the 2020s, 2 °C by the 2050s and 3 °C by the 2080s.
- The frequency of very hot days and nights will increase, while very cool days and nights will decrease.
- There is no statistically significant trend in historical rainfall which shows considerable inter-annual variability.
- There is a likelihood that the country will be drier (in the mean) by the end of the century. GCMs show a median decrease of up to 22 % for annual rainfall while the RCM suggests a decrease of up to 32 % by the end of the century.
- The proportion of total rainfall that falls in heavy events also decreases in most GCM projections, changing by -26 % to +6 % by the 2090s.
- Climate change will likely shift the dry period earlier in the year and June-July drier.
- Hurricane intensity is likely to increase (as indicated by stronger peak winds and more rainfall) but not necessarily hurricane frequency.
- Caribbean Sea levels are projected to rise by up to 0.5 – 0.6 m by the end of 21st century.
- Sea surface temperatures in St. Lucia are projected to increase by 0.8 °C - 3.0 °C by 2080s.

Chapter 4: TRANSPORT INFRASTRUCTURE: CRITICALITY

4.1 Overview of Transport Infrastructure

Saint Lucia's transportation network largely comprises a north-south highway that runs along the island's coast and connects all major urban communities, the two main airports and the country's two main ports (Figure 4-1).

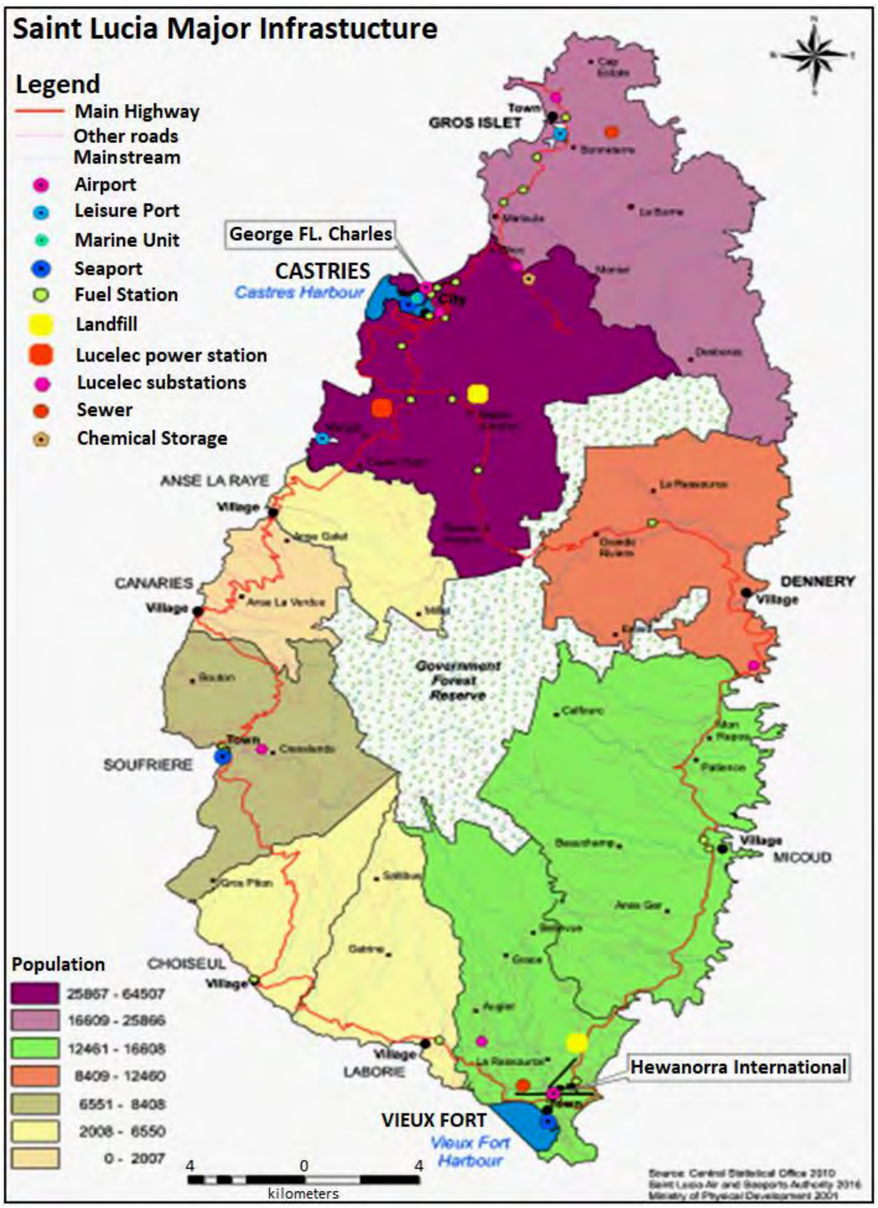


Figure 4-1 Saint Lucia major infrastructure

The two-lane highway forms a ring around the island and it represents a major artery for the flow of goods and services. The interior rural communities are connected to this main road through a network of secondary, tertiary, and smaller farm-to-market feeder roads. There are a little over 1000 km of main road; 816 km paved and 184 km otherwise improved. Ambitious road building and improvement projects continue to allow access to some of the most remote areas of the island.

In addition to the road transport, Saint Lucia has two airports: George F.L. Charles Airport and Hewanorra International Airport. George F. L. Charles Airport is situated in the north of the island, 3.21 km from the capital Castries and approximately 62 km from Vieux Fort. Due to its size and proximity to Castries, it plays host to a number of general aviation and commuter airlines linking Saint Lucia to the other territories of the Eastern Caribbean. Hewanorra International Airport is situated in the south of the island, close to the town of Vieux Fort and 72 km from the capital Castries. There are regularly scheduled jet flights from Europe and North America.

Figure 4-2 Left: *George FL Charles Airport and the capital, Castries; right: Hewanorra International Airport*

Saint Lucia has five sea ports, two of which are major harbours; Port Castries and Port Vieux Fort (refer to Table 4-1 for their physical characteristics). On the north-western side of Saint Lucia and within the heart of the capital city is the main port of Castries. It is a multipurpose port that provides facilities and services for both passengers and cargo. Port Vieux Fort is located at the southern tip of the island and is the second largest port which caters primarily to the needs of transshipment container operators. It is situated 2.5 miles from Hewanorra International Airport, the Industrial Free Zone, the goods distribution free zone and the Vieux Fort Industrial Estate.

Table 4-1 Physical characteristics of the ports (Source: Cubas et al, 2015)

Port	Terminal Area* (m^2)	Berth (#)	Berth Length (m)	Maximum Berth Depth (m)	Maximum Ship Draft (m)	Maximum Length of Vessel (m)	Crane Capacity Maximum Lifting Capacity (tonnes)
Castries	117,360	8	940.6 (cargo +cruise)	10	9	200	52
Vieux Fort	50,000	3	373	11	10	200	80

Figure 4-3 Left: Port Castries (Source: SLASPA); right: Port Vieux Fort (Source: www.express.co.uk)

The port infrastructure facilities in Saint Lucia were modernised to handle containerized cargo. Consequently, deck loadings, terminal designs and layouts, including space allocated to warehousing and storage spaces, meet the requirements for the rapid handling of containers.

In addition to these 2 ports, the island boasts three world-class marinas in Rodney Bay, Marigot Bay and Soufriere, all of which are official points of entry to the country. Rodney Bay Marina which is located at the north-western tip of the island and north of the port of Castries, is privately owned and operated by Rodney Bay Marina Ltd, and provides excellent facilities for all categories of yachts. The Marina is home to one of the world's premier yachting events - the Atlantic Rally for Cruisers (ARC), held every December. Marigot Bay, another yacht marina of international repute is located almost mid-way down the western coast of Saint Lucia and south of Castries. Marigot Bay is privately owned and operated by Discovery at Marigot Bay. This marina is a very safe haven for yachts escaping from turbulent seas during storms in the Caribbean region. Throughput for 2011 was 6,089 yachts and 33,133 persons at Rodney Bay marina and 1,771 yachts and 8,575 persons at Marigot Bay. Soufriere port which is located on the southwestern coast of Saint Lucia between Marigot Bay and Vieux Fort, receives some commercial cargo activity but it is best known for cruise and leisure travel. The port has the capability of berthing at anchorage, medium sized cruise ships and can accommodate alongside most yachts and catamarans. The Soufriere Foundation and the Soufriere Marine Management Area manage the port.

Figure 4-4 Left: Rodney Bay; right: Marigot Bay Marina

4.1.1 Social and Economic importance of the Transport Network

The contribution of transportation to the GDP is provided in Figure 4-5 below. Over a period of 10 years, between 2005 and 2015, more than 60 % of the contribution was from road transport while air transport contributed the smallest percentage. Auxiliary transport activities[6] accounted for more than air transport, and equal to sea transport.

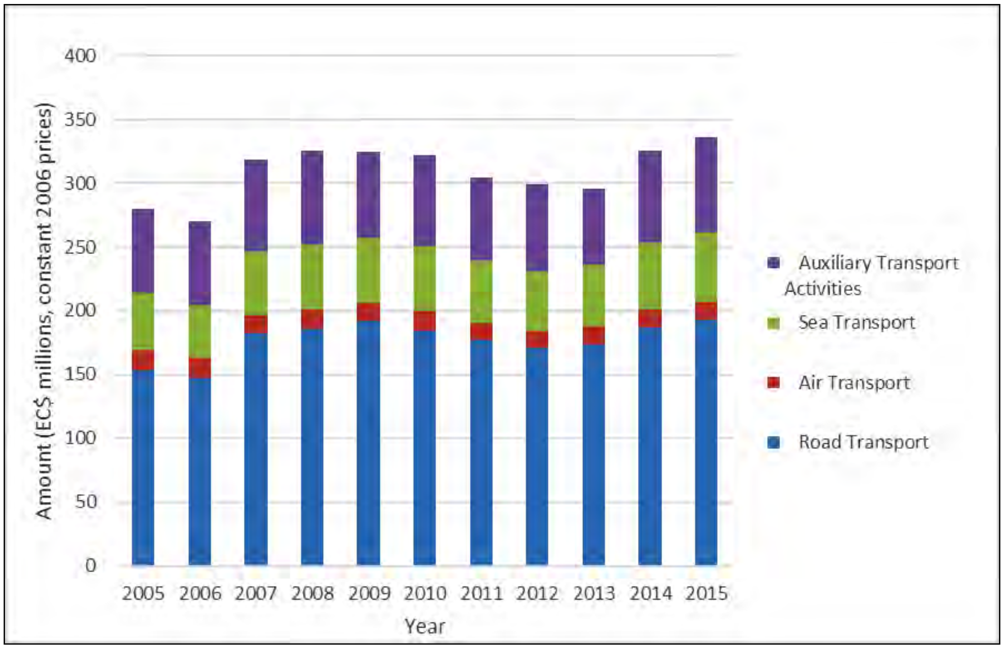


Figure 4-5 Transport contribution to GDP (Graphed from data available in: Review of the Economy, 2015)

Road transport contributes the highest percentage to GDP because of the volume of traffic that flows through the road network. In 2015, the volume of agricultural products sold to supermarkets, hotels and local consumers was estimated at a little over 10,000 tonnes totalling about EC$ 30 million. All of this produce was transported, from the farms to the point of sale, through the road network. In addition, in 2015, 71,364 Twenty Foot Equivalent Unit (TEU) of cargo was transported through Port Castries and Port Vieux Fort and 2,965,010 kg through both airports. Moreover, in 2015, visitor arrivals (stayovers and cruise passengers) totalled 1,073,017 tourists, the highest number of arrivals over the last 10 years. Tourists are transported by road to their hotel destinations and to the popular sites by road as it is the only form of transportation within the island. It was estimated that tourist expenditure for 2015 was EC$ 2.08 billion, figure that is further reinforcing the importance of the transportation network to the country's economy.

With Saint Lucia being sea locked, access to well-functioning and reliable transportation systems, in particular maritime and air transport systems, is vital. Seaports and airports are the lifelines sustaining the survival of the country, especially since Saint Lucia is highly dependent on transport-intensive imports for much of the nation's consumption needs, for example, food and energy. Although maritime transport is

[6] Activities undertaken by tour operators – tours provided to cruise passengers.

the predominant mode used to carry cargo and freight, air transport is relied upon primarily for passenger and tourist transport and domestic inter-island connectivity and mobility.

The ports are very important to the Saint Lucian economy since:

i. Imports and exports are tied to the functionality and efficiency of the ports – any disruption in the ports impacts on the availability of critical goods and services to the social and economic wellbeing of the citizens;
ii. All imported food is handled primarily through the sea ports, although a small percentage is also channelled through the airport;
iii. All energy products, primarily hydrocarbon fuels, are handled through the seaports;
iv. Saint Lucia earns significant foreign and local revenues from port-related activities, including: berthing, bunkering & airport landing fees, air and cruise passenger imposts, containerized and other storage charges and waste reception fees.

However, the small size of Saint Lucia poses daunting challenges in transport and trade logistics. These challenges are further exacerbated by concurrent trends such as globalization, environmental degradation, climate change and limited financial resources for infrastructure development and maintenance. In relation to maritime transport, relevant challenges are affecting, among others, shipping services, transport costs, port infrastructure, equipment and operations. Small cargo volumes in Saint Lucia limit its ability to benefit from economies of scale or attract shipping services and investors. Smaller vessels have to be used, which bring higher costs per 20-Foot Equivalent Units (TEUs) than larger vessels. The relatively low and imbalanced import and export volumes, together with considerations of ship economics (ship size in relation to volume of cargo, required service frequency, route length, ship speed, physical constraints to ship size at ports and time in ports) also create operational challenges and higher costs. Although many of these structural competitiveness weaknesses are typical of the region, costs associated with clearing imports and exports through the ports are unusually large. Priorities include continued modernization of port operations and customs, fully automation of the registration system and finalization of negotiations for a more flexible work schedule for port operations (IMF, 2016).

4.2 Road Network

As already alluded to above, the major road infrastructure is mainly coastal with the main two lane highway being a ring road connecting most of the towns and villages around the island. This road also connects the two (2) airports and two (2) sea ports. More importantly, this ring road is also connected to a network of secondary roads that connect communities in the interior of the island. The networks of secondary roads that connect with the main ring road are usually found on hilly terrain, along mountain ridges. Most of the interior settlements started as linear communities along these roads built on the mountain ridges. Today, however these settlements have begun to spread along the mountain sides and are connected to the road by footpaths and unpaved minor roads which are subject to erosion and degradation at the slightest rainfall. The network of secondary roads connecting to the main ring road is vital for communications, economic livelihoods and social connections. However, it does not cover the entire country as there are many uninhabited areas. Thus, the network cannot function in a redundancy capacity to the main ring road. There have been many major events when the northern part of the island has been cut off from the southern part because of landslides and flooding along the main ring road. The secondary roads were built as agricultural feeder roads during the heyday of Saint Lucia's "Green Gold"[7] era, and many of them are not well maintained. Despite the poor maintenance of these roads, they still play a significant role in that they are used to transport agricultural produce from the farming communities to the major supermarkets and tourism plants along the coast, primarily in the north of the island.

The road network plays a vital role to the life of the Saint Lucians. People who live in towns and villages all over the country have to travel to Castries daily to work or to attend school, to undertake any government business or to seek advanced health care. It is the only form of transportation within the island; there is no marine transportation between the towns and villages although in recent times there has been an increase in water taxis plying tourists between hotels in the north and west, and Castries. In addition, people travel to and from North America and the UK through the Hewanorra airport and at certain times of the day, and usually on weekends, resulting in a high volume of traffic at the road from Castries to Vieux Fort. It is estimated that more than 90 % of the tourists arrive at the Hewanorra Airport and are then transported by road to their hotel destinations mainly in the north of the island, and to a handful of hotels in Soufriere. It is further estimated that about 90 % of cruise passengers embark in Saint Lucia and about 70 % of these passengers go on day tours, by coaches or taxis, to Soufriere; others go to the beaches up North. The ring road is also used to transport cargo throughout the island. Most of the cargo enters the island through Port Castries and is then transported in trucks to other parts of Saint Lucia. The majority of the commercial places, including warehouses, are located in the Castries basin.

The main ring road was constructed before the country gained independence and although many sections have been upgraded, the road remains narrow and traverses through difficult terrain especially along the west coast and in the centre of the island. Rock falls and landslides are a common occurrence. The section of the ring road that transects through the middle of the island is also very prone to landslides and to slippage. The road has been widened in many sections but still remains difficult to navigate during bad weather. In addition to the rock falls and landslides, some sections of the ring road, along the flatter coastal areas, are also prone to flooding which, in turn, impacts on traffic flow; in some instances, the water levels are too high to allow for traffic to pass.

The road transport sector is the second main source of GHGs in Saint Lucia. Growth in this sector has been particularly rapid with a phenomenal increase in the number of registered vehicles increasing (Table 4-2). The rapid growth of road transport may have resulted in the sector now accounting for a larger share of fuel imports and greenhouse gas emissions than the energy generation sector. The composition of vehicles for land transport in Saint Lucia between 2009 and 2013 reflects the number of private vehicles being the highest, followed by goods vehicles, taxi/hires and passenger vans. There has also been a steady increase in the number of vehicles for the period 2009 to 2013, from 54,000 to 62,145.

[7] Bananas were referred to as "Green Gold" because it was an important source of income to rural communities and banana production supported the social and economic development of the country.

Table 4-2 Composition of vehicles for land transport in Saint Lucia 2009 – 2013 (Source: UNECLAC, 2014)

Type of Vehicle	Number of Vehicles				
	2009	2010	2011	2012	2013
Goods Vehicles	11,748	11,831	12,021	12,140	12,293
Taxis/Hires	3,695	3,461	3,595	3,765	3,904
Motorcycles	854	839	856	888	939
Private Vehicles	32,452	35,834	37,452	38,978	40,210
Passenger Vans	3,655	3,419	3,440	3,461	3,507
Tractor Trailers	38	153	153	153	156
Earth Moving Equipment/Tractors	290	202	224	244	262
Other	1,268	872	873	874	874
Total	54,000	56,611	58,614	60,523	62,145

4.3 Hewanorra International Airport

Hewanorra International Airport (HIA) is strategically located near the southern Seaport and Freezone area in Vieux-Fort. Hewanorra was originally a US Military Base but in the 1950s it was handed over to Saint Lucia and underwent a major rebuilding programme in 1975 to provide international arrivals and departure facilities. A number of expansions and improvements have been undertaken since then, and currently the airport is operating at maximum capacity, handling the large majority of international passenger traffic to and from the island.

Figure 4-6 Hewanorra International Airport

The HIA is 3.7 km north of Vieux Fort and 56 km south of Castries. It has a 2743.2 m long and 45.72 m wide asphalt runway, 3.3 m above sea level. There are 5 aircraft stands, two for wide-body aircraft and three for medium-sized aircraft such as the Airbus 320 and Boeing 737 aircraft and 250 slots in the car park. International Airlines that are serving the airport are: American Airlines, Delta Airlines, Air Canada, US Airways, Virgin Atlantic, British Airways, West Jet, Sunwing, Jet Blue, Condor Thomas Cook, Can jet and Air Transat. The Types of aircrafts that fly into HIA include, *inter alia*, Airbuses (A300's) Boeings (722 –

738), DC10, DHC 6 -8. The available services in the airport are: meteorological services, banking services, duty free shopping inside of departures lounge, restaurants - land and airside of terminal, auto rental services, taxi service, tour operators, and car park services.

The main highway from Castries to Vieux Fort separates the western and eastern ends of the runway from the Atlantic Ocean. The planes approach the airport from the western end on which there is some land between the runway and the fence next to which is the La Tourney River (Figure 4-7). The La Tourney River runs alongside the fence to the north and west of the runway. This river originally crossed the present runway and was then moved to run along the southern boundary of the airport. There is however water that drains under the runway into a pond on the northern side of the runway. The orange arrow in Figure 4-7 shows the present course of the river while the red arrow shows where the river used to flow under the runway into a pond on the southern side of the runway.

Figure 4-7 Location of the HIA Runway in relation to the La Tourney River

Saint Lucia Air and Sea Ports Authority (SLASPA) has decided to follow a Public-Private Partnership (PPP) for the redevelopment of HIA. The redevelopment is expected to address capacity constraints and improve the airport's competitiveness, service quality standards, and operational efficiency, as well as support sustainable growth and development, particularly in the tourism industry. The estimated capital investment would be US$207 million, with US$125 million in the initial phase. $54.6 million would be devoted for the terminal.

The Island's tourism market forecasts that some 800,000 passengers could pass through the airport annually by 2017. It is envisaged that Hewanorra's new terminal would be more than twice as large as the current facility, equipped with 6-8 jet bridges and a proposed 13 parking positions including one stand capable of handling the Airbus A380.

The HIA is a major component of Saint Lucia's tourism product, serving as the gateway to the international long-haul airlines that connect the island to the United States, Canada, Europe and the rest of the world. HIA facilitates approximately 80 % of all air traffic into the island. Annually, the airport handles more than 15,000 domestic and international aircraft movements and in 2016 it recorded 644,837 arriving and departing passengers in addition to 133,686 in-transit passengers. At HIA, 75 % of all passengers are foreign passengers with the primary market being the US, followed by Europe and Canada. The total amount of cargo declined from 2,500 tonnes in 2004 to just short of 1,500 tonnes in 2011. Since then, the figure is increasing, with 2,138 tonnes of cargo handled in 2016.

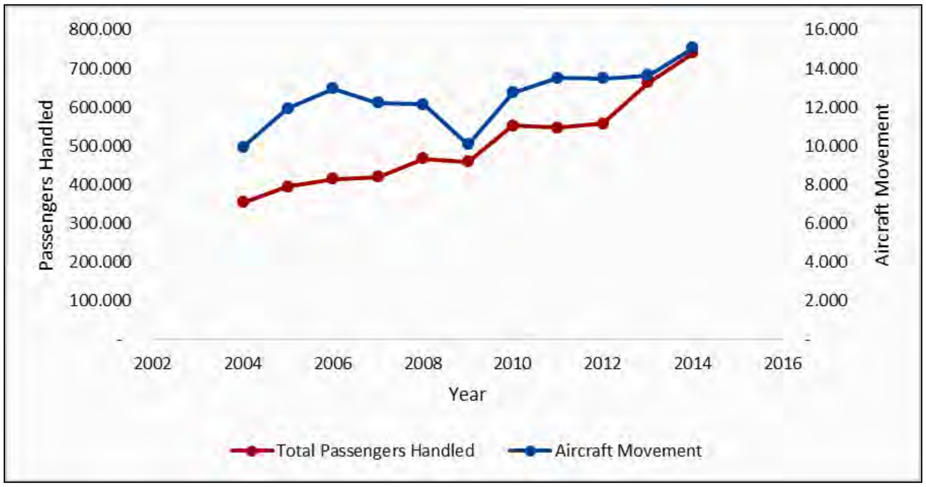


Figure 4-8 HIA – Total Passengers Handled and Aircraft Movement, 2003 to 2011

The aviation fees collected at HIA are summarized in Table 4-3 below.

Table 4-3 HIA aviation fees

Landing Fees (in EC$)	Basis: Maximum take-off weight in the Certificate of Airworthiness. 6,000 lbs or less: $20.00 per landing 6,001 - 50,000 lbs: $3.50 per 1,000 lbs or part thereof 50,001 - 350,000 lbs: $3.60 per 1,000 lbs or part thereof Above 350,000 lbs: $1,260.00 (350 x $3.60) plus $2.90 for every 1,000 lbs above 350,000 lbs.
Parking Fees	Whenever an aircraft is parked at HIA for period longer that two hours it must pay an apron parking fee equivalent to 20 % of the aircrafts' landing fee. The first two hours are free; thereafter parking must be per twenty-four hours or part thereof. The minimum parking fee is $10.00.
Extension	An extension fee equivalent to 50 % of the landing fee must be paid by an aircraft operator for any extension not exceeding one hour to the operating hours of the airports. If it exceeds one hour, the extension fee must be equivalent to the landing fee of the aircraft. In no case must the extension fee be less than $300.00. The operating hours for the purpose of calculating the extension fee must be 6:00 a.m. to 11:00 p.m. daily.
Navigation/ Communication	2,500 lbs or less: $40.00 per landing 12,501 - 75, 000 lbs: $60.00 per landing Over 75, 000 lbs: $150.00 per landing
Security Charge	A charge of $13.00 is levied on every departing passenger.
Facilitation Charge	A charge of $1.00 is levied on every arriving passenger.
Airport Service Charge	A charge of $68. Children under the age of twelve years are exempted from payment of Airport Service Charge
Permit Fee	A permit fee of $100 is levied for private jet operation.

These same fees also apply to George F.L. Charles Airport. While there is insufficient data to calculate the annual fees received from HIA, it is estimated that the fees are substantial. In 2011, for instance, there were 13,525 aircraft movements. These aircraft would have paid landing fees, parking fees, and navigation fees. In 2011 also, the airport handled 625,087 passengers, all of whom would have had to pay a $1.00 when they arrived and most of them a departing levy of $13.00.

4.4 George F.L. Charles Airport

George Charles International Airport (GCIA) is nestled between hills and the Vigie Beach, 3.7 km north of Castries. The sea is on the eastern end of the runway and runs parallel to the airport on the north and for about quarter of the length of the runway to south. The other half of the southern end of the runway runs parallel to and is separated by a fence from the main highway leading from Castries to Gross islet in the North. The western end faces a hill which is heavily settled. A single lane road separates the airport from the sea to the north. A number of food caravans are located on the beach side of the entrance to the airport. A new food mall is presently being constructed on the beach in front of the exit from the airport. The airport does not have a dedicated parking lot; cars are parked on the beach.

It has an 1890 m long and 45.72 m wide asphalt runway, 6.1 m above sea level. Currently, there are three main airlines that service George Charles Airport: Caribbean Airlines, Air Caraibe and LIAT. The airport primarily serves small, short-haul turboprop aircrafts in its four parking stands, such as the ATR-76, ATR-72 and ATR-42.

Figure 4-9 George F.L. Charles Runway from the eastern end

It is envisaged that though small in size, George F.L. Charles Airport has a major role to play in the development of Saint Lucia's aviation scene. Be that as it may, one idea that has been mooted around is to close the facility to scheduled, commercial air services and to move the airport towards general aviation status[8] – for which the terminal facilities and 1,890m (6,200 ft.) runway are well suited – including the medium-term establishment of a Fixed Base Operation (FBO)[9].

Visual observation of Vigie Beach show changes in the beach profile. Dramatic changes seem to occur to the beach profile during a single extreme weather event and although recovery is normal, it is, often, not to pre-hurricane conditions. After Tropical Storm Iris, followed by Hurricane Louis in 1995, Vigie Beach was narrowed by 11 m (Scott et al, 2006).

GCIA is a user-friendly, small-scale facility that plays a critical role in the economy. Its location close to the commercial centre of Castries makes the airport ideal for "just-in-time" deliveries. Helicopter services for sightseeing or transfer to other spots around the island also call GCIA home base. The airport handled 195,859 passengers in 2016, mainly on regional flights to/from Caribbean destinations, including St Vincent, Martinique, Grenada, Trinidad and Barbados. GCIA (along with the port) is particularly important for connecting Castries and the northwest urban corridor to the rest of the Caribbean. This also means that the airport can also serve as the only operative transport network in case of Castries is disconnected to the rest of the island for example, due to road infrastructure disruptions.

Aircraft movement had increased significantly since 2004, but there has been a decline over the period in the total number of passengers that the airport handles (Figure 4-10). From its busy apron once serving more than 50 daily flights, GCIA is now handling just a few scheduled services. Nevertheless, the airport is a valuable air cargo hub too; handling around 1,000 tonnes per annum, with the highest record being 1,327,996 kg of cargo handled in 2011, through its 742.2m^2 (8,000 sq. ft.) terminal. In 2016, 1,079,303 kg was handled in the airport.

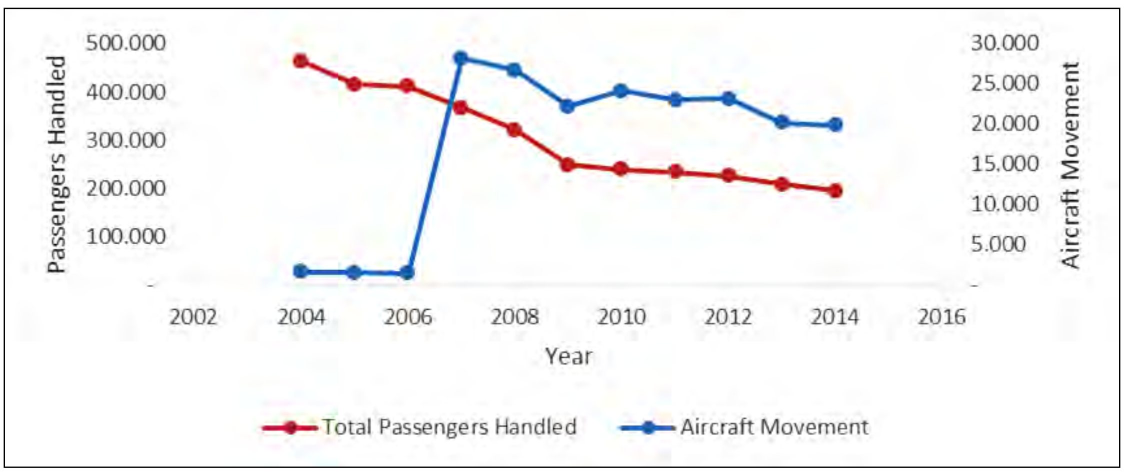


Figure 4-10 Total Passengers Handled and Aircraft Movement, 2004-2014

8 General Aviation Airports are public-use airports that do not have scheduled service or have less than 2,500 annual passenger boardings.

9 An FBO, refers to commercial businesses allowed to operate on airport grounds in order to provide services to the airport. In essence, they are private jet terminals typically located on the grounds of an airport.

4.5 Port Castries

Castries Seaport (CSP) is located on the north-western side of the island, within the heart of the capital city of Castries. It is a multipurpose service port[10] that provides facilities and services for both for cruise liners and cargo. It is the main port in Saint Lucia and as such, it handles most of the country's gateway cargo. Additionally, the port handles the majority of cruise activities. It is a natural harbour and the port's 12.8 m deep channel means many of the largest cruise ships can enter and leave with ease. The main docking facility is Pointe Seraphine, with 2 dedicated cruise berths that can handle two mid-to-large sized cruise ships although Port Castries can facilitate 5 cruise liners, in total, at any time. On rare occasions, if the port is unusually crowded, some ships may have to dock at Port Careenage, Queen Elizabeth docks, less conveniently located to the centre of town. Cruise passengers can get off at Pointe Seraphinen or at the La Place Carenage Duty Free Terminal which caters to passengers disembarking from liners anchored at the Queen Elizabeth II Wharf. The cargo terminal and the ferry terminal[11] share a same entrance and exit point located at the southern end of Port Castries and outside of the city centre.

Figure 4-11 Cruise Liners docked in Port Castries (Source: SLASPA)

The location of the berths is shown in Figure 4-11, while Table 4-4 summarises the main terminal characteristics.

Cargo Operations at Port Castries has changed significantly from predominantly handling break-bulk to containerized cargo. SLASPA has upgraded its cargo handling facilities in order meet the demands of shipping lines. This led to the introduction of cranes and top handlers at Port Castries which led to significant changes in cargo operations including improved quality of service to shipping lines, truckers and consignees, decreased cargo handling cost and the overall modernization of Port Castries. For ground operations, Port of Castries provides 4 reachstackers and 23 forklifts. Vessels are serviced by SLASPA's Liebherr 104 tons mobile harbour crane (MHC), which was procured in 2000 and refurbished in 2015. The MHC is only used on cargo berth 4, as other berths do not offer sufficient carrying capacity. However, SLASPA aspires to strengthen berth 5 and procure a second MHC. Additionally, SLASPA owns and operates

[10] Service ports are small ports serving specific islands with limited infrastructure and limited connection to larger ports.
[11] A ferry service between Saint Lucia, Martinique, Dominica and Guadeloupe.

two tugboats: (a) Tug Chale - 100 Ft 1500 horsepower; and (b) Doggersbank - 56 Ft 1350 horsepower, which are used to pilot the ships into harbour. Pilotage is compulsory for vessels over 100 GRT[12]. While awaiting a pilot, vessels may anchor one mile NW of Vigie Point in a depth of 22m with good holding in rock and sand. There is however no shelter for the vessels. Other anchorage is also available 2.5 cables NW of Vigie point in depths of less than 20m with good holding ground in coral and sand. Shelter is provided from the east but there is little swinging room.

Table 4-4 Port Castries: Terminal Characteristics

Berthing	*General Cargo*	Berth #1: 60.96 Long; Depth 5.48m – 6.09m Berth#2 & 3: 219.45m long (continuous); Depth 8.23m Berth#4: 151.79m long; Depth 9.75m Berth#5: 158.49m long; Depth 9.75m with a RoRo Ramp 14.63m wide Berth#6: 136.55m; Depth 9.14m
	Cruise Berths (Pointe Seraphine)	P/S #1: 121.92m long; Depth 10.97m P/S #2: 91.44m long; Depth 10.36m Berth #1: for ships of length 259.08m – 304.8m Berth #2: for ships of length 228.6m – 259.08m
Warehousing		Covered Storage Space: 30,480 m2 Container Yard Area: 1.6 ha
Yard Storage		TEU Ground Slots: 400 Reefer Slots: 27
Ground Operations: Equipment		Reachstackers: 4 Forklifts: 23 MHC (104 Tons): 1
Portable Water		Alongside all Berths. There is an 8" main at Pointe Seraphine and the applicable rates are EC$40.00 / 1000 gallons
Shipping Lines		Tropical, Sea Freight, CMA CGM, King Ocean and Geest

The development of cargo operations not only included equipment but also led to the upgrade of the berths in order to accommodate larger container ships while making navigational improvements for the smooth entry and exit of ships. In tandem with that development, came the upgrade of Unitrack[13] and the computerization of operating systems. The Container Park and Cargo Shed have been upgraded to feature a redesigned terminal layout, a reconfigured Cargo Shed and a new warehouse management system which allows for quicker retrieval of stored cargo. The port Container Park has a capacity of 400 TEU ground slots while there Sheds available have a total floor space in excess of 30,480 m^2. The Saint Lucia Port Authority is the custodian of all cargoes imported into the country by sea.

[12] Gross register tonnage (GRT) is a ship's total internal volume expressed in "register tons", each of which is equal to 100 cubic feet (2.83 m^3). Gross register tonnage uses the total permanently enclosed capacity of the vessel as its basis for volume.
[13] Unitrack enables the smooth layout and tracking of all cargo entering and exiting the Port.

Figure 4-12 Location of Berths in Port Castries (Source: SLASPA)

Saint Lucia is a major destination for cruise ships, with up to 3,668 cruise calls between 2004 and 2014. Much thought and effort has gone into ensuring that the Port has a comprehensive range of facilities to cater to the needs of cruise line passengers. This segment of Saint Lucia's tourism sector is highly dependent on marine transport, as cruise ships require investment in port infrastructure to accommodate the increased size and number of vessels. In 2015, the port received 388 cruise calls and 677,394 passengers. Container traffic was 32,085 TEUs and total cargo handled (containerized and break-bulk) was 480,770 tonnes (Figure 4-13). Table 4-5 summarises the handling charges and fees applied to Port of Castries.

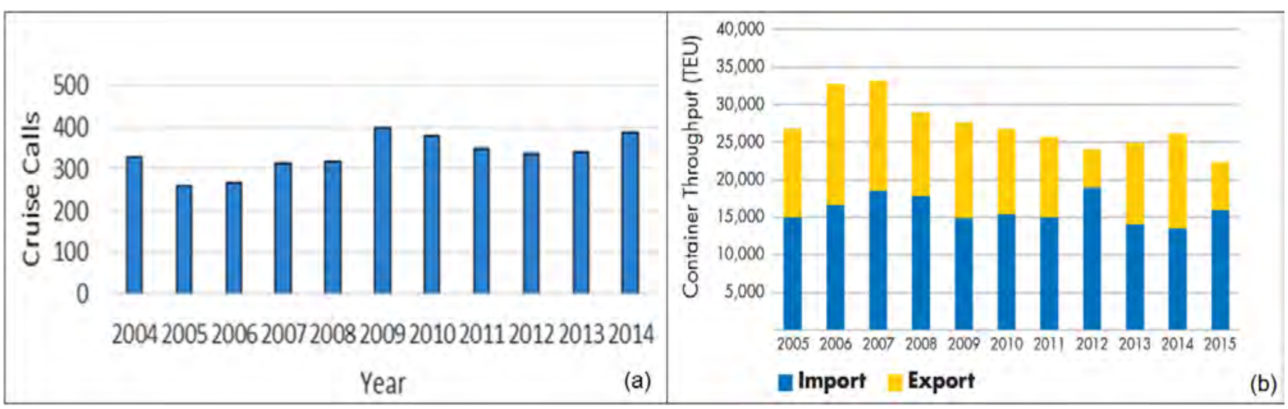


Figure 4-13 (a): Cruise Calls at Port Castries- 2004 to 2014 (Source: SLASPA Statistical Digest); (b): Container Throughput at Port Castries (2004-2011) (Source: CDB, 2016)

Information on the port contribution to the economy has not been available. However, an inference can be drawn from the passenger and cargo traffic figures and the handling charges/fees applied (Table 4-5).

Table 4-5 Handling charges and fees for Port of Castries (Source: Cubas et al, 2015)

Handling Charges by Type of Freight (2012)						**Port Fees (2012)**			
20' Dry Container	**40' Dry Container**	**Transshipment Container**	**General Cargo**	**Dry Bulk**	**Cruise**	**Cost per Vessel**		**Excess Storage Charges ($/tonne/day)**	
($/container)		*($/TEU)*	*($/tonne)*		*($/passenger)*	Cargo	Cruise	Dry Bulk	General Cargo
480	960	6	4	7	7	89	111	1	1

In a study by the Caribbean Development Bank (CDB, 2016) the efficiency of 12 Caribbean ports was investigated. The port efficiency score was derived from the assessment of seven weighted factors including: berth productivity, labour productivity (measured by TEU per employee), quality of infrastructure, nautical accessibility (measured by maximum vessel draught), type of equipment used for stevedoring operations, type of it systems being used in port operations and level of autonomy of port operator. Among the OECS countries, the most efficient port is Castries which scores high on the quality of infrastructure, availability of equipment and the implementation of IT systems.

4.6 Port Vieux Fort

Vieux Fort Seaport (VFSP) is located less than 5km away from the Hewanorra International Airport and the Saint Lucia Freezone. There is only one point of entry into the port; the road that connects the town of Vieux Fort with the terminal. The road is narrow and not ideal for containerised traffic. Vieux Fort in St. Lucia is the only port in the OECS dedicated to transshipment (85 % of throughput) and one of the few designed to be a container terminal. It is also the only one whose operations are set up to facilitate private participation (through a subsidiary of the St. Lucia Air and Sea Ports Authority that has yet to be privatized) (Cubas et al, 2015). Rarely, it gets the overflow of cruise ships calling at Castries.

Figure 4-14 Port Vieux Fort (Source: http://www.slmtl.com/

Berthing in Vieux Fort comprises:

a. a finger pier 163 m long and 15 m wide and can accommodate vessels on either side. The height of the quay from the water level is 2.3 m at low tide and 2 m at high tide. The water depth alongside is 11 m;

b. a 210 m long lift on/lift off container berth (exclusive of a Roll-on/roll-off ramp). The height of the quay from the water level is 2.5 m at low tide and 2 m at high tide. The depth of the water alongside is 11 m.

The Port, with a terminal area of 50,000 m^2, has 1 mobile harbour heavy lift crane with automatic spreader and a capacity of 80 tons. There are 2 -3 high stacking straddle carriers and 1 terminal tractor. In addition there are two storage sheds, six forklift trucks, stradlecarriers, trailer beds and one tugmaster. Storage capacity at Port Vieux Fort is 633 TEU bottom spaces or 1,899 TEU spaces stacking 3 high. There are forty (40) reefer points and twenty (20) forty-foot interchange slots.

The pier in Port Vieux Fort is more than 60 years old and needs replacing. There has been talk of relocating the pier further to the south, which would then bring into play unused land lying to the south of the current facility. It is envisaged that this currently deserted area could be configured for extra container storage, an important consideration as at peak times the port gets close to choking point. There is also a scheme for a fuel depot and SLASPA has already received an expression of interest. Moreover, an unused for 15 years old flour mill on the site is now being renovated and recommissioned. Moving the finger pier would also enable creation of a longer quay and a berth capable of handling Panamax sized vessels. Increased berthing capacity could be vital to the port's development in the years ahead. If long-term plans to make Vieux Fort a homeport for cruise lines materialise, then SLASPA will need to ensure that passenger vessels do not have to compete with cargo for space.

Despite a notable reduction in vessel calls, OECS ports have finally recovered the level of container volume traffic that they had before the global economic crisis. During 2008–2012, aggregate container volumes increased by 8 %. Container traffic is a good indication of trade intensity and, as such, is a sign of recovery. Shipping liners are using higher load factors on their vessels. Nowadays, nearly 95 % of finished consumer goods are transported in containers. OECS members are net importers; imports include nearly every consumable, including most foodstuffs, and supplies for the resort and hotel industries. The main ports driving this increase were Woodbridge Bay in Dominica and Vieux Fort in St. Lucia. Both Castries and Vieux Fort in St. Lucia received more than half of total OECS container traffic, with the transshipment Port of Vieux Fort alone handling 46,000 TEU per year, equivalent to 30 % of the total OECS traffic (Cubas et al, 2015).

The highest annual volume of container traffic was in 2012 (45,668 TEUs) (Figure 4-15). Since then, the figure declined; in 2014 cargo traffic was 14,456 TEUs. The significant drop in Vieux Fort's traffic in 2013 was mainly due to the breakdown of the port's only crane and its spreader. However, the decline in cargo vessel traffic was evident in most OECS ports and is most likely due to shipping liners using higher load factors on their vessels. It is also an indication that the ports are slowly moving from break-bulk to containerized practices (Cubas et al, 2015).

For the period 2008-2012, general cargo in Vieux Fort, mainly imports, represented only 20 % of the business; out of ten shipments, only two were bulk (and this includes dry and liquid bulk). As shown in Figure 4-15, the high volume of dry-bulk traffic in 2007 was linked to the construction of a resort, but the project failed due to financial reasons.

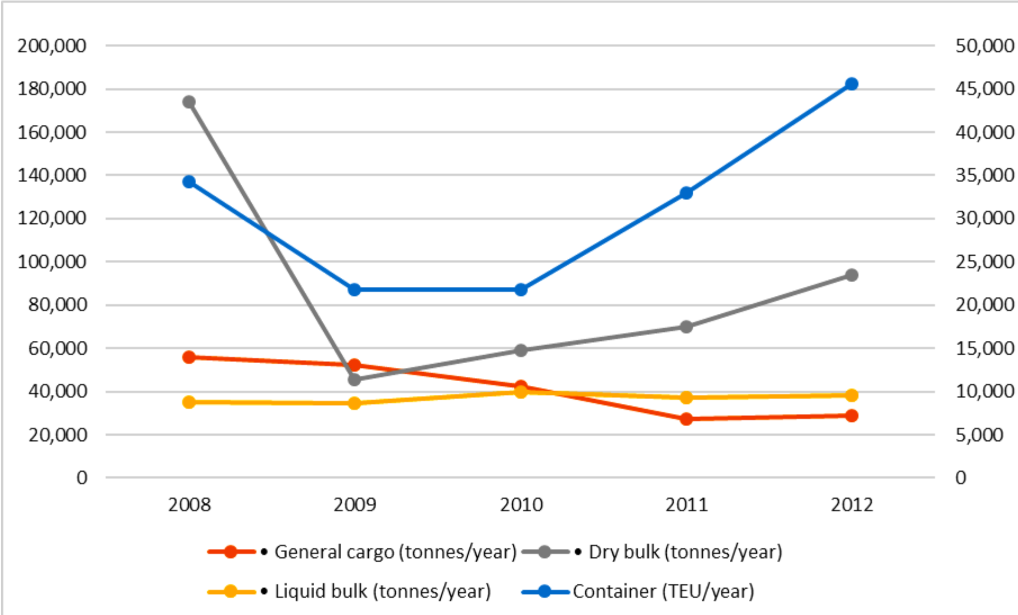


Figure 4-15 Traffic at Port Vieux Fort (Graphed from data available in: Cubas et al, 2015)

Fees collected in Vieux Fort are presented in Table 4-6 below.

Table 4-6 Handling charges and fees applied at Vieux Fort (Source: Cubas et al., 2015)

Handling Charges by Type of Freight (2012)					**Port Fees (2012)**		
20' Dry Container	40' Dry Container	Transshipment Container	General Cargo	Dry Bulk	Cost per Vessel	Excess Storage Charges ($/tonne/day)	
($/container)		*($/TEU)*	*($/tonne)*		Cargo	Dry Bulk	General Cargo
480	960	30	4	4	89	1	1

4.7 Criticality of major assets overview

The contribution of transportation to Saint Lucia's economy was estimated as EC$ 400,920,000 in 2015, a figure that highlights the importance of ports/airports -and their hinterland connections- for socio-economic development. As described, the four major transportation assets in Saint Lucia are the two airports (Hewanorra and George F.L. Charles) and the two seaports (Castries and Port Vieux Fort); their criticality can be assessed by their throughput:

- In 2015, 30,648 Twenty Foot Equivalent Units (TEUs) were transported via the 2 major ports and 3,022 tonnes of cargo via the 2 airports; this freight was carried to and from these major gateways by road.

- Both Castries and Vieux Fort in St. Lucia received more than half of total OECS container traffic, with the transshipment Port of Vieux Fort alone handling 30 % of the total OECS traffic.
- Visitor arrivals (stayovers and cruise passengers) totalled 1,073,017 tourists in 2015, the highest number of arrivals over the last 10 years, while tourist expenditure was estimated at EC$ 200 million.
- Saint Lucia is a major destination for cruise ships, with up to 677,394 arrivals in 2015 and has direct connectivity to major US gateways and the UK and is visited by major cruise liners such as Celebrity, Carnival, Norwegian, and Royal Caribbean.
- The HIA facilitates approximately 80 % of all air traffic into the island, serving as the gateway to the international long-haul airlines that connect the island to the United States, Canada, Europe and the rest of the world. George F.L. Charles airport handles passengers mainly on regional flights to/from Caribbean destinations, including St Vincent, Martinique, Grenada, Trinidad and Barbados. Both airports handled 840,696 passengers in 2016.

Chapter 5: ASSET VULNERABILITY/SENSITIVITY TO CLIMATE VARIABILITY & CHANGE

The objectives of this Chapter are to (a) present a brief summary of historical hydro-meteorological impacts and disruptions and (b) assess direct and indirect Climate Variability and Change (CV & C) impacts on the 4 most critical coastal transport infrastructure assets (i.e. the 2 seaports and 2 airports) of St. Lucia.

Regarding the former objective, information available from previous assessments of the impacts of extreme events during the recent decades is summarized. Concerning the latter, the approach adopted to assess the direct impacts of CV & C on the coastal transport infrastructure assets consists of the following: 1) Assessment of direct impacts on coastal transport asset operations, using the '*thresholds*' method, discussed/adopted during and after the Technical Expert Group meeting (June 2016). 2) Assessment of the direct impacts on coastal infrastructure through modelling of the flood/inundation due to extreme sea levels (ESLs) under the present and future climate. In this task, extreme sea levels (ESLs) for different periods in the 21st century are estimated using projections for: regional Mean Sea Level Rise; and waves and storm surges, modelled using atmospheric conditions forcing (ERA-INTERIM) for the area; and the available coastal DEM. In addition, in order to assess the impacts of a Caribbean hurricane, cyclone effects have been included on the previous projections. Flood/inundation assessment is being carried out through dynamic simulations using the open-access model LISFLOOD-ACC (LFP) (Neal et al., 2011)[14], and a DEM[15] of about 5 m resolution. Impacts under the AOSIS advocated 1.5 °C temperature cap are assessed an aspirational target in the 2015 Paris Agreement (Art. 2(a); Benjamin and Thomas 2016); as timelines are important in the planning/design of adaptation measures, the 1.5 °C temperature increase cap was also translated into a date year. The date year that the temperature will increase by 1.5 °C above pre-industrial levels has been projected using the complete ensemble of CMIP5 General Circulation Models (Taylor et al., 2012) and following an approach similar to Alfieri et al. (2017). The analysis projected that the 1.5 °C temperature increase cap would regrettably be reached by 2033 under the IPCC RCP4.5 and by 2028 under the RCP8.5 scenario. Therefore, marine inundation results for the 1.5 °C temperature increase cap are based on climatic factor projections for 2030 (see also Monioudi et al., under review).

In addition to the direct climate impacts on the major coastal transport infrastructure assets there will be also indirect impacts. Transport is a demand-driven industry. As international air passenger transport to St. Lucia is almost entirely depending on tourism, the CV & C impacts on tourism are also assessed. Since St. Lucia tourism has developed according to the 3S (Sea- Sand- Sun) tourism model and most of the tourist infrastructure assets are concentrated along the island beaches, CV & C impacts on St. Lucia's tourism (and thus the demand for air transport) are projected through a 'proxy', i.e. the decrease in the carrying capacity of St. Lucia beaches due to beach erosion/retreat/flooding under different climatic forcing. In addition, other indirect impacts on tourism and transport are related to the connectivity of the major gates of international tourism to the major destinations of the island, i.e. to the coastal areas/beaches

[14] http://www.bristol.ac.uk/geography/research/hydrology/models/lisflood/.
[15] http://www.charim-geonode.net/layers/geonode:dem.

showing extensive tourist infrastructure. This connectivity is under increased risk by the landslides at the connecting roads that have been recorded during extreme events (hurricanes).

5.1 Historical Impacts/Disruptions

5.1.1 Hewanorra Airport

Precipitation/Flooding

Disruptions at the Hewanorra International Airport (HIA) have resulted mainly from flooding and mud debris flows. These floods, in turn, have been the result of increased precipitation which caused the adjacent to the airport La Tourney River to break its banks. There have been no reports of damages caused by coastal flooding (i.e. from storm surge/waves), although the eastern end of the runway is separated from the Atlantic Ocean only by a single lane highway. Generally, there is a tendency for certain areas of the airport to be flooded by even moderate precipitation. This 'ponding' is the result of the slow buildup of water in depressions with clay soils and slow percolation rates. There are two water courses that flow under the runway. These were previously part of the La Tourney River which was re-trained to flow along the outskirts of the airport to drain into the Caribbean Sea, in an area referred to as the 'Mang'. One of the water courses under the runway flows into a pond that is outside of the airport perimeter fence to the south west. The water from this pond drains to the Caribbean to the north of Port Vieux Fort. Another water course under the runway drains, along a south-easterly direction, through a culvert into the Atlantic sea through the Point D' Sables Beach.

Historical weather events

The following historically significant weather events have had some impact on the operations of HIA. In some cases, these events have led to the shutdown of the facility during the duration of the event, with reopening occurring after the clean up/repairs had taken place (typically after 1 – 4 days).

1994 Tropical Storm Debby (September) made landfall on Saint Lucia with winds of 63 mph (Saint Lucia Meteorological Service, 1994). Heavy rains resulted in covering HIA with about 51 mm of silt. Unfortunately, no records are available to the damages/loss caused by the rain and mud.

2010 Hurricane Tomas. Following the passage of Hurricane Tomas, the runway of HIA had to be cleared of mud and run-off water; the airport opened 4 days later. Immediately after its reopening, and while the main roads were still blocked, LIAT, CariCom Airways and Virgin Atlantic operated a shuttle service between the HIA and GCIA. Table 5-1 shows the average and actual (following the storm) load factors for HIA which was significantly affected immediately following the event (30 October-10 November 2010), as far fewer passengers either arrived or left during that time.

2013 Christmas Eve Trough. On the 24^{th} of December 2013, severe weather caused the La Tourney River to swell and, around 7 pm, break its banks. The river water flooded the runway of HIA and rushed into Vieux Fort town (Figure 5-1). Low-lying areas in the Bacadere, the Mang and Bruceville flooded with 120 cm of muddy water. From the airport runway, the river water quickly flooded the low-lying area to the east of town, in the area of the Recreation Park. Just a few weeks before the Christmas Eve Trough, a backhoe had been used to clear an area (approximately 50 meters wide) along the road, apparently in order to open up visual access to the football field. The backhoe cut down some mature trees /bush and levelled what used to be a somewhat elevated sandy area with low dunes. The event caused temporary flooding of the terminal building and runway at the HIA. This forced the closure of the airport facility for 48 hours. The airport was reopened once the clean-up was completed, although additional rehabilitation works were needed to re-route the La Tourney River. A Virgin Atlantic A300 airbus had its landing gear damaged and undercarriage ripped apart when it landed at the airport (with close to 40 passengers) under the heavy rains of the event. The plane was on its final approach when La Tourney River burst its banks and flooded the runway and sections of the airport; the flood waters carried a baggage container and a refrigerator which damaged the aircraft. It is estimated that the cost to the aircraft was in the order of 400,000 USD, whereas the total damage costs sustained was about US$ 800,000 (Smith, 2014).

Table 5-1 Load Factors for Hewanorra Airport – arrivals and departures (Source: UNECLAC). Since aircraft fees are based on aircraft weight, substantial amounts were lost. The quantum of these lost landing fees is not available

	Land		**Depart**	
	Review Period	Average	Review Period	Average
Air Canada	43.8	79.25	67.52	84.35
American Airlines	78.19	72.5	28.06	72.86
British Airways	18.83	41.13	51.49	42.5
Delta	47.15	79.16	43.92	82.36
Virgin Atlantic	5.23	74.89	66.08	76.4
West Jet	33.19	74.29	53.4	79.92
Jet Blue	39.83	79.26	48.67	79.1
Condor	52.5	54.48	35	58.51
Us Airways	0	71.85	0	75.28
Total	**27.87**	**69.07**	**53.46**	**70.77**

Figure 5-1 Extent of flash Flooding at Hewanorra Airport on 24 December 2013 – Rainfall event of 1:5. (Source: GoSL and World Bank, 2014)

2016 Hurricane Matthew. Both airports were closed due to Hurricane Matthew. Although, 319.19 mm of rain was recorded during a 24-hour period (between 28 and 29 September) at Hewanorra, no damages were reported.

5.1.2 George F.L. Charles Airport

Precipitation/Flooding

The main drainage of the site runs underground to Ganters Bay, but is often overwhelmed by heavy precipitation and backs up. Site drainage has deteriorated further since the adjacent road was re-surfaced and the roadside drain blocked.

Historical weather events

2007 Hurricane Dean caused storm surge that washed sand onto the adjacent road and into the airport, creating a barrier near the existing terminal. Eroding sea defences that had been weakened and ineffective during past storm events compromised the west end of the runway (ICF GHK, 2012). The repair cost to the rock armouring at the end of the runway was estimated as EC$100,000 (UNECLAC, 2007). The maximum gust recorded at both the HIA and GCIA airports was 58 knots (67 mph) (Auguste, 2007). Nevertheless, the GCIA runway has never been closed as a result of storm surge/waves or land flooding prior to 2010 (King-Joseph, 2010).

Figure 5-2 Damage to Fence at George F.L. Charles Airport

2010 Hurricane Tomas. Following Hurricane Tomas (October 29th) the GCIA was closed. After 3 days the Airport was reopened for limited access and emergency operations. Immediately after the reopening and while the main roads were still blocked, LIAT, CariCom Airways and Virgin Atlantic operated a shuttle service between the south and the north of the island. In addition, two helicopters were used to ferry people around and for reconnaissance missions. Although there was no measurable damage at the airport, the losses to the facility included (UNECLAC, 2011c): (i) air shuttle passenger fees between the north and the south; (ii) loss of passenger taxes at both airports as a result of reduced numbers of arrivals and departures; and (iii) loss of aircraft landing fees at both airports Table 5-2 below shows the average and actual (following the storm) load factors for GCIA. It appears that the impacts were not as high for GCIA as they were for HIA.

As already presented in Chapter 3, these load factors have fees attached to them. A reduction in the load factors resulted in a decline in revenues earned by the airport. Losses for all ports was estimated at EC$ 999,417 (UNECLAC, 2011c).

Table 5-2 Load Factors for George F.L. Charles – Arrivals and Departures

	Land		Depart	
Airline	**Review Period**	**Average**	**Review Period**	**Average**
Air Caribes	18.69	41.98	45.48	45.95
American Eagle	25.32	58.9	65.73	67.51
LIAT	24.44	33.47	44.27	37.75
Winair	31.17	18.37	25.1	18.4
Total	**24.69**	**36.17**	**47.75**	**40.71**

2013 - Christmas Eve Trough. The excessive rainfall and storm surge from Vigie beach caused by Christmas Eve Trough resulted in flooding at the Airport. As a consequence, airport operations were suspended albeit for a few hours whilst clean-up operations ensued. There were no damages to the facility and the losses were only for clean-up of the airport. No record is available of the cost of damages and losses, if any, caused by the flooding.

2016 - Hurricane Matthew. Similarly, the airport was closed for a few hours after a storm warning following Hurricane Matthew (9.21 inches were recorded during the 12-hour period between 8.p.m., September 28, and 8 a.m., September 29). No significant damages were reported.

5.1.3 Port Castries

The principal port in Saint Lucia, Port Castries is a natural inland deep-water harbour, with a large berthing capacity and 4.8 km of water frontage. It is the island's primary supply centre and its only significant container facility. The vast majority of the goods and supplies available in Saint Lucia pass through this port.

Coastal Hazards

Port Castries is approximately 1.5 m above mean sea level. Changes in the landscape have increased the ESLs experienced in Ganters Bay within Castries Harbour. In addition, the southern tip at the entrance of Port Castries is at risk to global MSL rise (ICF GHK, 2012). The Castries docks have withstood past storm events and ESLs without sustained damage. A breakwater structure was built to reduce the impact of waves on the eastern harbour front and the major road next to the government buildings.

Large vessels return to open waters during storm events to prevent, in part, being damaged by floating debris that drain off the island into the harbour. Floating debris in the southwest end of the harbour can end up as deposits on the seabed of the harbour. Harbour dredging is required every four to five years to ensure there is enough depth for the safe passage/access of vessels (King-Joseph, 2010). The Dangerous Goods Shed, located some 180 m from the water's edge, is vulnerable to damage during extreme events.

Effects of ESLs in the Ganters Bay located within the Castries Harbour have significantly worsened according to SLASPA officials, since the mangroves were removed and replaced with a concrete wall, to the extent that small vessels moored there have been severely damaged during storm events; 3 small vessels are reported sunk during one event. Businesses adjacent to the Ganters Bay shoreline (in particular the Coal Pot restaurant which is located at sea level) are highly vulnerable during storm events.

Historical weather events

During extreme events, waves break against the eastern harbour front and onto the primary road adjacent to the Government buildings. A breakwater was constructed to mitigate these impacts.

2007 - Hurricane Dean. The constructed breakwater sustained damage during the passage of Hurricane Dean, when boulders from the breakwater structure were shifted by wave action onto the roadway. During Hurricane Dean, the south side of the harbour was eroded by wave action and the road in the Faux a Chaux area was undermined. The SLASPA carried out an assessment of damages (UNECLAC, 2007) following the passage of Hurricane Dean[16]. Based on this assessment, it was determined that damage occurred to the Port of Castries as a result of damaged seawall and/or revetment areas, and damage to sheds. The cost of damage [17] is itemized as follows:

Shed No.7: (i) Damage to revetment; damage to pavement adjacent to the shed; and replacement of security fencing totalling EC$205,400 (ii) Clean-up was estimated at EC$7,500.

Ferry Terminal/Berth No. 6: Reparation works related to the retaining structure and floor; demolition and reconstruction of reinforced concrete floor and walls of building; and reconstruction of revetment; all of which totalled EC$391,650. Replacement of the roofing structure and damaged guttering at the Ferry Terminal is costing EC$275,825. Reinstatement of fencing between the Ferry Terminal and bridge is costing EC$4,000.

CCTV equipment: for equipment and works, the estimate of damages was EC$38,000.

The total estimate for damages at Port Castries was approximately EC$1,000,000.

Some damage was observed to the rock armour at Pointe Seraphine, in addition to there being sand on the pier, necessitating some clean-up activities. In addition to the damage at Pointe Seraphine, there was also some damage to an area west of the Port and at the Ganters Bay area west of Pointe Seraphine. An estimate made of the cost of repair works for these areas was EC$150,000 (King-Joseph, 2010).

2010 Hurricane Tomas. Although Hurricane Tomas produced waves approximating the 1 in 15 year event, there was no measurable damage at Port Castries.

2013 Christmas Eve Trough. There was minimal damage as a result of the Christmas Eve Trough.

[16] Rainfall records collected from the gauge at the George Charles Airport reveal that on 16 August 2007, a total of 92.1 mm of rain fell. This was as a direct result of the passage of Hurricane Dean, and should be compared with the minimum and maximum limits previously recorded at this station, of 24.7mm and 31.8mm, respectively. Notwithstanding the amount of rainfall that fell, Hurricane Dean was not accompanied by an excessively large amount of rainfall.

[17] *Ibid.*

5.1.4 Port Vieux Fort

Port Vieux Fort is approximately 1.5 m above MSL. The port is more exposed than Port Castries, but the docks were built to withstand storm surges/waves, and have sustained no damage during storm surge events to date. The port was last upgraded in 1999/2000 and has never had to shut down due to storm damage (King-Joseph, 2010). There are no records of historical disruptions, even prior to the 1999/2000 upgrades.

5.1.5 Road network

Natural Hazards

The impacts identified in the transport sector largely relate to damage and loss incurred to the main roads and bridges as well as impacts resulting from compromised riverbanks. During major storm events the road network in Saint Lucia suffered damage causing them to be impassable, mainly due to landslides. This hazard in Saint Lucia is, however, correlated with a number of factors related to slope angle, slope curvature, slope aspect, bedrock type or geology, and soil type (Rogers, 1997). The most affected areas in Saint Lucia tend to be steep-sloped areas with soils or geological characteristics that are particularly susceptible to landslides. Some examples of natural hazards that have occurred, affecting the road network, are:

- The 1938 Ravine Poisson and Ravine Ecivisse landslides, which occurred an hour apart in these neighbouring ravines, creating a "sea of mud" that killed 6 and injured 32 people (Quinn, 2012). For eighteen days, landslides had prevented passage along this road connecting the capital of Castries with the south-eastern part of the island (UWI, 2005).
- The Barre de L'Isle landslide caused by Hurricane Allen in 1980 severely damaged the east coast road connecting Castries to the Vieux Fort. Transportation between the north and south of the island along the east coast was severely disrupted, the tourism industry significantly impacted and repairs to the road costed nearly half a million dollars (UWI, 2005).

Figure 5-3 Bare D L'Isle Ridge

- Tropical Storm Debbie in 1994, with wind gusts reaching 63 mph produced heavy rainfall and thunderstorms over a six-hour period, which caused flooding along rivers and in low lying areas. Several villages were isolated after roadways were washed out or covered by landslides and 10 bridges were destroyed or severely damaged. Damage totalled about $103 million (1994 USD).
- Hurricane Lenny with wind speeds of 155 mph reached a Category IV level and was the most powerful late November storm on record. It affected the Lesser Antilles from November 15 – 19, 1999. The west coast of Saint Lucia was affected by the wave action of Lenny. The hardest hit areas were Soufriere, Gros Islet and the villages of Anse La Raye and Choiseul. Beach erosion was significant on the northwest coast

of the island with roads and pedestrian walkways that were close to the beaches washed away. Portions of Soufriere waterfront were washed away as was the seawall while the adjacent road was destroyed. In addition, the rising floodwaters from the Soufriere River that runs through the town added to its inundation. The hospital was cut off from the rest of the town (USAID/J-CAR, 2000).

- A heavy precipitation event occurred in October, 2006. During this event, flooding in Cul de Sac cut the North off from the rest of the island (SNC, 2011). Air travel was the means of transport between North and the rest of the island.
- Tropical Storm Lili developed on September 21, 2002 about 900 miles east of the Windward Islands. Damage was estimated to be around $7.6 million.
- In 2007 Hurricane Dean, a Category 2 storm with winds of 104 mph, disabled bridges and triggered landslides; the cost to clean up all of the roads and drains was $900,000.
- On 31 October 2010, Hurricane Tomas passed very near to Saint Lucia, just 46.7 km south of the island, as an intensifying cyclone; producing 92 mph (148 km/h) winds (UNECLAC, 2011c). Later in the day, it became increasingly better organized, and reports from the Hurricane Hunters indicated that the winds increased to 98 mph, a Category 2 hurricane. The CIMH classified this event as a 1:180-year event, in terms of rainfall (UNECLAC, 2011c). Road and bridge infrastructure were severely impacted from flooding and from landslides. According to the ministry of works of Saint Lucia estimation, the transportation subsector has incurred a total impact of EC$141.66 million (around 52.47 million US dollar- 2011). The confirmed number of deaths from this event was seven, most of which were landslide related.

Figure 5-4 Left: Damage to the Choc Bridge caused by Hurricane Tomas – the bridge connects the north of the island to Castries (Source: Kimberly Mathurin - https://internationalmedicalcorps.org); Right: Landslide in Barre D'Isle showing compromised north-south (Source: APESL, 2010)

- The intensity and volume of rainfall over the course of only a few hours made the December 24–25 Christmas Eve Trough of 2013 especially significant. The staff at the Meteorological Office evaluated the three-hour rainfall intensity to be possibly in excess of a 1-in-100 year event (GoSL and World Bank, 2014). The Christmas Eve Trough severely damaged the main highway, which connects communities in Saint Lucia's south and west to one another and to the north. Approximately 12 sections of road required extensive reconstruction. Nevertheless, within a few days of the flood event, the Saint Lucia government had restored primary network access by removing debris and constructing temporary emergency bypasses and bridge infrastructure in heavily damaged areas. Principal rivers and tributaries in the west and south of the island were quickly overwhelmed during the storm, leading to flash floods in most communities along the Western Highway (e.g., Anse La Raye, Canaries) as well as in Vieux Fort. Across Saint Lucia, public and private infrastructure and facilities were severely damaged or destroyed; roadways, bridges, energy distribution, and drinking water networks were particularly affected. A total of EC$1.983 million was spent in the immediate aftermath in clearing of landslides and creating temporary by-passes to provide access to road users. An additional EC$1.154 million was required for further clearing and minor repairs to the road and drainage infrastructure (Ministry of Infrastructure Port Services and Transport, 2014). Estimated damage to bridges and roadways caused by the Christmas Eve Trough was US$68.8 million. This figure, however, did not include the rerouting of the La Tourney River, which caused the flooding at the airport, nor any estimates for the potential land acquisition required in the implementation of necessary rehabilitation works. Sedimentation at John Compton Dam as well as damages to pipe networks left the entire island without piped water—for up to 10 ten days in some communities. In many locations, flooding was exacerbated by poor local drainage infrastructure (e.g., Canaries, Castries, Vieux Fort), with one section of the East Coast Highway collapsing due to insufficient drainage capacity. Accumulated sediment deposits restricted the flow at river mouths, worsening flooding in low-lying communities (GoSL and World Bank, 2014).

Mott McDonald (2013) undertook a mapping of landslide density for the St. Lucia roads. The results of the study are provided in the left map of Figure 5-6 below; on the right are the maps showing the landslides that appeared along the primary road network during 2010 Hurricane Tomas and the 2013 Christmas Trough. The maps show that within a period of about 30 years the landslide density along the major highway around the island had increased.

Figure 5-5 The Marc Bexon Road along the north-south highway after the Christmas Trough, 2013. Source: https://www.stlucianewsonline.com/

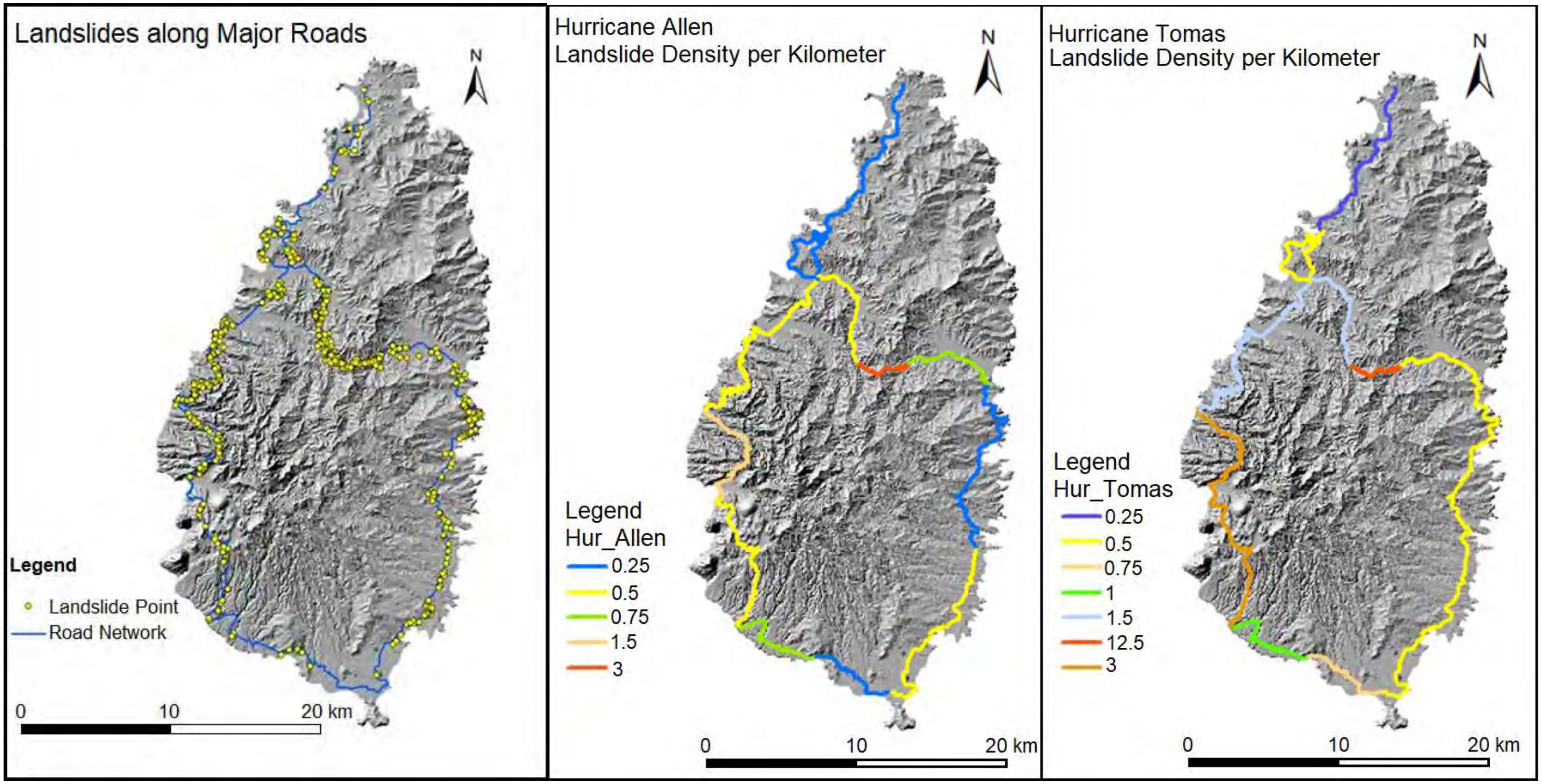


Figure 5-6 Landslide density per Kilometre of Road – Post hurricane Allen (left) and Post Hurricane Tomas (Right)

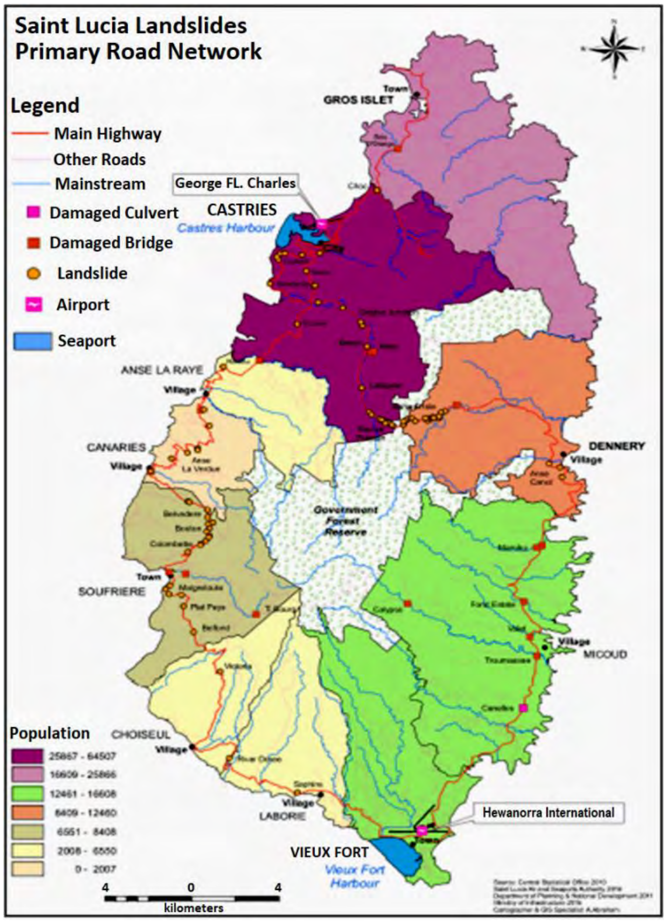


Figure 5-7 Landslides along Saint Lucia's Primary Network

Figure 5-7 above shows the damages caused to roads, bridges and culvert between 2010 (hurricane Tomas) and 2013 (Christmas Eve Trough). The dislocation of transportation and the economic disruption was inevitable.

5.2 Future disruptions

Specific operational thresholds associated with each facility were identified in order to determine the climatic conditions under which the facility would be damaged or being unable to operate. The analysis was focused on climate variables linked to CV & C, such as sea level, precipitation/flooding, temperature, and tropical storms. The methodology of the operational thresholds developed as part of the project and described in the UNCTAD (2017b) report was used. The objective of the approach has been to project threshold exceedance in the future and, thus, estimate the potential impacts of such events.

Identifying the operational thresholds

Employee ability to work safely outdoors and heat index

Employee ability to work safely outdoors depends on the Heat Index (a function of temperature and relative humidity), see http://www.nws.noaa.gov/om/heat/heat_index.shtml. For a relative humidity of

70 %, Heat Index would exceed 39.4 °C (103°F) at 32.2 °C (90 °F) and would exceed 46 °C (115 °F) at 34 °C (94 °F).

Table 5-3 Estimation of Heat Index threshold

	Combinations of temperature and relative humidity						
Humidity / Heat index thresholds	70%	75%	80%	85%	90%	95%	100%
Heat Index over 39.4 °C (103 °F) is "high" risk	31.6 °C (89.1 °F)	31 °C (87.8 °F)	30.6 °C (87.1 °F)	30.1 °C (86.2 °F)	29.7 °C (85.5 °F)	29.2 °C (84.6 °F)	28.8 °C (83.8 °F)
Heat Index over 46 °C (115 °F) is "very high" risk	33.8 °C (92.8 °F)	33.1 °C (91.6 °F)	32.5 °C (90.5 °F)	31.9 °C (89.4 °F)	31.4 °C (88.5 °F)	30.9 °C (87.6 °F)	30.4 °C (86.7 °F)

The days of future disruptions were estimated for all combinations of temperature and humidity. It was found that most disruptions are likely to be associated with relative humidity of 80 %.

Aircraft Runway Length Requirements and Temperature

The types of aircrafts that fly into HIA include, inter alia, Airbuses (A300's) Boeings (722 – 738), DC10, DHC 6 -8. The days that Boeing aircrafts could not take off from HIA were estimated. The Table 5-4 below shows takeoff runway length requirements for 4 models of Boeing 737 aircraft under multiple temperature conditions. Takeoff length requirements vary by aircraft type, and are available from aircraft manufacturers. Hewanorra International Airport (HIA) has a runway length of 2,744 m (9,003 ft.) (DAFIF, 2012). The temperature that Boeing aircrafts will require a runway longer than the existing runway of HIA was estimated and used as a threshold.

Table 5-4 Takeoff length requirements by aircraft type and temperature

	Maximum daily temperature				
	STD* 15 °C (59 °F)	STD + 15 °C 30 °C (86 °F)	STD + 22.2 °C 37.2 °C (99 °F)	STD + 25 °C 40 °C (104 °F)	**Threshold temperature for 2,744 runway length of HIA**
Boeing 737-600	2,134 m (7,000 ft)	2,316 m (7,600 ft)	**3,048 m (10,000 ft)**	n/a	**34.2 °C**
Boeing 737-800/-800W/BBJ2	2,377 m (7,800 ft)	2,469 m (8,100 ft)	n/a	**3,078 m (10,100 ft)**	**34.5 °C**
Boeing 737-500	2,469 m (8,100 ft)	2,652 m (8,700 ft)	n/a	n/a	**31.2 °C**
Boeing 737-400	2,530 m (8,300 ft)	2,682 m (8,800 ft)	n/a	n/a	**31 °C**

Source: Boeing, 2013 (http://www.boeing.com/assets/pdf/commercial/airports/acaps/737.pdf). All values assume the following conditions: maximum aircraft takeoff weight, sea level, dry runway, zero wind, zero runway gradient, air conditioning off, and optimum flap setting. *STD = Standard Day.

Energy Cost and Temperature

Extreme heat can raise energy costs for cooling. According to generic standard 1°C warming will result to 5 % increase in energy costs (in one illustrative terminal). Mean temperature for the period 1986-2005 was estimated to be 26.8 °C, so if temperature exceeds 27.8°C, 29.8°C and 32.8 °C the energy cost will raise by 5 %, 15 % and 30 % respectively.

Other Generic Thresholds

Generic standards for precipitation and wind speed thresholds (shown on Table 5-5), were used, since there was no information available of specific thresholds for the port and airport facilities of Saint Lucia.

Climate data sources

There are two overall categories of climate change information: (1) pre-existing synthesis reports and (2) raw climate model data (for temperature and precipitation projections). Since the specific variables of interest (e.g., number of days above a specific threshold) have not yet been analysed in another study, raw climate data were used. The Caribbean Community Climate Change Centre (CCCCC) database was used as a source, since it provides daily-scale climate data. The CCCCC website is a portal for climate change information in the Caribbean, and includes a portal to view and download climate projections. Available at: http://clearinghouse.caribbeanclimate.bz/#. Daily-scale climate data for the period 1970 - 2099 from the Regional Climate Model (PRECIS) were obtained. The available projections were based on the A1B scenario which is compatible with the RCP 6.0.

A quality control of the data took place though the comparison of monthly-scale climate data from the Regional Climate Model (PRECIS) on the CCCCC database with monthly observed data from Met Office. It appears that: (a) Temperature discrepancies range from 0 to 4.3 °C (with an average of 1.5 °C); Wind speed discrepancies range from 0 to 3.8 m/s with an average of 1 m/s (unusual large values observed for December 2035); Precipitation discrepancies range from 0 to 18.3 mm/day, with an average of 4.8 mm/day (unusual large values observed for December 2035).

Results of the operational thresholds method

The application of the operational thresholds method showed that there will be future disruptions in both airports and sea ports and in most cases the disruptions seem to increase over the years. Nowadays the airport employees that work outdoors are exposed in “high” risk about 2 days/year. For the period 2020 -2039 they will be in “high” risk about 4 days/year and in “very high” risk 1 day/year. The days that the employees will not be able to work safely outdoors will significantly increase by the years 2080-2099 since it is shown that about 54 and about 12 days/year they will be at “high” and “very high” risk respectively. The analysis showed that some Boeing aircrafts will not be able to take off from HIA without reducing the loads during the extreme heat days. Particularly the Boeing 737-500 and 737-400 aircrafts will not be able to take off ~12, ~35 and ~68 days/year during the periods 2040- 2059, 2060 – 2079 and 2080 – 2099 respectively. It was found that by 2030, Boeing 737-400 aircrafts will have to decrease their take-off load for 2 days at HIA, assuming no targeted aircraft design changes. The projected increase in temperature appears to increase the energy costs of the seaports by 5 %, 15 % and 30 % if the temperature exceeds 27.8 °C, 29.8 °C and 32.8 °C respectively. For the period 2080-2099 during ~352, 179 and ~15 days/year the energy costs will be higher by 5 %, 15 % and 30 % respectively. By the year 2030 a 1 °C temperature rise (from the baseline period 1986-2005) will increase energy requirements by 5 % for 138 days. The analysis showed that future disruptions due to intense (e.g., > 20 mm/day) and very heavy rainfall (e.g. >50 mm/day) will not differ from those nowadays. Also the wind does not seem to affect the operation of the airports and seaports (see also Monioudi et al., under review). It should be noted here that the modelled climate data from the CCCCC database does not include extreme events such hurricanes, so the results of the analysis with regard to the wind speed and precipitation effects can be considered underestimations.

Table 5-5 Days of disruptions for the airports and sea ports in Saint Lucia

Climate Stressor	Sensitivity	Threshold	Disruptions (average days/year)						
			1970-1999	2000-2019	2030	2020 -2039	2040- 2059	2060 - 2079	2080 - 2099
Airports									
Extreme Heat	Aircraft maximum take-off operational temperature	47.7 °C (118 °F)	0	0	0	0	0	0	0
	Employee ability to work safely outdoors	Heat Index (NOAA) over 39.4 °C (103 °F), resulting from 30.6 °C (87.1 °F) and relative humidity 80 % presents “high” risk	0.6 (18 days)	2.05 (41 days)	2	3.95 (79 days)	13.2 (264 days)	31.4 (628 days)	53.7 (1073 days)
		Heat Index (NOAA) over 46 °C (115 °F), resulting from 32.5 °C (90.5 °F) and relative humidity 80 % presents “very high” risk	0	0	0	0.06 (1 day)	1.05 (21 days)	4.15 (83 days)	11.8 (236 days)
	Aircraft take-off length requirements	Boeing 737-600 aircraft would not be able to take off from HIA if the temperature exceeds 34.2 °C without reducing aircraft loads	0	0	0	0	0	0.25 (5 days)	2.2 (44 days)
		Boeing 737-800/-800W/BBJ2 aircraft would not be able to take off from HIA if the temperature exceeds 34.5 °C without reducing aircraft loads	0	0	0	0	0	0.05 (1 days)	1.2 (24 days)
		Boeing 737-500 aircraft would not be able to take off from HIA if the temperature exceeds 31.2 °C without reducing aircraft loads	0.17 (5 days)	1.1 (22 days)	0	2.45 (49 days)	12.1 (242 days)	34.4 (688 days)	67.5 (1350 days)
		Boeing 737-400 aircraft would not be able to take off from HIA if the temperature exceeds 31 °C without reducing aircraft loads	0.33 (10 days)	1.7 (34 days)	2	2.65 (53 days)	12.25 (245 days)	35 (700 days)	67.9 (1357 days)
Wind Speeds	Inability of aircraft to land or take off	Commercial airports: sustained winds of 20 m/s	0	0	0	0	0	0	0
		General Aviation airports: 11.2 m/s	0.1 (3 days)	0.2 (4 days)	0	0.05 (1 days)	0.1 (2 days)	0	0.05 (1 days)
Ports									
Extreme Heat	Energy costs	1 °C warming = 5 % increase in energy costs if temperature exceeds 27.8 °C (mean temperature for the period 1986-2005: 26.8 °C)	N/A	N/A	138	118.9 (2378 days)	221 (4419 days)	302.7 (6054 days)	351.5 (7029 days)
		3 °C warming = 15 % increase in energy costs if temperature exceeds 29.8°C (mean temperature for the period 1986-2005: 26.8 °C)	N/A	N/A	18	17.1 (341 days)	47.6 (951 days)	101.2 (2024 days)	179.1 (3581 days)
		6 °C warming = 30 % increase in energy costs if temperature exceeds 32.8 °C (mean temperature for the period 1986-2005: 26.8 °C)	N/A	N/A	0	0.1 (2 days)	1 (20 days)	4.7 (93 days)	15.4 (308 days)
Precipitation	Low visibility inhibits crane operation	Intense rainfall (e.g., > 20 mm/day)	45.9 (1377 days)	43.5 (870 days)	51	46.8 (935 days)	45.5 (910 days)	45.1 (902 days)	46.7 (934 days)
		Very heavy rainfall (e.g. >50 mm/day)	0.47 (14 days)	0.9 (18 days)	1	0.45 (9 days)	0.8 (16 days)	0.5 (10 days)	0.8 (16 days)
Wind Speed	Ability to berth ships (due to waves)	Winds ≥18 m/s (40.3 mph, 35 knots) force operational shutdown	0	0	0	0	0	0	0
		With winds of 12.8-18 m/s (28.8-40.3 mph, 25-35 knots), discretion is applied	0	0	0	0	0.05 (1 days)	0	0

5.3 Vulnerability to coastal flooding

Coastal flooding related to marine extreme events has severe socioeconomic impacts, and is projected to increase under the changing climate (IPCC, 2014). The coastline hosts a high concentration of hotels, ports, roads, and settlements with a majority of the island population and critical infrastructure located on low-lying reclaimed coastal land (Lewsey et al., n.d). Climate change will likely exacerbate the current impacts of coastal flooding; growth in population and tourism will likely compound this impact.

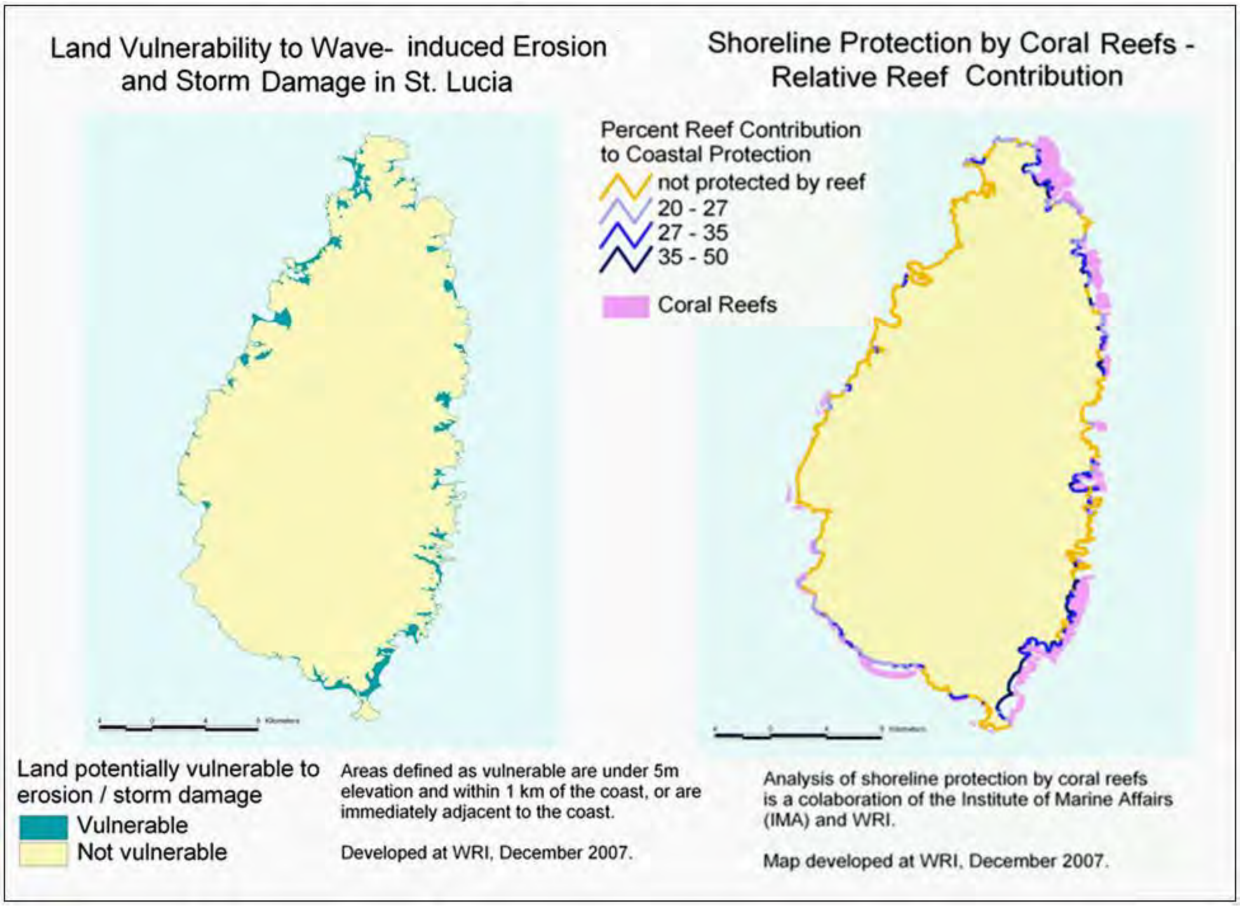


Figure 5-8 Land Vulnerability to wave induced erosion (left) and storm damage. Coastal protection by coral reefs (right). (WRI, 2008a; 2008b)

The relative stability of Saint Lucia's shoreline has been evaluated using the coastal protection framework developed by the Institute of Marine Affairs (IMA) and the World Resources Institute (WRI, 2008a). Data on coastal geomorphology, geology, vegetation, wave height, storm events, elevation, and slope, were integrated with coral reef type, continuity, and distance offshore to evaluate the stability of the shoreline. Shoreline stability is, in general, higher on the leeward coast, and in areas of steep terrain. Wide bays in the southeast and northwest have the lowest shoreline stability. The framework was also used to evaluate the contribution of coral reefs to shoreline stability. The relative reef contribution is zero in areas not protected by a coral reef, and ranges from 20 % to nearly 50 % in some areas (WRI, 2008a). Areas along

Point Sable in the southeast, some bays along the southeast coast, and bays in the northeast have the highest proportion of shoreline stability provided by coral reefs.

The land vulnerability to wave-induced erosion and storm damage have been estimated by the World Resources Institute (WRI), based on expected wave heights and storm surge associated with a 25-year storm event, adjusted to be precautionary in light of anticipated SLR and the (potentially increased) storm intensity associated with warming seas (WRI, 2008b). Vulnerable lands are defined as any land area of 5m or less elevation, within one km of the coast, as well as all land immediately adjacent to the coast (as defined by the 25m grid cell adjacent to the sea). Just over 4 % of land in Saint Lucia was classified as vulnerable to wave-induced erosion and storm damage (about 24.5 sq. km).

Extreme Sea Level projections

Coastal flooding is driven by Extreme Sea Levels (ESLs), being the result of several components, namely the mean sea level (MSL), astronomical tide (η_{tide}) and episodic water level fluctuations due to climate extremes (waves and storm surges) (η_{w-ss}) (Vousdoukas et al., 2017). Coastal impact assessments to date typically focused solely on SLR, considering stationary contributions from tides, waves and storm surges (Hinkel et al., 2010, 2014; Brown et al., 2013; Hauer et al., 2016). However, most coastal impacts are related to extreme sea levels (ESLs) when waves and surges transfer considerable amounts of energy towards the coast, driving morphological changes and erosion (Ciavola et al., 2011), as well as coastal protection failure (Oumeraci, 1994) and overwash/inundation (Matias et al., 2008; McCall et al., 2010).

As a result, ESL can be defined as (Vousdoukas et al., 2017):

$$ESL = MSL + \eta_{tide} + \eta_{CE} \qquad [5\text{-}1]$$

The episodic contribution η_{CE} from waves and storm surge can be estimated according to the following equation:

$$\eta_{CE} = SSL + 0.2 \times H_s \qquad [5\text{-}2]$$

where SSL is the storm surge level, H_s is the significant wave height and $0.2 \times H_s$ is a generic approximation of the wave setup (U.S. Army Corps of Engineers, 2002). Projections of MSLR were extracted from Hinkel et al. (2014), whereas present-state tidal elevations (η_{tide}) were obtained from the TOPEX/POSEIDON Global Inverse Solution (Egbert and Erofeeva 2002); given the focus on extreme events, the maximum tide (η_{tide}^{max}) was used. DFLOW FM was then used to assess changes in global tidal elevations due to MSLR (Vousdoukas et al. 2017).

Hindcasts of waves and storm surges (1980-2015) were obtained through dynamic simulations forced by ERA-INTERIM atmospheric conditions. Storm surges were simulated using a flexible mesh setup of the DFLOW FM model (Jagers et al. 2014; Muis et al. 2016), and the waves using the third generation spectral wave model WW3 (Mentaschi et al. 2017); both models have been extensively validated with detailed information provided in the references above. Regarding the tropical cyclone effects which are not represented in global reanalyses (Hodges et al. 2017), these have been simulated by the DFLOW FM model forced by the IBTrACS best-track archive (Knapp et al. 2010). Cyclone effects have been included in the reanalysis time series, with the ERA-INTERIM conditions in the re-analysis replaced by those from the cyclone runs when the latter gave higher values. It appears that effect of cyclones on the ESL represents approximately the 100-year event.

Cyclone effects on the waves were considered using the peak maxima of *Hs* measured by altimeter data provided by 6 different satellites (Queffeulou and Croizé-Fillon 2014): ERS-2, ENVISAT, Jason 1 and 2, Cryosat 2 and SARAL-AltiKa. Simulations of the wave and storm surge changes were forced by outputs from 6 CMIP5 climate models (Mentaschi et al. 2017; Vousdoukas et al. 2017), for 1980-2005 and the present century under RCP4.5 and RCP8.5. These projections were combined to estimate η_{CE}, and non-stationary extreme value analysis (Mentaschi et al. 2016) was used to obtain values for different return periods, derived for historical and future runs. Final η_{CE} projections were obtained after adjusting the reanalysis values according to the relative changes obtained from the CMIP5 simulations. Future tides were obtained following a similar procedure. ESLs were simulated for the baseline historical period (1995) and under the 1.5 °C warming scenario, for 9 return periods (1, 1/5, 1/10, 1/20, 1/50, 1/100, 1/200, 1/500, 1/1000 years). In addition, simulations were also carried out for 2020, 2030, 2040, 2050, 2060, 2070, 2080, 2090 and 2100 under two emission scenarios (RCP4.5 and RCP8.5).

The 100-year ESL (ESL_{100}), i.e. the combination of the RSLR, tides and the 100-year η_{CE} (including the effects of simulated cyclones on the basis of the IBTrACS best-track archive) is estimated as 1.29 m above the mean sea level (MSL) of the baseline year (1995). Future ESLs due to 1.5 °C warming (2030) are projected as 1.28, 1.32, 1.37 and 1.41 m for the 10- (ESL_{10}), 20- (ESL_{20}), 50- (ESL_{50}) and 100-year event (ESL_{100}), respectively (Figure 5-9) under RCP4.5. For the ESL_{100}, an increase of about 0.53 m is projected, compared to 1995. As the century progresses, ESLs are projected to intensify and to be increasingly controlled by the emission scenario (see also Monioudi et al., under review).

Table 5-6 Table summarizing the Extreme Sea Levels (ESLs: MSL + tide + storm surge + wave set up + cyclones) under RCP4.5 and RCP8.5, during the years 2020, 2030, 2060, 2080 and 2100, for all return periods (RPs)

	Baseline	RCP 4.5					RCP 8.5				
RPs	1995	2020	***2030***	2060	2080	2100	2020	***2030***	2060	2080	2100
1	1.03	1.13	***1.16***	1.34	1.46	1.57	1.14	***1.18***	1.44	1.66	1.90
5	1.12	1.21	***1.24***	1.42	1.54	1.65	1.22	***1.26***	1.52	1.74	1.98
10	1.16	1.26	***1.28***	1.46	1.58	1.69	1.26	***1.30***	1.56	1.78	2.01
20	1.20	1.30	***1.32***	1.50	1.62	1.73	1.30	***1.34***	1.60	1.81	2.05
50	1.25	1.35	***1.37***	1.55	1.67	1.78	1.35	***1.39***	1.65	1.86	2.10
100	1.29	1.39	***1.41***	1.59	1.71	1.82	1.39	***1.43***	1.68	1.90	2.13
200	1.34	1.44	***1.47***	1.64	1.76	1.87	1.44	***1.47***	1.73	1.94	2.18
500	1.37	1.48	***1.51***	1.68	1.80	1.91	1.48	***1.51***	1.76	1.98	2.21
1000	1.41	1.52	***1.55***	1.72	1.84	1.95	1.52	***1.55***	1.80	2.01	2.25

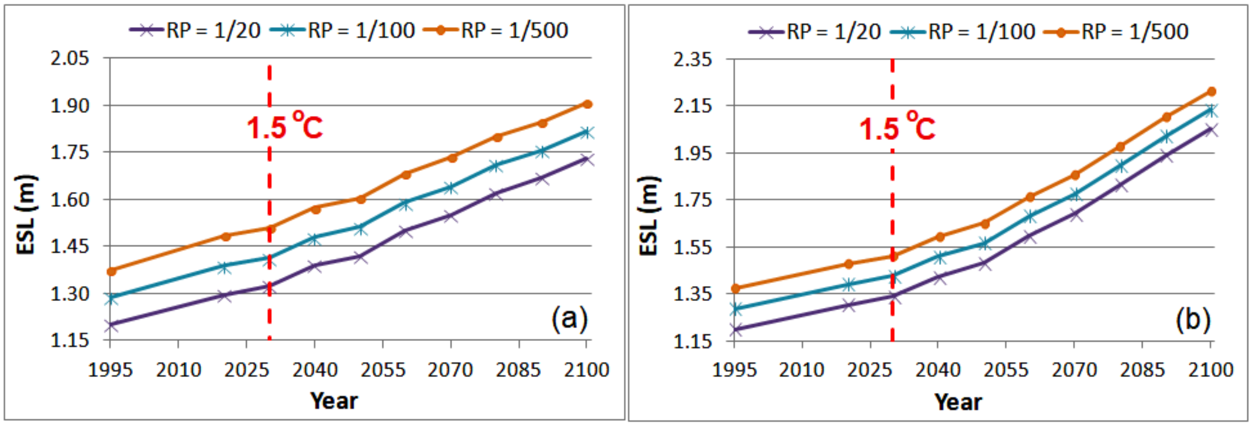


Figure 5-9 Time evolution of ESLs for 3 return periods (RP) and according with the RCP scenarios (a) 4.5 and (b) 8.5

Estimation of future exposure to coastal flooding/inundation

In Saint Lucia, coastal flooding is primarily caused by tropical storms and hurricanes. In order to assess the impacts of a Caribbean hurricane, the effect of cyclones on coastal sea levels was taken under consideration. Flood/inundation assessment is being carried out (This work is made by the collaborating institute Joint Research Centre (JRC), Directorate for Space, Security and Migration Disaster Risk Management, European Commission), following Vousdoukas et al. (2016b) using dynamic inundation model LISFLOOD-ACC, a 2-D hydraulic model which is part of the LISFLOOD-FP model; LISFLOOD-ACC has a 1-D inertial model (e.g., advection is not considered) where x and y directions are decoupled in 2-D simulations over a raster grid (Vousdoukas et al., 2016b).

Table 5-7 Table summarizing the impacts to major transportation assets due to coastal flooding. 0: no impacts, 1: Low impact, 2: medium impact, 3: high impact. (These scenarios concerns previous total ESLs + effects of Hurricane)

Scenarios	ESL plus Hurricane (m)	Graded impacts to the Major Assets			
		HIA	GCIA	VFSP	CSP
RCP 4.5 – 2050 (RP=1/10)	1.38	1	0	3	3
RCP 4.5 – 2050 (RP=1/50)	1.47	1	1	3	3
RCP 4.5 – 2050 (RP=1/100)	1.51	1	1	3	3
RCP 8.5 – 2050 (RP=1/10)	1.44	1	0	3	3
RCP 8.5 – 2050 (RP=1/50)	1.53	1	1	3	3
RCP 8.5 – 2050 (RP=1/100)	1.57	1	1	3	3
RCP 4.5 – 2100 (RP=1/10)	1.69	1	1	3	3
RCP 4.5 – 2100 (RP=1/50)	1.78	2	2	3	3
RCP 4.5 – 2100 (RP=1/100)	1.82	2	2	3	3
RCP 8.5 – 2100 (RP=1/10)	2.01	2	2	3	3
RCP 8.5 – 2100 (RP=1/50)	2.10	3	2	3	3
RCP 8.5 – 2100 (RP=1/100)	2.13	3	2	3	3

The results of the LISFLOOD model showed that several low-lying bay areas are under increased flood risk (ICF GHK, 2012), including the areas where the critical assets are located. Hewanorra International Airport (HIA) appears vulnerable at its eastern (seaward) edge. There, the runway is projected to be inundated at lengths of about 150, 130, and 380 m under the ESL_{100} (1.5 °C warming, 2030), the ESL_{50} (2050, RCP4.5) and the ESL_{100} (2100, RCP8.5) scenarios, respectively (Figures 5-10, 5-12b). Until now, HIA has been mainly impacted by strong rainfall events that in some cases forced overflowing of the redirected La Tourney River resulting in severe airport flooding.

Under a 1.5 °C warming scenario, GCIA appears vulnerable to the *ESL_{100}* mostly at its northern side (Vigie beach), as the western end of the runway is located at an elevated and armoured coastline. As the century progresses, its vulnerability will increase (Fig. 5-11, 5-12c). Vigie beach, located only 30 m away from the airport fence, has been projected to face also significant beach erosion; this will increase further the marine inundation risk. Under a 50-year ESL by 2050 (under RCP 4.5) water will enter the runway from the Vigie beach (Monioudi et al., under review).

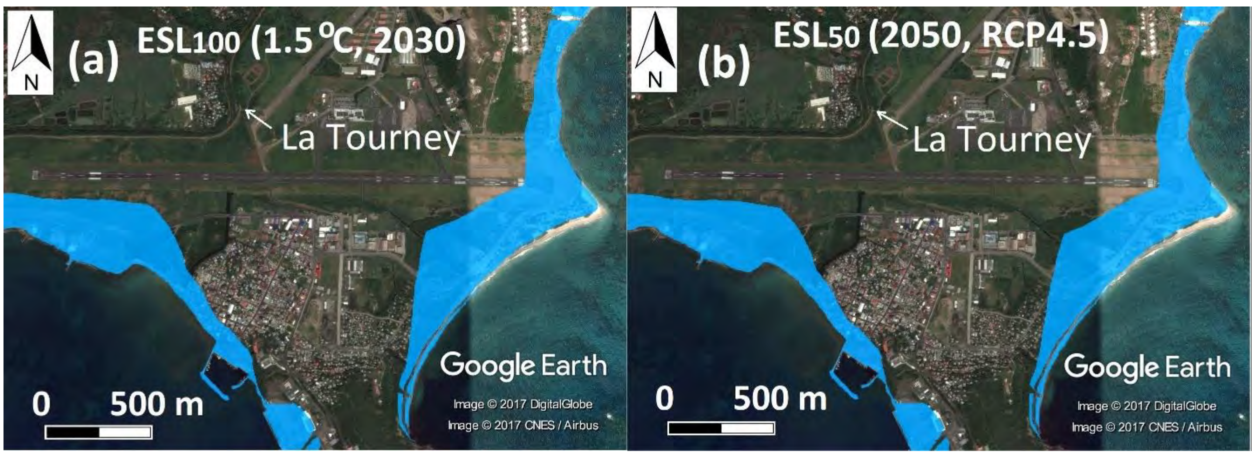


Figure 5-10 Inundation map of the Hewanorra Airport and Port Vieux Fort under a (a) 100-year ESL-ESL100 (1.5 °C, 2030), (b) 50-year ESL-ESL50 (2050, RCP4.5)

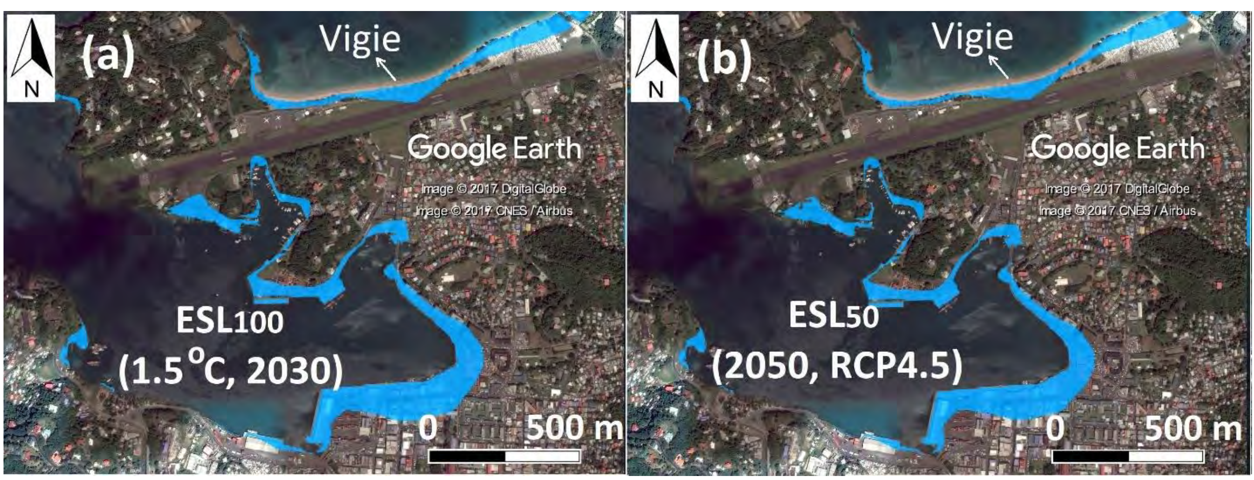


Figure 5-11 Inundation map of the George F.L. Charles Airport and Port Castries under a (a) 100-year ESL-ESL100 (1.5 °C, 2030), (b) 50-year ESL-ESL50 (2050, RCP4.5)

Given that Port Castries (CSP) is only about 1.5 m above mean sea level, there will definitely be significant damage to the Port for most of the examined scenarios. It is projected that the ESL_{100} will impact its docks severely, inundate its berths, cargo sheds and cruise ship facilities and cause flooding of the city, even under 1.5 °C warming; later in the century and under both RCP scenarios tested, CSP flooding is projected to deteriorate in the absence of effective adaptation measures. CSP has already experienced damages during extreme events, involving its breakwater armour, revetment, fencing and roofing (Figures 5-11, 5-12c). Port Vieux Fort is approximately 1.5 m above mean sea level. So similar to the Port Castries, all studied scenarios will devastate Port Vieux Fort causing flooding of the docks and berths and the surrounded areas. Breakwaters will be also under the water level (Figures 5-10, 5-12b).

The transportation infrastructure in Saint Lucia has mostly been designed for typical weather patterns and is therefore particularly vulnerable to the new extreme conditions. More research is necessary to determine how the new extreme conditions will impact on the infrastructure and the necessary steps to be taken to develop appropriate adaptation strategies. It is worthy of note that in 2010, UNDP stated that 1m SLR in CARICOM would cause severe disruption of transportation networks, and the reconstruction costs of lost roads would be about US$4,178 million (Simpson et al, 2010).

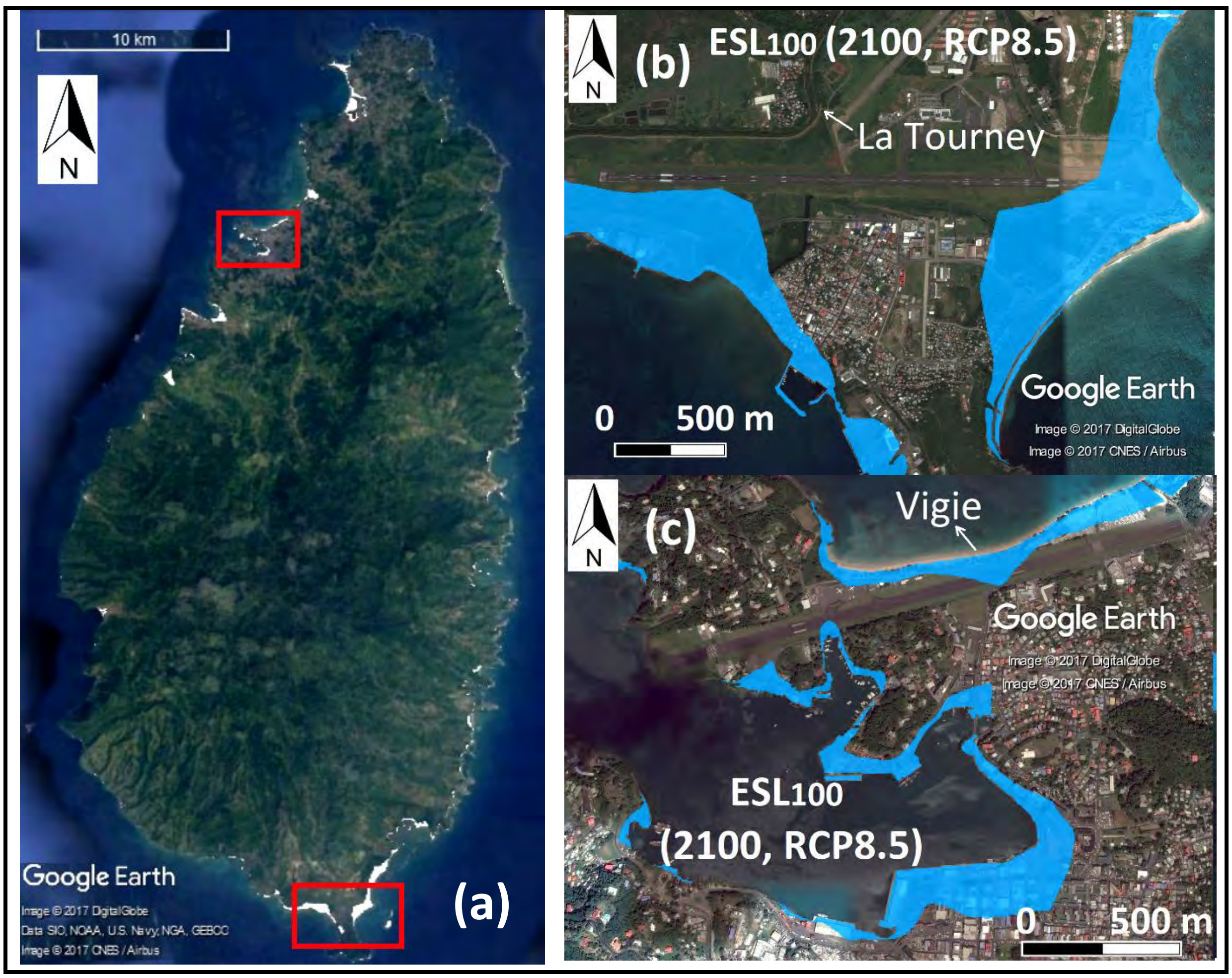


Figure 5-12 Inundation maps of (a) Saint Lucia, (b) Northern Ports and (c) Southern ports under a 100-year ESL projected for the year 2100 according with the RCP scenario 8.5

5.4 Indirect impacts of climate change: the effects on tourism

Transport and tourism are inextricably linked. Transport is a demand-driven, time-controlled industry. An unsold flight seat or unused cargo capacity cannot be re-sold as additional capacity later. One of the major drivers of transport demand in SIDS (and islands generally) is tourism. So the effects of CV &C on tourism will also impact on transportation demand. In Saint Lucia, where coastal 3S tourism has a major role in the national economy, sustainable management of beaches is crucial for maintaining their carrying capacity and quality and therefore their attractivity to international tourists. Therefore, indirect impacts on transport are also related to the potential reductions in the beach carrying capacity due to the coastal erosion under CV & C (see also Section 5.4.1).

Another indirect impact is related to connectivity of critical transportation assets to the St. Lucia major tourist destinations (major destinations in St. Lucia are coastal areas (beaches) with large tourist infrastructure, Section 5.4.2). Transport is a key enabler of tourism and plays a vital role in moving tourists from the island gateways to the island residences and on to various other attractions. In St. Lucia, road transport facilitates the internal movement of international visitors between transportation gateways, accommodations, attractions, and commercial/administration services). The location, capacity, efficiency and connectivity of road transport can, therefore, play an important role in the mobility/connectivity within the island.

5.4.1 CV & C impacts on the primary "3S" tourism natural resource (beaches)

The tourist industry in St. Lucia is based on the "3S" model (Sea, Sand and Sun). A most critical component of 3S tourism is the availability of beaches that are environmentally and aesthetically sound and retain adequate carrying capacity (e.g. McArthur, 2015; Cisneros et al., 2016; Monioudi et al., 2017). Carrying capacity is defined as the "maximum number of people that may visit a tourism destination at the same time, without causing destruction of the physical, economic and socio-cultural environment and an unacceptable decrease in the quality of the visitor' satisfaction" (WTO,1981).

Tourism carrying capacity assessment is considered as an appropriate tool for beach management, as it enables the preservation of the high quality and quantity of coastal resources. The concept of tourism carrying capacity is based on the general statement that any form of development within the carrying capacity of ecosystem means sustainable utilization of tourist resources and development of ecosystem. When an area is used beyond its capacity, the quality of natural resources changes and gets destroyed (Zacarias et al., 2011; Rajan et al., 2013). Beach erosion due to e.g. sea level rise might reduce significantly the carrying capacity and the quality of the beaches as environments of leisure and consequently the attractiveness of the country to tourism and travel, resulting to significant international travel expenditure loss.

Beach retreat predictions methodology

Seven cross-shore morphodynamic models were used to project the response of the St. Lucia pocket beaches to SLR: the *Bruun* (Bruun, 1988), *Edelman* (Edelman, 1972) and *Dean* (Dean, 1991) analytical models and the numerical models *SBEACH* (Larson and Kraus, 1989), *Leont'yev* (Leont'yev, 1996), *XBEACH* (Roelvink et al. 2010) and a model, the hydrodynamic component of which involves high-order *Boussinesq* equations- *Boussinesq* model (Karambas and Koutitas, 2002).

The models were used in an ensemble mode in order to assess the range of long- and short-term beach retreats/erosion for different beach slopes, sediment textures (grain size) and wave conditions, and under different scenarios of MSL changes and/or storm induced SLRs. Two model ensembles were created, a 'long-term' ensemble consisting of the analytical models *Bruun, Dean* and *Edelman* and a 'short-term' ensemble comprising the numerical *SBEACH, Leont'yev, XBEACH* and *Boussinesq* models; the former is used to assess beach retreat/erosion under MSLR, whereas the latter retreat due to temporary SLR (i.e. episodic storm-induced).With regard to combined SLRs (i.e. storm-induced SLR superimposed on MSLRs), the long-term and short-term ensembles were used consecutively (see also Monioudi et al, 2017). The methodology is detailed in Appendix A.

Input Data

Beach characteristics/database

The geo-spatial characteristics of all the ('dry') pocket beaches of St. Lucia have been recorded, on the basis of the images and other related optical information available in the Google Earth Pro application. In this study, 'dry' beaches were defined as the low-lying coastal sedimentary bodies bounded on their landward side by either natural boundaries (vegetated dunes and/or cliffs) or permanent artificial structures (e.g. coastal embankments, seawalls, roads, and buildings) and on their seaward side by the shoreline, i.e. the median line of the foaming swash zone shown on the imagery. Regarding the lateral extent of individual beaches, these were delimited by natural barriers, such as rock promontories. Tiny beaches (length less than 50 m) were ignored/not included in the data set. Beaches were digitized as polygons. There has been no geo-rectification, as the aim of the exercise has not been to provide definitive locations and elevations of beach features, but to extract/record (horizontal) geo-spatial characteristics. In addition to beach dimensions, other relevant information was recorded and codified, including: the presence of (a) natural features, such as river mouths, vegetation and (b) artificial features such as coastal protection schemes and the density of the backshore infrastructure/assets (as a percentage of beach length).

Environmental forcing

Given the large scale of the application, the input data of the models for the evaluation of beach retreat could not be based on in situ measurements. So the models were set up using a plausible range of environmental conditions. As initial bathymetry linear profiles were considered with different profile slopes (bed slopes of 1/10, 1/15, 1/20, 1/25 and 1/30 were examined). The lack of accurate bathymetry data may introduce some uncertainty. However, validation of the models against physical experiments showed that the results of the models set with the equivalent linear profile were reasonably close to those of the physical experiments (Monioudi et al., 2017).

Table 5-8 Input data

Data	Source	Publicly Available	Expertise Needed	Required Software or Other Resources
Beach location and width	Manually digitized from Google Earth	Yes	None	Google Earth Pro, Arc GIS
Beach slope	Plausible range of beach slopes	No	None	None
Wave conditions	Plausible wave condition range based on ERA-INTERIM wave data (1979-2015)	Yes	Manipulation of NetCDF Data	Software for Manipulating or Displaying NetCDF Data
Median sediment size D_{50}	Optical information (Google Earth and other available information)/collated from scientific literature/reports	Yes	None	None
Mean Sea Level Rise Projections	Integrated Climate Data Centre - ICDC	Yes	None	None
Total Water Level Projections	Joint Research Centre (JRC)	Yes	Manipulation of NetCDF Data	Software for Manipulating/ Displaying NetCDF Data

Wave forcing was provided though the analysis of ERA-INTERIM wave data (1979-2015) and it was found that significant wave heights in Saint Lucia ranged between 1 - 4 m. Experiments were carried out using various plausible wave conditions, i.e. waves with offshore heights (H_s) of 1, 1.5, 2, 3 and 4 m and periods (T) of 4, 5, 6, 7 and 8 s. With regard to the sediment texture, descriptive information (e.g. sand, gravel) was collected from the available photos on the Google Earth Pro application and other available information collated from scientific literature/reports. It was found that most beaches are composed of sandy sediments, so a range of d_{50} values between 0.2 - 1 mm was used (d_{50} of 0.2, 0.33, 0.50, 0.80, 1 mm).

Sea level projections

Recent MSLR projections for (i) South ports (Hewanorra Airport and Port Vieux Fort (13.5° N, 60.5°W)) and (ii) North ports (George F.L. Charles Airport and Port Castries (14.5° N, 60.5° W)) were used (Integrated Climate Data Centre - ICDC, Church et al., 2013). Under RCP 4.5 and RCP 8.5 scenarios sea level rise will be (i) 0.185 m and 0.19 respectively for the year 2040; and (ii) 0.56 m and 1.2 m respectively for the year 2100. Projections of episodic extremes (η_{CE}) (due to the combined effect of storm surges and wave set up) for (i) South ports and (ii) North ports were provided from the Joint Research Centre (JRC).

Outputs of the approach

Experiments were carried out for all combinations of environmental conditions and for twelve (12) SLR scenarios (0.05, 0.1, 0.15, 0.22, 0.30, 0.40, 0.50, 0.75, 1, 1.25, 1.50 and 2 m) (about 5500 experiments), and the means (best fits) of the lowest and highest projections by all models of the two ensembles were estimated. With regard to combined SLRs (i.e. coastal ESLs due to storm surges and wave set ups (e.g. Vousdoukas et al., 2016a) superimposed on the MSLRs), the long-term and short-term ensembles were used consecutively. It was found that the 'low' mean of the beach retreat projections by the short-term ensemble (i.e. the best fit of the lowest projections from the 4 numerical models) is given by S = 0.1 α^2 +

9.7 α + 0.3 and the 'high' mean by S = 0.7 α^2 + 28.5 α + 4.8, where S is the beach retreat and α is the SLR. Also, the low projection mean of the long-term ensemble is given by S = 0.1α^2 + 10 α + 0.2 and the high projection mean by S = 1.5 α^2 + 30.01 α +2.3. Ranges in beach temporary inundation/flooding due to wave run-up combined with (a) episodic (short term) SLRs were estimated as S(i) = 0.2 α^2 + 9.5 α + 3.5 (minimum) and S(i) = -0.7 α^2 + 31.2 α + 27.2 (maximum) and with long-term SLRs as S(i) = 0.4 α^2 + 10.1 α + 3.3 (minimum) and S(i) = 0.4 α^2 + 30 α + 28.1 (maximum).

Table 5-9 Minimum and maximum mean estimates of beach retreat (S) and inundation/flooding (S(i)) by the long-term, short-term and combined ensembles and the empirical model of Stockdon et al. (2006). Ranges of cross-shore retreat/erosion (R) and temporary inundation/flooding (F) for the beaches of Saint Lucia are projected by comparing the highest and lowest mean S and S(i) with the maximum width of the 91 beaches of Saint Lucia under different SLRs. Numbers (N) and percentages of beaches where backshore infrastructure/assets are projected to be affected by beach retreat/erosion and flooding are also shown

	SLR (m)						R	F	R	F	R		F	
					S	S(i)	Equal to 50 % of max. width (%)		Equal to max. width (%)		Beaches with assets affected			
	Year	RCP	value		(m)	(m)					N	%	N	%
Long-term	2040	4.5 & 8.5	0.19*	Min	2.2	5.6	0.0	9.9	0.0	0.0	0	0.0	0	0.0
				Max	8.0	33.8	19.8	90.1	0.0	58.2	0	0.0	16	51.6
	2100	4.5	0.56	Min	5.9	9.5	9.9	24.2	0.0	6.6	0	0.0	1	3.2
				Max	19.5	45.0	65.9	97.8	24.2	75.8	5	16.1	24	77.4
	2100	8.5	0.76	Min	8.0	11.6	19.8	30.8	0.0	9.9	0	0.0	1	3.2
				Max	25.9	51.1	80.2	98.9	39.6	80.2	9	29.0	26	83.9
Short -term	2040 & 2100	4.5 & 8.5	1**	Min	10.2	13.8	25.3	49.5	8.8	13.2	1	3.2	1	3.2
				Max	34.0	57.7	90.1	100.0	59.3	84.6	16	51.6	28	90.3
MSLR + Short -term	2040	4.5 & 8.5	1.19	Min	12.4	19.4	35.2	65.9	11.0	24.2	1	3.2	5	16.1
				Max	42.0	91.5	96.7	100.0	72.5	97.8	21	67.7	31	100.0
	2100	4.5	1.56	Min	16.1	23.3	58.2	75.8	19.8	30.8	3	9.7	7	22.6
				Max	53.5	102.7	100.0	100.0	81.3	98.9	27	87.1	31	100.0
	2100	8.5	1.76	Min	18.2	25.4	63.7	80.2	23.1	39.6	4	12.9	9	29.0
				Max	59.9	108.8	100.0	100.0	85.7	100.0	28	90.3	31	100.0

* Projected MSLRs for the years 2040 under RCPs 4.5 and 8.5 are very close and equal to ~0.19 m

** Projected η_{CE} for the years 2040 and 2100 under RCPs 4.5 and 8.5, with return period 1/20yr are very close and equal to ~1m ($\eta_{CE\ 2040,\ RCP4.5}$=0.93 m, $\eta_{CE\ 2040,\ RCP8.5}$=1.02 m, $\eta_{CE\ 2100,\ RCP4.5}$=0.99 m, $\eta_{CE\ 2100,\ RCP8.5}$=1.03m).

The above equations were used for the estimation of the final "outputs" of this approach which are: (i) potential ranges of beach retreat/erosion and temporary inundation/flooding, (ii) ranges of decreases in 'dry' beach widths projected through the comparison between the ranges of beach retreat/erosion (*S*) and the maximum widths of the Saint Lucia beaches, (iii) ranges in beach temporary inundation/flooding, estimated by the comparison between the ranges of combined beach retreat and wave run-up excursions (*S(i)*) and the beach maximum widths and (iv) numbers (N) and percentages of beaches where backshore infrastructure/assets are projected to be affected by beach retreat/erosion and flooding. In Table 5-9, estimations are presented for 7 SLR scenarios: (i) 0.19, 0.56 and 0.76 m MSLRs according to downscaled projections for the area (Church et al., 2013) using the long-term ensemble; (ii) short-term SLRs due to short-term extreme level of 1 m (total water level with return period 1/20 yr) using the short-term ensemble; and (iii) combined MSLRs and short-term extreme levels of 1.19, 1.56 and 1.76 m, using consecutively the long- and short-term ensembles.

According to the projections of the long-term ensemble, MSLRs of 0.19, 0.56 and 0.76 m will result to beach retreats/erosion by about 2.2 - 8, 5.9 – 19.5 and 8 – 25.9 m, respectively, whereas short-term ensemble estimates show that storm-induced levels of +1 m could result in ranges of beach retreat/erosion of about 10.2 - 34 (Table 5-9). For the considered SLR scenarios, there will be significant impacts on the Saint Lucia beaches as shown by the percentages of beaches that are projected to be eroded/shifted landward to a distance equal to 50 % and 100 % of their maximum width (Table 5-9).

Under a MSLR of 0.19 m (RCPs 4.5 and 8.5 in 2040), there could be some impacts on the basis of the mean maximum projections of the long-term ensemble (Table 5-9). Temporary inundation (S(i)) could overwhelm 58.2 % of the beaches, flooding (occasionally) 51.6 % of the beaches fronting currently existing coastal infrastructure/assets. Under a MSLR of 0.56 m (RCP 4.5, 2100), projected impacts will be significant. 9.9 to 65.9 % of all beaches will be eroded by a distance equal to half of their maximum width, whereas between about 6.6 and 75.8 % of all beaches are projected to be occasionally overwhelmed by flooding (Table 5-9 and Figure 5-13).

In 2100, under the high emission scenario (RCP8.5, MSLR of 0.76 m), impacts could be severe (Table 5-9): 19.8 – 80.2 % of Saint Lucia beaches will be eroded by a distance equal to half of their maximum width and 9.9 – 80.2 % of the beaches will be occasionally overwhelmed by flooding. Associated infrastructure/assets are also projected to be greatly impacted, with less than 29 % and 3.2 – 83.9 % of all beaches fronting currently existing assets projected to be lost to beach erosion and occasionally overwhelmed by flooding, respectively.

According to the mean low projections of the short-term ensemble, storm coastal sea level of +1 will result in significant (temporary) beach retreats (8.8 % of all beaches will retreat more than their maximum width) and temporary flooding (13.2 % of the beaches will be occasionally completely flooded). On the basis of the mean high projections (forced by the high wave conditions expected in storms), beach retreats and flooding will be substantial with severe reductions in 'dry' beach widths and potential damages of assets located at the back of the beach. About 59.3 % of all Saint Lucia beaches will retreat by more than their maximum width and 84.6 % will be completely overwhelmed by temporary flooding under short-term SLR of +1 m (Table 5-9). Up to 28 % and 90.3 % of all beaches fronting assets will be affected by beach retreat/erosion and temporary flooding, respectively (Table 5-9, Figure 5-13).

The worst impacts are projected from the combined mean and short-term SLRs. In 2040, in the case that storm-induced sea levels of +1 m is combined with a projected MSLR of 0.19 m (combined SLR of 1.19 m), 11 – 72.5 % of beaches are projected to be (at least temporarily) eroded and 24.2 – 97.8 % of beaches flooded. In 2100, superimposition of storm levels on the projected MSLRs will have devastating effects. A combined sea level rise of 1.56 m (e.g. a storm-induced extreme level of +1 m superimposed on a MSLR of 0.56 m (RCP4.5)) will have very severe impacts, indeed (Figure 5-13): 19.8 – 81.3 % of all beaches will be completely (at least temporarily) eroded (9.7 – 87.1 % of all beaches fronting assets) under the low and high mean projections of the ensemble, respectively, with 30.8 – 98.9 % of all beaches occasionally overwhelmed by flooding (Table 5-9).

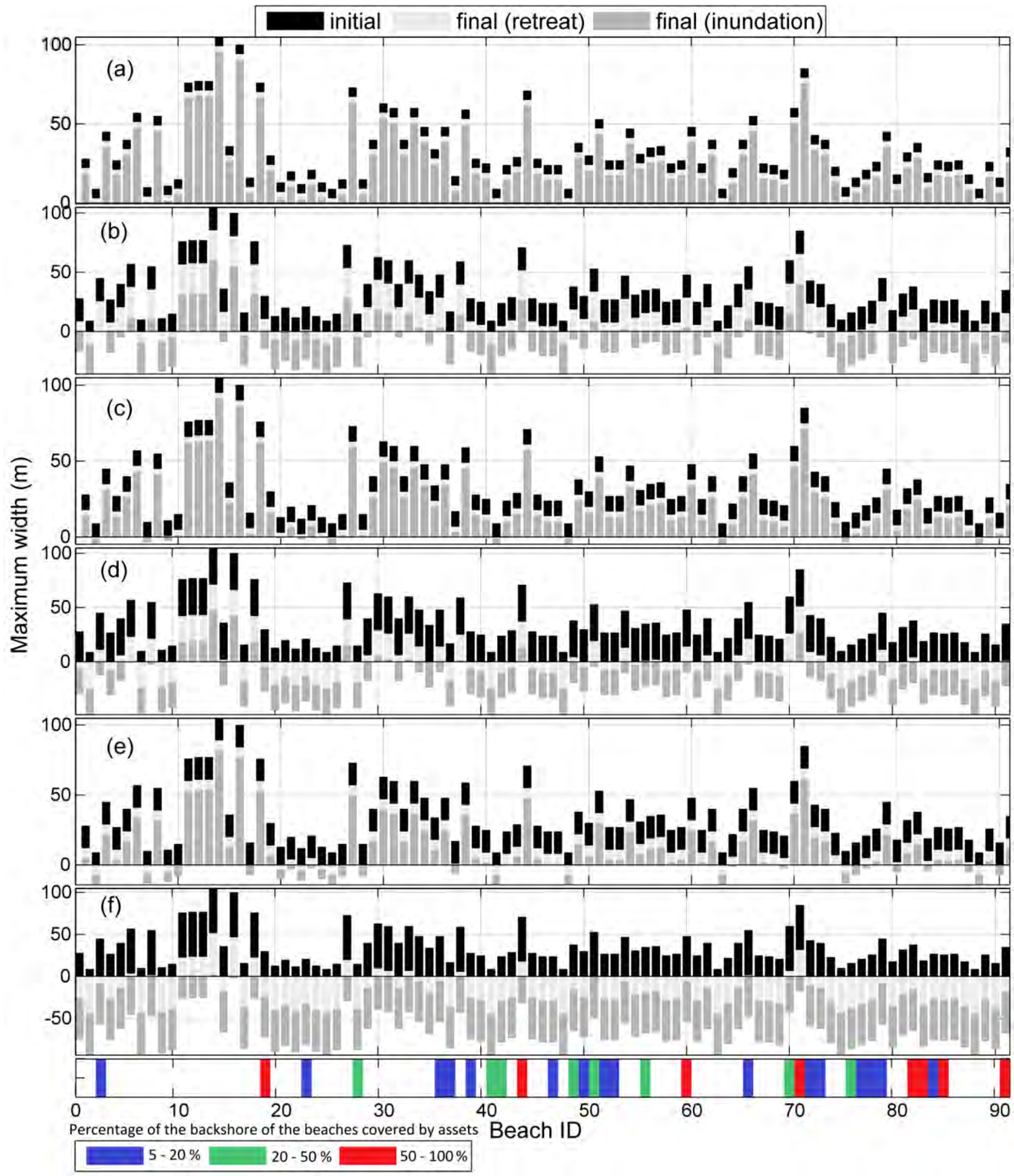


Figure 5-13 Minimum and maximum retreat and flooding of Saint Lucia beaches for different SLR scenarios on the basis of the low and high means respectively of the ensemble projections. a) and b) Minimum and maximum retreat and flooding under a MSLR of 0.56 m. c) and d) Minimum and maximum retreat and flooding under a storm-induced level of +1 m. e) and f) Minimum and maximum retreat and flooding under a combined long- and short-term SLR of 1.56 m (see text). Initial and final (after SLR) maximum beach widths are shown (note: the bars show the overall width of the initial and reduced beach). Final widths < 0 show beaches lost or shifted landward or flooded by their entire maximum width. Bars show currently existing infrastructure/assets fronted by beaches

A combined SLR of 1.76 m (RCP8.5, a MSLR of 0.76 m combined with a storm-induced coastal sea level of +1 m) represents a 'doom' scenario for the beaches of Saint Lucia. Based on the low projections of the combined ensembles, about 63.7 % of beaches will be shifted landward (and/or drowned) to a distance equal to 50 % of their maximum 'dry' width, whereas about 23.1 % of all beaches will be (at least temporarily) completely eroded; 12.9 % of beaches fronting existing assets will be fully eroded and 29 % fully flooded. Based on the high projections of the combined ensembles, about 85.7 % of beaches will be completely eroded, whereas all beaches will be (at least temporarily) fully flooded; 90.3 % of beaches fronting existing assets will be fully eroded and 100 % fully flooded.

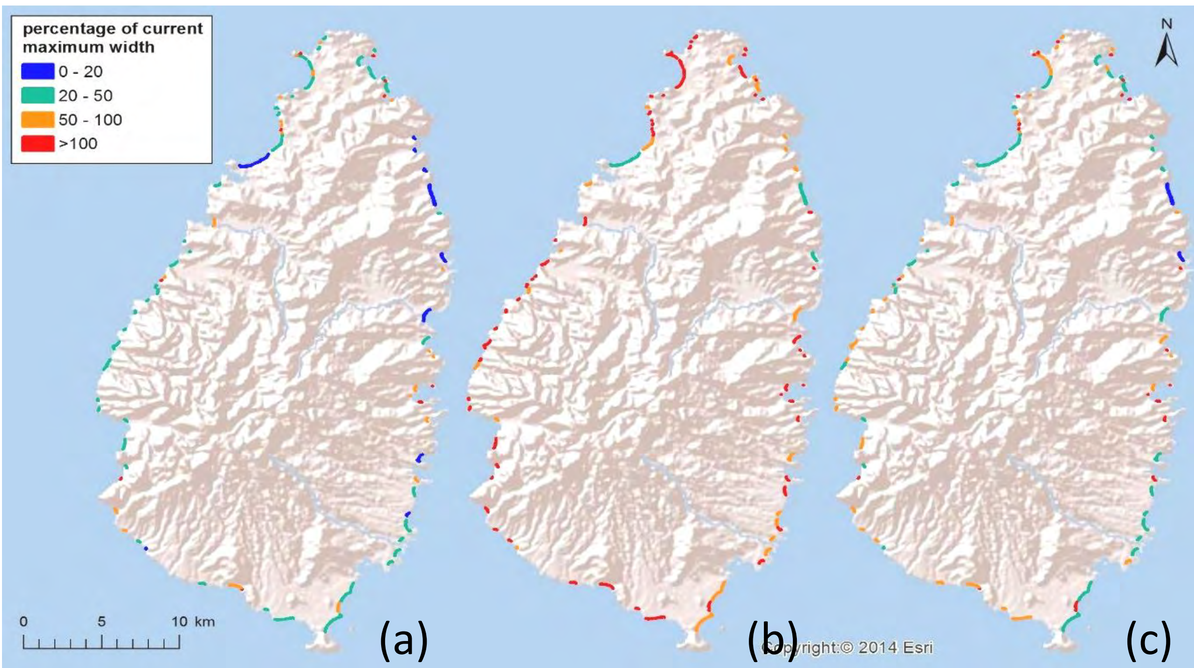


Figure 5-14 Projections of (a) and (b) minimum and maximum beach retreat under a combined SLR of 1.19 m (for the year 2040) and (c) minimum beach retreat under a combined SLR of 1.76 m (for the year 2100), showing beaches projected to retreat by distances equal to different percentages of their initial maximum widths

5.4.2 Estimation of airport connectivity (redundancy)

In addition to the direct climate impacts on airports there will be also indirect impacts due to airport connectivity to the St. Lucia major tourist destinations (major tourist destinations in St. Lucia are coastal areas (beaches) with large tourist infrastructure). This connectivity is under increased risk by the large density of landslides at the connecting roads that have been recorded during extreme events (hurricanes).

Climate changes affect the stability of natural and engineered slopes and have consequences on landslides, but it is not clear the type, extent, magnitude and direction of the changes in the stability conditions, and on the location, abundance, activity and frequency of landslides in response to the projected climate changes. Gariano and Guzzetti (2016) examined the advantages and limits of the approaches adopted to evaluate the effects of climate variations on landslides, including prospective modelling and retrospective methods that use landslide and climate records. They concluded that all approaches add uncertainties in the evaluation of the impacts of climate change on landslides and the stability of natural and engineered slopes. Since it is difficult to get landslide projections, information of landslides occurrence during past events is used for the estimation of the airport connectivity.

An estimation of connectivity impacts on the basis of the number of potential landslides (Table 5-10) has been carried along the connecting road network between the 2 international airports and the 30 tourist beaches identified along the island coastline; this was achieved through (i) digitization of the major road network using the Google Earth Application and (ii) the landslide density per kilometer recorded during the Hurricane Tomas (Figure 5-15). It was found that during such an event and in the absence of major technical works to armour the cliffs against road affecting landslides, access to major touristic destinations from HIA is generally at much greater risk than that from George Charles IA.

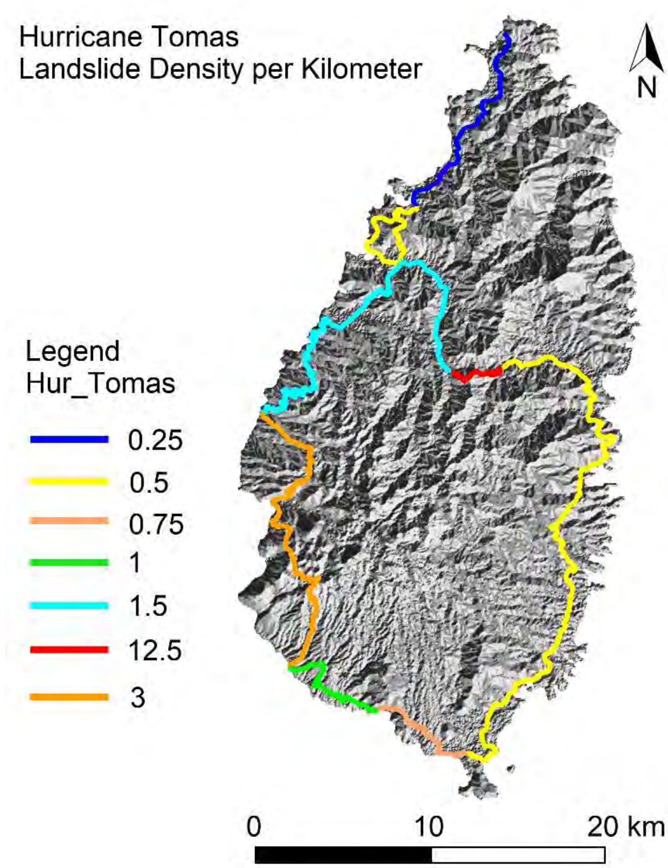


Figure 5-15 Landslide density per Kilometer of Road –Post Hurricane Tomas. (Van Westen, 2016)

Table 5-10 Numbers of landslides along the road network

Landslides along the road network		
Major touristic destinations	**From HIA (No)**	**From GCIA (No)**
Cas en Bas	45.9	2.8
Anse Petience	9.5	33.5
Coconut Bay	0.4	42.6
Anse de Sable_1	0.4	43.0
Anse de Sable_2	0.9	44.3
Sugar Beach	46.6	83.9
Malgretoute	53.2	77.4
Soufriere	60.2	70.4
Anse Chastanet	65.9	64.7
Canaries	98.0	38.3
Anse Cochon	111.3	25.0
Anse Galet	114.6	21.6
Anse La Raye	116.7	19.6
Roseau	124.4	11.9
Marigot	126.5	9.8
Grande Cul DeSac	40.6	3.3
La Toc	42.2	1.4
Vigie	43.0	0.0
Choc	43.5	0.5
Almond Morgan	43.8	0.8
St. James	43.9	0.8
Labrelotte_1	44.2	1.1
Labrelotte_2	44.2	1.2
Trouya	44.3	1.3
Reduit	44.9	1.8
Rodney_1	45.4	2.4
Rodney_2	45.6	2.5
Pigeon Island	45.7	2.6
Smugglers Cove	45.9	2.8
Le Sport	46.2	3.1

5.5 Vulnerability Overview

5.5.1 Airports

Hewanorra International Airport (HIA) is increasingly impacted by rainfall precipitation that causes the nearby river to swell and cause severe flooding of the airport and its environs. Even the passage of Hurricane Dean which was supposed to have caused surges in excess of 10m resulted in flooding caused by precipitation. An increase in rainfall extremes has been noted at the HIA, reaffirming the trend of increased rainfall noted in the climatological shift of recent years (Environment Solutions, 2015). There have been marked increases in maximum 5-day rainfall, annual total precipitation when rainfall is above the 95th percentile (very wet days) and cumulative annual rainfall over the 42 year period. Both GCM and RCM projections suggests that mean annual rainfall will decrease in the future; however since the major damage and losses, from hazard events, experienced by the airport have centred on precipitation resulting in the overflowing of the La Tourney River, adaptation interventions should be implemented in order to address this hazard. HIA appears vulnerable at its eastern (seaward) edge. There, the runway is projected to be inundated at lengths of about 150, 130, and 380 m under the ESL_{100} (1.5 °C warming, 2030), the ESL_{50} (2050, RCP4.5) and the ESL_{100} (2100, RCP8.5) scenarios, respectively (Figures 5-10, 5-12b).

George F.L. Charles airport (GCIA), as mentioned previously is about 30 m from the Vigie Beach and has suffered from sand washed from the road onto the airport compound. As a result of global mean sea level rise, the shoreline, will recede in response to rising sea level (10.8cm by 2019 and 18.9 cm by 2026) (ICF GHK, 2012). The flooding of the runway that airport officials reported to ICF GHK officials was probably as a result of poor drainage into Ganters Bay rather than storm surge from the western end of the runway. Storm surge from the side of the airport parallel to the airport has only resulted in flooding to the entrance of the airport and the area between the airport building and the firehouse. Any storm surge from Vigie Beach has resulted only in sand being swept across the road and onto the perimeter of the runway where the walkway is located. GCIA appears vulnerable to the ESL_{100} mostly at its northern side (Vigie beach), as the western end of the runway is located at an elevated and armoured coastline. As the century progresses, its vulnerability will increase (Figures 5-11, 5-12c). Vigie beach has been projected to face also significant beach erosion; this will increase further the marine inundation risk.

Operational threshold analysis suggests that, by the early 2030s (the period during which the 1.5°C warming cap is projected to be exceeded), staff working outdoors at the Saint Lucian international transportation assets could be at "high" risk for 2 days/year; by 2080-2099, such days could increase to ~54 days/year, respectively (Table 5-5). Higher temperatures will reduce aircraft lift, requiring longer runways (Coffel et al. 2017). Some types of Boeing aircrafts will require runways longer than those of the Saint Lucian airports. Particularly the Boeing 737-500 and 737-400 aircrafts will not be able to take off ~12, ~35 and ~68 days/year during the periods 2040–2059, 2060–2079 and 2080–2099 respectively (Table 5-5).

5.5.2 Seaports

Regarding Port Castries (CSP), it is projected that the ESL_{100} will impact its docks severely, inundate its berths, cargo sheds and cruise ship facilities and cause flooding of the city, even under 1.5 °C warming; later in the century and under both RCP scenarios tested, CSP flooding is projected to deteriorate in the absence of effective adaptation measures (Figures 5-11, 5-12c). CSP has already experienced damages during extreme events, involving its breakwater armour, revetment, fencing and roofing.

In Vieux Fort Seaport (VFSP), the Christmas Eve trough had caused significant flooding in the area; many houses were damaged and the road that cuts through the settlement was also flooded. The flooding of the Mankote mangrove can result in losses to the mangrove which is already under significant stress from anthropogenic factors. The VFSP appears vulnerable to marine flooding under all tested scenarios (Figures 5-10, 5-12b).

Extreme heat can also raise energy demand/costs for heating, ventilation and cooling (HVAC) systems. According to a generic standard, 1 °C warming will result in a 5 % increase in energy requirements (assuming current technology) (IDB 2015). It was found that by 2020-2039 a 1 °C temperature rise (from the baseline period 1986-2005) will increase energy requirements by 5 % for ~119 days/year, whereas by 2080-2099 a 3 °C rise will increase energy requirements by 15 % for 179 days/year. Extreme rainfall can severely limit visibility and inhibit operations (e.g. crane operations at commercial seaports). Future disruptions due to intense (> 20 mm/day) and very heavy rainfall (> 50 mm/day) are projected not to differ significantly from those of the baseline period (Table 5-5).

5.5.3 Indirect impacts

Indirect impacts on transport are related to the potential reductions in the beach carrying capacity due to the coastal erosion under CV & C. The application of the beach retreat prediction methodology showed that the beaches in Saint Lucia are vulnerable to SLR. The quality of the beaches as environments of leisure and consequently the attractiveness of the country to tourism and travel will be significantly affected, resulting to significant international travel expenditure loss. The connectivity of the major gateways of international tourism to the major tourist destinations of the island, i.e. to the coastal resorts/beaches is under increased risk by the large density of landslides that have been recorded during extreme events (hurricanes) at the connecting roads. It was found that during such an event, access to major touristic destinations from HIA is generally at much greater risk than that from GCIA.

Chapter 6: POTENTIAL APPROACHES TO ADAPTATION

6.1 Summary of historical damages and potential plans

Both airports and Port Castries have suffered damages and losses from climatic events, primarily flooding and storm surge. Port Vieux Fort has been able to withstand storm surges and there have been no reported incidents of flooding. The coastal transportation network including roads and bridges, on the other hand, is continuously damaged by landslides, flooding and storm surges.

6.1.1 Airports

Of the airports, the George F.L. Charles Airport (GCIA) seems to be better equipped to respond to climatic events. The airport is small and caters only to inter-regional air traffic. The buildings, runway and surrounding environs are well maintained. In those instances when the airport had to be closed because of flooding, or sand in the airport and in the walkways, it was able to resume operations within 72 hours at the most.

Under the present climate, ponding of water takes place between the airport building and the firehouse, even where there is a slight rainfall. This is a drainage problem, which can be easily rectified. Flooding is also caused by the poor drainage leading to Ganters Bay. When the drain in clogged up the water backs up onto the runway; this too can be easily rectified by proper maintenance of the drainage channelling run-off from the airport to the bay. The boulder revetment at the western end of the runway is old and has not been regularly maintained; the rocks are old and appear to have been loosened. Another storm event similar to that of Hurricane Dean which had a storm surge slight over 10 m might easily loosen further the revetment and transport rocks on to the runway.

Unlike George Charles airport, Hewanorra International Airport (HIA) takes a longer time to recover from weather-related damage. Here, damages are primarily from flooding and mud deposits from the nearby La Tourney River. In the recent past, within a period of 3 years, the airport had to be closed twice for more than 24 hours for the facility and runway to be cleaned. In 2013, when the river broke, it is reported that a wave of water came into the terminal, with a height of approximately 3 ft. Users of the terminal, at the time, which saw the water approaching had to move rapidly upstairs. Once that wave of water had gone through, there was about 3 inches of standing water that remained on the terminal (Smith, 2014).

Storm water runoff exceeds the capacity of collection systems causing flooding, delays and closing of airport. The flooding has also caused damage to meteorological equipment located in the ground floor of the airport tower. As this St. Lucia's meteorological service depends on this equipment, a movement of this equipment in more secure environment is recommended.

In terms of the current adaptation plans, part of the financing received through the DVRP (Disaster vulnerability reduction project) will be applied towards an intervention on comprehensive flood protection of the HIA and its environs, and the GCIA.[18] An ongoing study includes a pre-feasibility study and analysis of engineering mitigation and drainage options designed to protect the airports' facilities from periodic flooding. The study covers three broad areas which include the following services:

- Activity 1- Data Collection of all relevant data required to support the development of engineering options to be presented. Such data should include rainfall, wind, storm surge, tide, wave height data, bathymetry, piezometric head, and other relevant data of sufficient quality to support the development of event return periods of 5, 10, 25, 50 and 100 years with respect to anticipated flooding. Identification and mapping of flood water sources affecting the airport facility, including on and offsite storm water discharges, surface runoff, streams and airport surfaces.
- Activity 2 - Modelling of flood scenarios, modelling of the impact of the La Tourney River and supporting watershed, modelling options for flood control interventions suitable for managing surface runoff and flood waters expected, with respect to the 5, 10, 25, 50 and 100 year return periods, and modelling past flood events for estimating flood impacts and flow dynamics
- Activity 3 – Development of Engineering Options to prevent or mitigate potential airport flooding, in conformance with ICAO and statutory requirements.

Another initiative to be pursued involves analysing the elevation of runways to adapt to sea level rise and flooding, and the installation of a 250,000 gallon tank and purifying equipment for rainwater harvesting at both airports.

The World Bank/CIF funded Disaster and Vulnerability Reduction Project[19] includes the commissioning of a study to assess the impact of sea level rise on all facilities of SLASPA and analysing the elevation of runways to adapt to sea level rise and flooding. The Project will also undertake an evaluation of the causes and impact of flooding and storm surge in both airports.

6.1.2 Seaports

Of the sea ports, Port Vieux Fort appears to be able to cope better with weather events. As previously mentioned, port vulnerability to storm surges and flooding was considered during construction, and then again when the Port was refurbished about 15 years ago. It is not known, however, whether it will be able to accommodate significant climatic changes, particularly increased storm surges accompanying the mean sea level rise. This could possibly damage cranes, other docks and terminal facilities.

Port Castries has sustained damage from winds and storm surges. In addition, increased precipitation has resulted in changes in underwater surface and silt and debris buildup at the mouth of the channel. This could affect channel depth, which could potentially affect the large cruise ships. SLASPA has therefore spent substantial amounts of money in dredging the channel. SLASPA intends to redesign all ports and install pumps to combat sea level rise; and to redesign port infrastructure in order to reinforce them for more intense hurricanes and storms (through the Disaster vulnerability reduction project (DVRP)).

[18] DVRP Project Document. Available at http://www.worldbank.org/. Accessed on June 4 2016.
[19] The DVRP seeks to measurably reduce vulnerability to natural hazards and climate change impacts in the country through urgent risk mitigation measures and by strengthening its capacity to understand and manage disaster risks.

6.1.3 Road Network

The impacts identified in the transport sector also relate to damage and loss incurred to the main roads and bridges as well as impacts resulting from compromised riverbanks. The Christmas Eve Storm, for example, severely damaged the main highway, which connects communities in Saint Lucia's south and west to one another and to the north. Approximately 12 sections of road required extensive reconstruction. Within a few days of the flood event, the Saint Lucia government had restored primary network access by removing debris and constructing temporary emergency bypasses and bridge infrastructure in heavily damaged areas. Estimated damage to bridges and roadways was US$68.8 million.

Risk exposure to natural hazards for coastal transportation comes in the form of extreme rainfall and/or river flooding events that threaten to wipe out roads, bridges and culverts. In the reconstruction and rehabilitation of roads and bridges damaged by the Trough, the Ministry of Infrastructure has ensured rebuilding to a higher standard than previously existed, in order to reduce vulnerability to future flooding events. Nevertheless, the Ministry still needs to achieve clarity on the application of design criteria for waterway crossings, rivers and roads. This is an issue that will require some attention in the face of climate change impacts with the increasing potential for extreme rainfall events.

The transportation system in Saint Lucia is designed to withstand local weather and climate and is built to last 30 years or so. Transportation engineers typically refer to historical records of climate, especially extreme weather events when designing transportation systems. However, due to climate change, historical climate is no longer a reliable predictor of future impacts. The rainfall intensity that occurred during the Christmas Eve Trough event was thought to be close to a 1 in 100 year event, which led to flash flooding, and debris flows, and which ultimately caused the destruction of many waterway structures and the road infrastructure, particularly in the southern two thirds of the country.

It is now clear that climate change could lead to potentially sudden or dramatic changes far outside historical experience (e.g. record rainfall as in the case of the Christmas Eve Trough). Transportation infrastructure, designed for normal weather patterns, is not being able to cope with these new extremes.

In Saint Lucia, the road infrastructure and other similar assets do not accommodate changes in climate. Hence, one of the primary issues is the adoption of appropriate design criteria, taking into account the potential for climate change and the occurrence of more extreme rainfall events. In addition, it is critical that bridge and culvert designs account for the occurrence of debris coming down from the mountainous sections of the catchment, as these often result in debris jams followed by re-routing of the river paths and subsequent loss of roadways, bridges, and adjacent infrastructure (Smith, 2014). Bridge designs on the main highways should be done to accommodate a minimum 1 in 100 year return period event. For smaller bridges and culverts in the interior, this criterion could be relaxed to the 1 in 25 year event.

6.2 Detailed risk assessment for adaptation

The above assessment of the asset operational disruptions and marine inundation risk from extreme events represents a first evaluation of the vulnerabilities of critical international transportation infrastructure of Saint Lucia to climatic change, which should be fine-tuned if the following are available:

- facility-specific operational sensitivities that cannot be captured by generic thresholds (e.g., the disruptive effects of wind and wave directional changes on ship berthing). The use of facility-specific thresholds will significant improves the results of the present study.
- a DEM of good quality and of high resolution which is needed for the application of accurate modelling. The results of the inundation model Lisflood that was used for the purposes of the present study good be significant improved with LIDAR survey or generation of a DEM at higher resolution.

Coastal transportation assets could be directly and indirectly impacted by additional hazards and their combinations, making multi-hazard assessments (e.g. Forzieri et al. 2016) necessary for effective adaptation planning. For example, extreme rainfalls are associated with significant inland landslides that have in the past seriously compromised the connectivity of international airports and seaports with urban centres and tourist resorts, demanding redundancy adaptation options. Also, as international transportation is a demand-driven industry, indirect impacts may arise from the impacts of CV & C on the capital/product of other economic sectors; for instance, "3S" tourism destinations may require additional adaptation measures to mitigate beach erosion, which is projected to deteriorate very significantly in the future. Effective adaptation requires detailed, down-scaled research on the climate change risks (e.g. long-term and short-term sea level rise, for seaports changes in the wave regime that may affect the penetration of long waves into the port and changes in the flow and sedimentation patterns should be taken under consideration) (e.g. Becker et al., 2013).

Approaches to incorporate climate change considerations into the road design and operation include: (i) risk assessments that evaluate the exposure, vulnerability, resilience and adaptation responses of the road systems (ii) planning of timeframes (consideration of longer-term climate change effects during the planning processes) and (iii) adaptation strategies.

The methodological framework for the implementation of adaptation options may include the following steps:

- Collation/collection of detailed information (e.g. historical disruptions, climate data, facility specific operational thresholds, good quality DEM etc.). Installation of a water level recorder at the facilities (or their vicinity) would provide added benefits particularly if there would be adequate data storage as well as integration with other relevant available climatic data such as wind speed and direction, rainfall etc.). Accurate data records at the airport over the long term are essential to monitor trends and will help to feed into the climate projection models to get more specific forecasts.
- Detailed 2-D modelling for integrated combined hazards from marine and flash flooding to provide multi-hazard risk assessments, i.e. assessments of combined impacts of marine and river flooding, and probably wind under the present and future climate.

- Design/testing (using simulations) of appropriate technical adaptation responses under climate change, including cost benefit analyses.
- Study of socio-economic parameters (including a review of pertinent national policies and regulation).
- Planning/implementation of technical responses; essential is the monitoring of the technical projects after their completion to assess their effectiveness and identify potential problems needing fixing.

6.3 Future disruptions and technical responses

The inundation modelling undertaken in the present study has shown that several low-lying bay areas are under increased flood risk (ICF GHK, 2012), including the areas where the critical assets are located.

Until now, HIA has been mainly impacted by strong rainfall events that in some cases forced overflowing of the redirected La Tourney River resulting in severe airport flooding. Flood control interventions suitable for managing surface runoff from La Tourney River should be implemented. HIA also appears vulnerable to marine inundation at its eastern (seaward) edge. There, the runway is projected to be differentially inundated according to the ESL scenarios. The construction of appropriate coastal protection works (e.g. a seawall) at its eastern edge may address this problem, although there could be repercussions for the adjacent beach. Raising the runway level, which might provide increased resilience against mean sea level rise and the hurricane storm surges/waves, appears to be a very costly technical measure, option, both in terms of funds and operational disruptions.

The 'operational thresholds' method employed in the present study showed that there will be future disruptions in both airports and, in most cases, the disruptions seem to increase over time. The analysis showed that some planes (aircraft type) currently used will not be able to take off from HIA without reducing their payloads during extreme heat days (assuming no targeted aircraft design changes). In addition, temperature increases could result in heat related weathering and buckling of pavements and concrete facilities. Therefore, a second area of specific adaptation will be the extension of the runway (preferably to the west). Note that this measure could also serve commercial purposes, as it will allow larger aircraft to land/take off from the facility.

GCIA appears vulnerable to marine flooding mostly at its northern side (Vigie beach), as the western end of the runway is located at an elevated and armoured coastline. Vigie beach, located only 30 m away from the airport fence, has been projected to face also significant beach erosion; this will increase further marine inundation risk. In order to address this hazard, a potential adaptation measure could be raising of Vigie beach through beach nourishment, which however would probably need also construction of a limited number of offshore breakwaters. Raising of the runway, which would provide additional resilience is also deemed very costly.

Regarding Port Castries (CSP), this is projected that the ESL_{100} will impact its docks severely, inundate its berths, cargo sheds and cruise ship facilities and cause flooding of the city, even under 1.5 °C warming; later in the century and under both RCP scenarios tested, CSP flooding is projected to deteriorate in the absence of effective adaptation measures. CSP has already experienced damages during extreme events, involving its breakwater armour, revetment, fencing and roofing. The Vieux Fort Seaport (VFSP) also appears vulnerable to marine flooding under all tested scenarios, which is markedly different from its previous experience. Both seaports should be raised in order to cope with the projected ESLs. Another adaptation measure is the raising and reinforcement of the present breakwaters; projected changes in wind, sea level and wave conditions as well as changes in the return period (frequency) of extreme events should be considered at the design, although special care should be given to avoid over-engineering of the structures. The roads in and out of seaports should be also appropriately modified to respond to flooding issues. Regarding the seaport operational disruptions, there are operational thresholds for winds (regardless of whether they are associated with a storm) above which the cranes seize operations and are tied down. However, research into their reinforcement could potentially increase such thresholds and is worth investigating further.

As international transportation is a demand-driven industry, indirect impacts may arise from the impacts of CV & C on the capital/product of other economic sectors; for instance, "3S" tourism destinations may require additional adaptation measures to mitigate beach erosion, which is projected to deteriorate very significantly in the future. Indirect impacts on transport are related to the potential reductions in the beach carrying capacity due to the coastal erosion under CV & C (e.g. Scott et al., 2012). Application of the beach retreat prediction methodology showed that the beaches in Saint Lucia are vulnerable to SLR. Under increasing beach erosion/retreat and flooding, the long-term recreational value of the Saint Lucia beaches as well as the value of associated assets may fall considerably (e.g., Gopalakrishnan et al., 2011). Against this background, it appears that plans to respond effectively to the projected beach erosion risk should be urgently drawn up with different adaptation options analysed. Options based on the ecosystem approach should be considered first in order to protect both beaches and backshore ecosystems and infrastructure/assets (e.g., Peduzzi et al., 2013), although "hard" works might, in some cases, be still deemed necessary. However, the significance of beaches as critical economic resources and the low effectiveness of hard coastal works (e.g., breakwaters) to protect beaches from MSLR indicate that beach nourishment schemes will also be required, at least for the most economically important beaches. As marine aggregates constitute the most suitable, but often scarce (Peduzzi, 2014) material for beach nourishment, particular care should be taken to ensure sustainability of marine aggregate deposits (Velegrakis et al., 2010). The significance of such deposits should be certainly considered in any future marine spatial planning, as a matter of priority (see for example the EU Directive 2014/89/EU).

Finally, it appears that the road network connecting the major gateways of international tourism and the major tourist resorts is under an increased risk of landslides, especially during and following extreme precipitation (hurricanes). It was found that during such events, access to major touristic destinations from HIA is generally at much greater risk than that from GCIA. Technical works to armour the cliffs against road affecting landslides should be urgently considered. It is also noteworthy, that redundancy needs make necessary the maintenance of GCIA, as well as the development of appropriate (water-taxi) connecting services.

6.4 Potential adaptation measures

6.4.1 Seaports and airports

A variety of adaptation measures might be employed (following detailed risk assessments) which could be differentiated into the following (see also UNECE, 2013; McEvoy et al., 2013):

Engineering

- Enhance the structural integrity and efficiency of critical facility components including sea defences, berths, mooring facilities, runways and parking aprons, based on design criteria that consider potential changes in wind, sea-level and wave conditions; recalculation of the return periods of major events (e.g. hurricanes and floods) should be undertaken, so that more resilient structures can be engineered.
- Future procurement of mechanical components for the assets (such as conveyor belts, shore cranes etc) needs to be assessed against future operating environment requirements. That is, the expected life of the equipment should be considered against the anticipated future climate.
- Storage facilities need to be upgraded.
- Assess and develop new design standards for hydraulic structures such as drainage systems to cope with projected intense rain events.
- Ongoing hydrographical monitoring to identify if dredging requirements/strategies need modification.
- More robust dust suppression systems may be required (such as covering coal stockpiles, rather than just dampening).
- Road ways in and through ports may need to be raised to respond to flooding issues.
- Construction of storm retention basins for flash flooding.

Technology

- Investment in more climate-resilient technologies and equipment in planned expansion and upgrade programmes, for example: gantry cranes that can operate at higher winds; solar photovoltaics to generate electricity more efficiently for both operations and administration.
- To address increased temperatures, refrigerated storage specifications should be upgraded to meet demands of temperature changes and seek less energy intensive alternatives.
- Onsite renewable and low emission energy for a range of functions to avoid risks associated with power disruption, the increased cost of energy and environmental requirements.
- Automation of logistics procedures.

Planning, design and development

- Internal capacity-building and retraining that recognizes the magnitude and implications of the threat; building of redundancy into critical operations, wherever feasible.

- Ensure ports have a proactive infrastructure and management plan that considers asset lifecycle elements, including altered materials deterioration regimes.
- Working in partnership with governments and supply chain logistics infrastructure providers to appropriately plan and design connected logistics hubs, resilient to the impacts of CC relevant for the area.
- Re-examine land use planning in flood prone areas in order to alleviate flash floods affecting major transport assets.

Management

- Various operational systems need to mainstream climate-change considerations into their procedures, for example, shut-down and start-up operations, emergency protocols and evacuation, environmental management systems, occupational safety and health protocols.

Insurance

- Some risks cannot be avoided; therefore, they must be insured by third parties; collaboration with port management, climate scientists and insurance providers might provide a basis for more reliable quantification of exposure and risks that must be covered.

6.4.2 Technical and operational adaptation options for road network

- New heat thresholds for road surfaces and bridge expansion joints, edge strengthening of road embankments, incorporation of steel grids in the road structure.
- Elevation of roads, bridges and tunnels above the flood fields and development of ‘submergible’ road pavements, tolerant to frequent flooding.
- Addition of drainage canals near coastal roads, relocation of sections of roads, strengthening and heightening of existing levees, seawalls and dikes, additional pumping capacity for tunnels.
- Integration of emergency evacuation procedures into operations and protection of critical evacuation routes.
- Expansion of systems for monitoring scouring of bridge piers/abutments.
- Addition of slope retention structures and retaining facilities for landslides.
- Changes in drainage capacity standards for new infrastructure and rehabilitation (e.g., assuming the current 1 in 500-year rather than 1 in a 100-year storm).

Chapter 7: CONCLUSIONS

The assessment of the impacts of Climate Variability and Change (CV & C) carried out for the major coastal transportation assets of Saint Lucia within the framework of UNCTAD's Development Account Project has shown the following.

The most critical transportation assets (seaports and airports) are all located along the coast and have small elevations; this makes them vulnerable to a number of climatic factors and their projected changes. There is also a strong nexus between these transportation assets and tourism, the main driver of Saint Lucia's economy, which has been estimated to contribute up to 41.5 % of GDP (direct and indirect contributions, 2015), being also the largest earner of foreign exchange.

Since Saint Lucia is a windward island located in the "hurricane alley" of the Atlantic and is characterized by mountainous and rugged topography, it is relatively prone to natural disasters. The island is vulnerable to hydro-meteorological (e.g. high winds, excess rainfall, hurricanes) and geophysical events (e.g. earthquakes, volcanic activity), the impacts of which can be severe and pronounced by the island's small economy. Historical information indicates that storm-induced flooding and associated landslides have been the most likely hydro-meteorological impacts affecting Saint Lucia. Average annual economic losses associated with extreme hydro-meteorological events for the period 1992-2011 have been equivalent to roughly 2 % of GDP or about US$ 26.94 million PPP. Singular high-impact events like Hurricane Allen (1980) and Hurricane Tomas (2010) can be devastating, resulted in damages/losses estimated about 60 % and 43.4 % of St. Lucia's GDP respectively.

Regarding the climate trends and the future projections in Saint Lucia the following conclusions were derived: (i) The average temperature will rise to about 1.8 °C by the 2050s and 3 °C by the 2080s compared with the average temperature of the period 1970-1999. The frequency of very hot days/nights will increase and that of very cool days/nights decrease. (ii) Both GCMs (Global Climate Model) and RCM (Regional Climate Model) projected median decreases in annual rainfall of up to 22 % and 32 %, respectively. Also, projections suggest likely decreases in total heavy rainfall. (iii) Small/moderate increases in storm surge levels are projected, as well as decreases in the wave power of the extreme storms (the 100-year event). (iv) Hurricane intensity is projected to increase, but not necessarily the hurricane frequency. (v) Sea surface temperatures in St. Lucia are projected to increase by 0.8 °C - 3.0 °C by 2080s with potential adverse effects on the island's coral reefs.

The vulnerability of the assets to CV & C was assessed through (a) historical hydro-meteorological impacts and disruptions; (b) assessment of direct impacts on transport operations, using the '*thresholds*' method; (c) assessment of the direct impacts on coastal infrastructure through modelling of the flood/inundation due to extreme sea levels (ESLs) under the present and future climate and (d) indirect impacts associated with the impacts on tourism (3S (Sea- Sand- Sun) model - beaches) and the connectivity/redundancy of the major assets. The vulnerability of the 4 critical coastal transport infrastructure assets of St. Lucia is summarized as follows:

Hewanorra International Airport (HIA) is mainly impacted by rainfall precipitation which results in overflowing of the (re-directed) La Tourney River, causing severe flooding of the airport and its environs. Since recent studies project milder precipitation events (with the exception of hurricanes) and assuming that a proper management of the current terrestrial flooding issues will take place, no further increase of the current risk is anticipated. There has been, to date, no significant damage caused by storm surges and waves and according with the results of the inundation modelling, no impacts are expected in the future due to the effect of storm surges/waves alone. However, the combined effect of MSLR, episodic extremes (combined effect of storm surge and wave set up) and the effects of cyclones will cause the eastern edge of the runway to flood; a 100-year ESL by the year 2100 under RCP 8.5 will inundate a length of about 380 m of the runway. The application of the operational threshold method showed that the projected increase in extreme heat days may have significant effects on the airport operations and energy costs. For example, assuming no major technological advances in aircraft design, decreasing the take-off payload will be necessary for an order of magnitude more days per year by 2050 than is currently the case.

George F.L. Charles airport has experienced flooding of the runway in the past reported by airport officials. This event was probably due to poor drainage into Ganters Bay. Storm surge/waves at the Vigie Beach have resulted only in sand being swept across the road and onto the perimeter of the runway where the walkway is located. However, according to previous research marine flooding levels may exceed 1.8-2.4 m and result in at least partial inundation of the airport runway. The potential erosion of Vigie beach in response to extreme storm events may increase the exposure of the backshore elements of the airport. The inundation modelling carried out within the framework of the present project (courtesy of EC-JRC) has shown that under a 100-year ESL by 2100 (under RCP 8.5) superimposed by a hurricane the entire stretch of the Vigie beach will be inundated, causing water to flow on the runway from the Vigie beach. The inundation of the beach will make the airport very vulnerable to the incident waves.

Port Castries facilities are located at approximately 1.5 m above MSL. No damages have been reported by past storm events and ESLs, although floating debris reaching the port from the land have presented problems to berthing vessels. A 100-year event based on previous research may exacerbate the elevation of parts of the port, suggesting increased risk of inundation particularly close to the entrance. In the present work the effects of a hurricane superimposed on the projected ESLs were studied and the results confirmed that the water level may rise above the elevation of the Port, causing significant damages/flooding to the port facilities. It must be also noted that projections regarding the wave power of extreme events for Saint Lucia in the course of the 21st century are generally optimistic, although the projected changes in direction of wave approach (in the absence of hurricanes) may necessitate some rearrangement of the structural elements of the port.

Port Vieux Fort appears to have been resilient to storm surges and there have been no reported incidents of flooding. Previous studies have shown that a SLR of about 1 m (the mid-century MSLR plus a storm surge of 0.6 m) will not cause any damages to the port to speak of, although the seaward side of the Town of Vieux Fort will be likely flooded. It should be also noted, that flooding of the Mankote mangrove may result in its degradation as it is already under stress from anthropogenic factors. Model results of the present study suggest that cyclone effects superimposed on anticipated ESLs will result to SLR of 1-2.4 m (according to all tested scenarios from the baseline to the year 2100). Given that Port Vieux Fort is approximately 1.5 m above mean sea level, the examined SLR scenarios will cause damages/flooding to the port facilities and the surrounding area, affecting houses as well. The application of the operational threshold method suggests that CV & C may have significant effects on the energy costs of both ports due to the projected increase in extreme temperatures.

It should be noted that the inundation model LISFLOOD-ACC (LFP) used in the present study is a dynamic hydraulic model and its results are much more appropriate than a static model. Its results can be further improved by the use of a better resolution DEM that has not been available in the present study. Sufficient digital elevation model (DEM) resolution is crucial for accurate inundation modelling. Also, although the marine inundation projections take into account the effects of cyclones, these have not been based on direct landfalls on the assets, such as those that several Caribbean SIDS experienced recently (hurricanes Irma and Maria, September 2017). Thus, the above projections may be regarded as underestimations.

Transport and tourism are inextricably linked. The tourist industry in St. Lucia is based on the "3S" model (Sea, Sand and Sun). So, indirect impacts on transport are related to the potential reductions in the beach carrying capacity, due to the coastal erosion under CV & C. Projections of beach erosion/retreat on the basis of appropriate morphodynamic model ensembles have shown that the beaches in Saint Lucia are vulnerable to SLR. Modelling results project significant erosion and flooding under SLR from as early as 2040 under the combined effects of the projected MSLR and storm-induced sea levels. By 2100, beach erosion from combined MSLR and storm events is projected to be very substantial with potentially severe impacts on both coastal infrastructure and tourism. Under increasing beach erosion/retreat and flooding, the long-term recreational value of the Saint Lucia beaches as well as the value of associated assets may fall considerably. Against this background, it appears that plans to respond effectively to the projected beach erosion risk should be drawn up with different adaptation options analysed. Options based on ecosystem approaches should be considered first in order to protect both beaches and backshore ecosystems and infrastructure/assets, although "hard" works might, in some cases, be deemed necessary.

Indirect impacts on tourism/transport are also related to the connectivity of the major gateways of international tourism to the major tourist destinations of the island, i.e. to the coastal resorts/beaches. This connectivity is under increased risk by the large density of landslides that have been recorded during extreme events (hurricanes) at the connecting roads. In the present study, related impacts have been assessed on the basis of landslide density recorded after Hurricane Tomas at the connecting road network between the 2 international airports and the 30 most touristic beaches of the island. It was found that during such an event, access to major touristic destinations from HIA is generally at much greater risk than that from GCIA. Redundancy needs make necessary the maintenance of GCIA in operation. For the same reason the development of water-taxi services should be considered.

REFERENCES

Alexandrakis, G., Manasakis, C., Kampanis, N.A. (2015) Valuating the effects of beach erosion to tourism revenue. A management perspective. Ocean & Coastal Management 111, 1-11.

Alfieri, L., Bisselink, B., Dottori, F., Gustavo, N., de Roo, A., Salamon, P., Wyser, K., Feyen, L. (2017) Global projections of river flood risk in a warmer world. Earth's Future 5, 171–182. doi: 10.1002/2016EF000485.

APESL (2010) Hurricane Tomas Damage Assessment Report, With Technical Assistance by Association of Professional Engineers of St. Lucia (APESL Inc.) Version 1.0 - December 07, 2010.

Auguste, T. (2007) Report on The Passage of Hurricane Dean: St. Lucia. Saint Lucia Meteorological Services. Retrieved September 4, 2012, Available from: http://www.cmo.org.tt/docs/cmc47/PDFs/St._Lucia_Hurricane_Dean.pdf [Accessed 10 August 2016].

Barker, N.H.L. (2003) Ecological and socio-economic impacts of dive and snorkel tourism in St. Lucia, West Indies. PhD Thesis, Environment Department, University of York, pp.232.

Becker, A., Acciaro, M., Asariotis, R., Cabrera, E., Cretegny, L., Crist, P., Esteban, M., Mather, A., Messner, S., Naruse, S., Ng, A.K.Y., Rahmstorf, S., Savonis, M., Song, D.W., Stenek, V., Velegrakis, A.F. (2013) A note on climate change adaptation for seaports: A challenge for global ports, a challenge for global society. Climatic Change 120, 683-695. doi: 10.1007/s10584-013-0843-z.

Benjamin, L., Thomas, A. (2016) 1.5^{o} C to stay alive? AOSIS and the long term temperature goal in the Paris Agreement. IUCNAEL e-Journal, Available from: http://www.iucnael.org/en/e-journal/current-issue [Accessed 10 May 2017].

Bi, X., Lu, Q., Pan, X. (2013) Coastal use accelerated the regional sea-level rise. Ocean & Coastal Management 82, 1-6.

Boeing (2013) 737 Airplane Characteristics for Airport Planning. Boeing Commercial Airplanes, D6-58325-6, September 2013, Available from: http://www.boeing.com/assets/pdf/commercial/airports/acaps/737.pdf.

Bosom, E., Jiménez, J.A. (2010) Storm-induced coastal hazard assessment at regional scale: application to Catalonia (NW Mediterranean). Advances in Geosciences 26, 83–87.

Brown, S., Nicholls, R.J., Lowe, J.A., Hinkel, j. (2013) Spatial variations of sea-level rise and impacts: An application of DIVA. Clim. Change 134(3), 403–416. doi:10.1007/s10584-013-0925-y.

Bruun, P. (1988) The Bruun Rule of erosion by sea level rise: A discussion on large-scale two- and three-dimensional usages. Journal of Coastal Research 4(4), 622-648.

CARIBSAVE (2012) The CARIBSAVE Climate Change Risk Atlas – Climate Change Risk Profile for Saint Lucia, Final draft Country Risk Profile. CARIBSAVE.

Catherine, E. (2013) Analysis of the Saint Lucia Labour Market Needs Assessment Survey 2012, Castries, St Lucia: Central Statistical Office.

CDB – Caribbean Development Bank (2016) Transforming the Caribbean Port Services Industry: Towards the efficiency frontier, Available from: http://www.caribank.org/wp-content/uploads/2016/05/Study_Transformation-of-Caribbean-Maritime-Port-Services-Industry.pdf [Accessed 10 October 2016].

CDB – Caribbean Development Bank (2012) St. Lucia country strategy paper (2013-16). Available from: http://www.caribank.org/uploads/2014/12/BD123_12_CSP_STL_FINAL.pdf [Accessed 15 May 2016].

Christensen, J.H., Krishna Kumar, K., Aldrian, E., An, S.-I., Cavalcanti, I.F.A., de Castro, M., Dong, W., Goswami, P., Hall, A., Kanyanga, J.K., Kitoh, A., Kossin, J., Lau, N.-C., Renwick, J., Stephenson, D.B., Xie, S.-P., Zhou, T. (2013) Climate Phenomena and their Relevance for Future Regional Climate Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex V., Midgley, P.M. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1217–1308.

Church, J.A., Clark, P.U., Cazenave, A., Gregory, J.M., Jevrejeva, S., Levermann, A., Merrifield, M.A., Milne, G.A., Nerem, R.S., Nunn, P.D., Payne, A.J., Pfeffer, W.T., Stammer, D. and Unnikrishnan, A.S. (2013) Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

CIA (2016) The World Factbook 2016. Central Intelligence Agency, Washington, DC, Available from: https://www.cia.gov/library/publications/the-world-factbook/geos/print_st.html [Accessed 20 May 2016].

Ciavola, P., Ferreira, O., Haerens, P., Van Koningsveld, M., Armaroli, C. (2011) Storm impacts along European coastlines. Part 2: Lessons learned from the MICORE project. Environ. Sci. Policy 14(7), 924–933. doi:10.1016/j.envsci.2011.05.009.

Cisneros, H.M.A., Revollo, Sarmiento, N.V., Delrieux, C.A., Piccolo, M.C., Perillo, G.M.E. (2016) Beach carrying capacity assessment through image processing tools for coastal management. Ocean & Coastal Management 130, 138-147.

Corbella, S., Stretch, D.D. (2012) Predicting coastal erosion trends using non-stationary statistics and process-based models. Coastal Engineering 70, 40–49.

CSO (2016a) Saint Lucia Economic Growth, Available from: http://192.147.231.244:9090/stats/index.php/gross-domestic-product [Accessed 28 June 2016].

CSO (2016b) Saint Lucia: Labour Force [WWW] Available from: http://192.147.231.244:9090/stats/index.php/labour-force [Accessed 28 June 2016].

Cubas, D., Briceño-Garmendia, C. and Bofinger, H.C. (2015) OECS Ports: An Efficiency and Performance Assessment, Policy Research Working Paper 7162, Transport and ICT Global Practice Group, World Bank Group.

Dean, R.G. (2002) Beach nourishment: Theory and practice. In: Advanced Series on Ocean Engineering, Singapore, World Scientific Publishing Company.

Dean, R.G. (1991) Equilibrium beach profiles: characteristics and applications. Journal of Coastal Research 7(1), 53–84.

Ding, Y., Kuiry, S.N., Elgohry, M., Jia, Y., Altinakar, M.S., Yeh, K.-C. (2013) Impact assessment of sea-level rise and hazardous storms on coasts and estuaries using integrated processes model. Ocean Engineering 71, 74–95.

Edelman, T. (1972) Dune erosion during storm conditions. In: Proceedings of the 13th International Conference on Coastal Engineering ASCE, 1305-1312.

EFR (2016) Economic and Financial Review, Eastern Caribbean Central Bank, 36(1), pp.172.

Egbert, G.D., Erofeeva, S.Y. (2002) Efficient Inverse Modeling of Barotropic Ocean Tides. Journal of Atmospheric and Oceanic Technology 19, 183-204. doi: 10.1175/1520-0426(2002)019<0183:EIMOBO>2.0.CO;2.

Elsner, J.B., Kossin, J.P., Jagger, T.H. (2008) The increasing intensity of the strongest tropical cyclones. Nature 455, 92–95. doi:10.1038/nature07234.

Emanuel, K., Sundararajan, R., Williams, J. (2008) Hurricanes and global warming: Results from downscaling IPCC AR4 simulations. Bull. Am. Meteorol. Soc. 89, 347–367.

Environment Solutions (2015) Final – Volume I Impact Assessment Report and National Adaptation Strategy and Action Plan Saint Lucia. Prepared for the Caribbean Community Climate Change Centre Belmopan, Belize and Ministry of Sustainable Development Energy Science and Technology and the Ministry of Tourism Heritage and Creative Industries Saint Lucia.

ESL (2015) Impact Assessment and National Adaptation Strategy and Action Plan to Address Climate Change in the Tourism Sector, Saint Lucia, Prepared for: Caribbean Community Climate Change Centre (CCCCC) and the Government of Saint Lucia (GoSL) under the European Union Global Climate Change Alliance (EU-GCCA) Caribbean Support Project, pp.111.

FAO (2016) Drought characteristics and management in the Caribbean. Caribbean Institute for Meteorology and Hydrology, St. James, Barbados and Land and Water Division, FAO, Rome.

Forzieri, G., Feyen, L., Russo, S., Vousdoukas, M., Alfieri, L., Outten, S., Migliavacca, M., Bianchi, A., Rojas, R, Cid, A. (2016) Multi-hazard assessment in Europe under climate change. Climatic Change 137, 105-119. doi: 10.1007/s10584-016-1661-x.

Gallop, S.L., Bosserelle, C., Eliot, I., Pattiaratchi, C.B. (2012) The influence of limestone reefs on storm erosion and recovery of a perched beach. Continental Shelf Research 47, 16–27.

Gariano, S.L. and Guzzetti, F. (2016) Landslides in a changing climate. Earth-Science Reviews 162, 227–252.

Ghermandi, A. and Nunes, P.A.L.D. (2013) A global map of coastal recreation values: Results from a spatially explicit meta-analysis. Ecological Economics 86, 1–15.

Gopalakrishnan, S., Smith, M.D., Slott, J.M., Brad Murray, A. (2011) The value of disappearing beaches: A hedonic pricing model with endogenous beach width. J. Environ. Econ. Manag. 61, 297–310.

GoSL – Government of Saint Lucia (2000) First National Report to the Convention on Biological Diversity.

GoSL and World Bank (2014) Saint Lucia: Flood Event of December 24–25, 2013. Joint Rapid Damage and Needs Assessment. Report by the Government of Saint Lucia and the World Bank, Available from: https://www.gfdrr.org/sites/default/files/publication/pda-2014-saint-lucia.pdf [Accessed 04 September 2017].

Harmeling, S., Eckstein, D. (2012) Global Climate Risk Index 2013. Who Suffers Most from Extreme Weather Events? Weather-Related Loss Events in 2011 and 1992 to 2011. German Watch, Bonn and Berlin, Germany, pp.28.

Hauer, M.E., Evans, J.M., Mishra, D.R. (2016) Millions projected to be at risk from sea-level rise in the continental United States. Nature Climate Change 6(7), 691–695. doi:10.1038/nclimate2961.

HDR - Human Development Report (2015) Work for human development, Briefing note for countries on the 2015 Human Development Report, Saint Lucia. United Nations Development Programme.

Hinkel, J., Lincke, D., Vafeidis, A.T., Perrette, M., Nicholls, R.J., Tol, R.S.J., Marzeion, B., Fettweis, X., Ionescu, C., Levermann, A. (2014) Coastal flood damage and adaptation costs under 21st century sea-level rise. Proc. Natl. Acad. Sci. U.S.A. 111(9), 3292–3297. doi:10.1073/pnas.1222469111.

Hinkel, J., Nicholls, R.J., Vafeidis, A.T., Tol, R.S.J., Avagianou, T. (2010) Assessing risk of and adaptation to sea-level rise in the European Union: An application of DIVA. Mitigation and Adaptation Strategies for Global Change 15(7), 703-719.

Hodges, K., Cobb, A., Vidale, P.L. (2017) How well are tropical cyclones represented in reanalysis datasets? Journal of Climate 30, 5243-5264. doi: 10.1175/JCLI-D-16-0557.1.

Hoeke, R.K., McInnes, K.L., Kruger, J.C., McNaught, R.J., Hunter, J.R., Smithers, S.G. (2013) Widespread inundation of Pacific islands triggered by distant-source wind-waves. Global and Planetary Change 108, 128-138.

Holland, G., Bruyère, C.L. (2014) Recent intense hurricane response to global climate change. Climate Dynamics 42, 617–627. doi:10.1007/s00382-013-1713-0.

Holland, G.J., Webster, P.J. (2007) Heightened tropical cyclone activity in the North Atlantic: Natural variability or climate trend? Philosophical Transactions of the Royal Society A 365, 2695-2716.

Hurricane Disaster (n.d.), Available from: http://www.nhc.noaa.gov/archive/storm_wallets/atlantic/atl1960/abby/news/stlucia.gif [Accessed 24 July 2017].

ICF GHK (2012) Climate change adaptation planning in Latin American and Caribbean cities. Final report Castries, Saint Lucia, pp.156.

IICA (2015) Annual report 2015 - Saint Lucia: IICA's contribution to the development of agriculture and rural communities. Inter-American Institute for Cooperation on Agriculture, Castries, pp.36.

IMF (2016) St. Lucia: 2015 Article IV Consultation—Press Release and Staff Report. International Monetary Fund, Washington, D.C., pp.79.

IPCC (2014) Coastal systems and low-lying areas. In IPCC WGII AR5, Intergovermental Panel on Climate Change, Cambridge, U.K.

IPCC (2007) Summary for Policy Makers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., Qin, D., Manning, V., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (eds)]. Cambridge University Press, United Kingdom and New York, NY, USA.

Jagers, B., Rego, J.L., Verlaan, M., Lalic, A., Genseberger, M., Friocourt, Y., van der Pijl, S. (2014) A Global Tide and Storm Surge Model with a Parallel Unstructured-Grid Shallow Water Solver. American Geophysical Union Fall Meeting Abstracts 1, 5.

Jiménez, J.A., Bosom, E., Valdemoro, H.I., Guillén, J. (2012) Storm-induced damages along the Catalan coast (NW Mediterranean) during the period 1958–2008. Geomorphology 143-144, 24-33.

Kairi Consultants LTD (2007) Trade Adjustment and Poverty in Saint Lucia 2005/06, VOLUME I: MAIN REPORT, Submitted to: THE CARIBBEAN DEVELOPMENT BANK, Available from: http://www.caribank.org/uploads/publications-reports/economics-statistics/country-poverty-assessment-reports/SLUCPAMainReport.pdf [Accessed 20 July 2016].

Karambas, Th. (2006) Prediction of sediment transport in the swash zone by using a nonlinear wave model. Continental Shelf Research 26, 599–609.

Karambas, T.V., Koutitas, C. (2002) Surf and swash zone morphology evolution induced by nonlinear waves. Journal of Waterway, Port, Coastal and Ocean Engineering, ASCE 128 (3).

Khouakhi, A., Snoussi, M., Niazi, S., Raji, O. (2013) Vulnerability assessment of Al Hoceima bay (Moroccan Mediterranean coast): a coastal management tool to reduce potential impacts of sea-level rise and storm surges. Journal of Coastal Research SI 65, 968-973.

King-Joseph, A. (2010) Vulnerability and Adaptation Study for Saint Lucia's Second National Communication – Critical Infrastructure, Ministry for Physical Development and the Environment.

Klotzbach, P.J. (2006) Trends in global tropical cyclone activity over the past twenty years (1986–2005). Geophys. Res. Lett. 33, L10805. doi:10.1029/2006GL025881.

Klotzbach, P.J., Landsea, C.W. (2015) Extremely Intense Hurricanes: Revisiting Webster et al. (2005) after 10 Years. Journal of Climate 28(19), 7621-7629.

Knapp, K.R., Kruk, M.C., Levinson, D.H., Diamond, H.J., Neumann, C.J. (2010) The International Best Track Archive for Climate Stewardship (IBTrACS): Unifying tropical cyclone best track data. Bulletin of the American Meteorological Society 91, 363-376. doi:10.1175/2009BAMS2755.1.

Knutson, T.R., McBride, J.L., Chan, J., Emanuel, K., Holland, G., Landsea, C., Held, I., Kossin, J.P., Srivastava, A.K., Sugi, M. (2010) Tropical cyclones and climate change. Nature Geosc. 3, 157–163.

Kossin, J.P., Olander, T.L. and Knapp, K.R. (2013) Trend analysis with a new global record of tropical cyclone intensity. J. Climate 26, 9960–9976. doi:10.1175/JCLI-D-13-00262.1.

Kreft, S., Eckstein, D., Melchior, I. (2016) Global Climate Risk Index 2017, Who Suffers most from Exterme Weather Events? Weather-related loss events in 2015 and 1996 to 2015, Available from: https://germanwatch.org/en/download/16411.pdf [Accessed 02 November 2016].

Landsea, C.W., Vecchi, G. A., Bengtsson, L., Knutson, T. R. (2010) Impact of duration thresholds on Atlantic tropical cyclone counts. J. Climate 23, 2508–2519.

Larson, M., Kraus, N.C. (1989) SBEACH: numerical model for simulating storm-induced beach change; report 1: empirical foundation and model development. Technical Report - US Army Coastal Engineering Research Center 89-9.

Leont'yev, I.O. (1996) Numerical modelling of beach erosion during storm event. Coastal Engineering 29(1-2), 187-200.

Lewsey, C., Cid, G., Kruse, E., Virdin, J. (n.d.) Mainstreaming Adaptation to Climate Change (MACC), Climate Change Impact on Land Use Planning and Coastal Infrastructure. National Oceanic and Atmospheric Administration's National Ocean Services (NOS).

Ministry of Infrastructure Port Services and Transport (2014) Damage Assessment Report Of Torrential Rains of 24 December 2013, St. Lucia.

Matias, A., Ferreira, O., Vila-Concejo, A., Garcia, T., Dias, J.A. (2008) Classification of washover dynamics in barrier islands. Geomorphology 97(3–4), 655–674. doi:10.1016/j.geomorph.2007.09.010.

McArthur, S. (2015) Why Carrying Capacity Should be a Last Resort (2015). In: T.Vir Singh (Ed.), Challenges in Tourism Research. Channel View Publications, 288-302.

McCall, R.T., Van Thiel de Vries, J.S.M., Plant, N.G., Van Dongeren, A.R., Roelvink, J.A., Thompson, D.M., Reniers A.J.H.M. (2010) Two-dimensional time dependent hurricane overwash and erosion modeling at Santa Rosa Island. Coast. Eng. 57(7), 668–683. doi:10.1016/j.coastaleng.2010.02.006.

McEvoy, D., Mullett, J., Millin, S., Scott, H., Trundle, A. (2013) Understanding future risks to ports in Australia, Enhancing the resilience of seaports to a changing climate report Series. National Climate Change Adaptation Research Facility, Gold Coast. ISBN: 978-1-921609-84-8 NCCARF.

McLeod, E., Poulter, B., Hinkel, J., Reyes, E., and Salm, R., (2010) Sea-level rise impact models and environmental conservation: A review of models and their applications. Ocean & Coastal Management 53, 507-517.

McSweeney, C., New, M., Lizcano, G. (2010) UNDP Climate Change Country Profiles: St. Lucia Available from: http://www.geog.ox.ac.uk/research/climate/projects/undp-cp/UNDP_reports/St_Lucia/St_Lucia.hires.report.pdf [Accessed 07 November 2016].

Mentaschi, L., Vousdoukas, M. I., Voukouvalas, E., Dosio, A. and Feyen, L. (2017) Global changes of extreme coastal wave energy fluxes triggered by intensified teleconnection patterns. Geophys. Res. Lett. 44, 2416-2426. doi:10.1002/2016GL072488.

Mentaschi, L., Vousdoukas, M.I., Voukouvalas, E., Sartini, L., Feyen, L., Besio, G., Alfieri, L. (2016) Non-stationary Extreme Value Analysis : A simplified approach for Earth science applications. Hydrol. Earth Syst. Sci. Discuss, 1–38. doi: 10.5194/hess-2016-65.

Mishra, P. (2006) Emigration and Brain Drain: Evidence From the Caribbean. IMF Working paper.

Monioudi, I.N., Asariotis, R., Becker, A., Bhat, C., Dowding-Gooden, D., Esteban, M., Feyen, L., Mentaschi, L., Nikolaou, A., Nurse, L., Phillips, W., Smith, D.A-Y., Satoh, M., Trotz, U., Velegrakis, A.F., Voukouvalas, E., Vousdoukas, M.I., Witkop, R., (submitted) Climate change impacts on critical international transportation assets of Caribbean Small Island Developing States (SIDS): The case of Jamaica and Saint Lucia. Regional Environmental Change.

Monioudi I.N, Velegrakis A.F., Chatzipavlis A.E., Rigos A., Karambas, Th., Vousdoukas, M.I., Hasiotis, Th., Koukourouvli, N., Peduzzi, P., Manoutsoglou, E., Poulos, S.E., Collins, M.B. (2017) Assessment of island beach erosion due to sea level rise: The case of the Aegean Archipelago (Eastern Mediterranean). Natural Hazards and Earth System Science 17, 449–466.

Monioudi, I.N., Karditsa, A., Chatzipavlis, A., Alexandrakis, G., Andreadis, O.P., Velegrakis, A.F, Poulos, S.E., Ghionis, G., Petrakis, S., Sifnioti, D., Hasiotis, Th., Lipakis, M., Kampanis, N., Karambas, Th., Marinos, E. (2016) Assessment of the vulnerability of the eastern Cretan beaches (Greece) to sea level rise. Regional Environmental Change 16 (7), 1951–1962.

Mott MacDonald (2013) Landslide Risk Assessment for Saint Lucia's Primary Road Network, Hurricane Tomas Rehabilitation and Reconstruction Final Feasibility Report, September 2013, Government of Saint Lucia, Castries, pp.258.

Muis, S., Verlaan, M., Winsemius, H.C., Aerts, J.C.J.H., Ward, P.J. (2016) A global reanalysis of storm surges and extreme sea levels. Nature Communications 7, 1-11. doi: 10.1038/ncomms11969.

Murakami, H., Wang, Y., Sugi, M., Yoshimura, H., Mizuta, R., Shindo, E., Adachi, Y., Yukimoto, S., Hosaka, M., Kitoh, A., Ose, T., Kusunoki, S. (2012) Future changes in tropical cyclone activity projected by the new high-resolution MRI-AGCM. Journal of Climate 25, 3237–3260.

Next Steps in Saint Lucia Recovery After Tropical Storm Matthew (2016) St. Lucia Times. 30th Sept, Available from: https://stluciatimes.com/2016/09/30/steps-recovery-saint-lucia-tropical-storm-matthew [Accessed 04 September 2017].

Nurse, L.A., McLean, R.F., Agard, J., Briguglio, L.P., Duvat-Magnan, V., Pelesikoti, N., Tompkins, E. and Webb, A. (2014) Small islands. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1613-1654.

Nurse, L. (2013) Climate Change Impacts and Risks: The Challenge for Caribbean Ports, STC-13, April 15-18 Georgetown, Guyana.

Palanisamy, H., Becker, M., Meyssignac, B., Henry, O., Cazenave, A. (2012) Regional sea level change and variability in the Caribbean Sea since 1950. Journal of Geodetic Science 2(2), 125-133.

Parker, A., Saad Saleem, M., Lawson, M. (2013) Sea-level trend analysis for coastal management. Ocean & Coastal Management 73, 63-81.

Paula, D.P., Dias, J.M.A., Ferreira, O., Morais, J.O. (2013) High-rise development of the sea-front at Fortaleza (Brazil): Perspectives on its valuation and consequences. Ocean & Coastal Management 77, 14-23.

Peduzzi, P. (2014) Sand, rarer than one thinks. Article reproduced from United Nations Environment Programme (UNEP) Global Environmental Alert Service (GEAS), Environmental Development 11, 208–218

Peduzzi, P., Velegrakis, A.F., Estrella, M., Chatenoux, B. (2013) Integrating the role of ecosytems in disaster risk and vulnerability assessments: Lessons from the Risk and Vulnerability Assessment Methodology Development Project (RiVAMP) in Negril Jamaica. In: FG Renaud et al. (eds), The role of Ecosystems in Disaster Risk Reduction. United Nations University Press (ISBN 978-9280812213), 109-139.

Phillips, M.R., Jones, A.L. (2006) Erosion and tourism infrastructure in the coastal zone: Problems, consequences and management. Tourism Management 27, 517-524.

Pielke, R., Rubiera, J., Landsea, C., Fern_andez, M., Klein, R. (2003) Hurricane vulnerability in Latin America and The Caribbean: Normalized damage and loss potentials. Natural Hazards Review 4(3), 101–114. doi:10.1061/(ASCE)1527-6988(2003)4:3(101).

PSAR (2014) The Private Sector Assessment Report, Caribbean Development Bank - Compete Caribbean, Available from: http://www.caribank.org/uploads/2014/11/2014-St.-Lucia-PSAR.pdf [Accessed 03 September 2016].

Queffeulou, P., Croizé-Fillon, D. (2014) Global altimeter SWH data set. Rep., Laboratoire d'Océanographie Spatiale, IFREMER.

Quinn, P. (2012) Landslide susceptibility and risk in Saint Lucia. Draft paper submitted to Canadian Geotechnical Journal. Available from: https://petequinnramblings.wordpress.com/2012/04/02/landslide-susceptibility-and-risk-in-saint-lucia-draft-paper/ [Accessed 21 March 2016].

Oumeraci, H. (1994) Review and analysis of vertical breakwater failures—Lessons learned. Coast. Eng. 22(1–2), 3–29. doi:10.1016/0378-3839(94)90046-9.

Rajan, B., Varghese, V.M., Pradeepkumar, A.P., (2013) Beach Carrying Capacity Analysis for Sustainable Tourism Development in the South West Coast of India. Environmental Research, Engineering and Management 1 (63), 67-73.

Ramieri, E., Hartley, A., Barbanti, A., Duarte Santos, F., Laihonen, P., Marinova, N., Santini, M., (2011) Methods for assessing coastal vulnerability to climate change. ETC CCA Background Paper, Copenhagen (DK) 8-9 June 2011. European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation European Environment Agency, 76pp. http://www.oannes.org.pe/.

Ranasinghe, R., Duong, T.M., Uhlenbrook, S., Roelvink, D., Stive, M. (2013) Climate-change impact assessment for inlet-interrupted coastlines. Nature Climate Change 3, 83-87.

Rappaport, E. (1994) Tropical Storm Debby Preliminary Report. National Hurricane Center. http://www.nhc.noaa.gov/archive/storm_wallets/atlantic/atl1994-prelim/debby/ [Accessed 20 August 2017].

Review of the Economy (2015) Government of Saint Lucia, Available from: https://www.google.gr/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&uact=8&ved=0ahUKEwiCkeGYi5TQAhVIwBQKHfO8AsQQFggsMAI&url=https%3A%2F%2Fwww.finance.gov.lc%2Fresources%2Fdownload%2F2041&usg=AFQjCNEQSVwoLh3ye7WbOoSa1XWzwlFjGw&bvm=bv.137904068,d.bGg [Accessed 24 June 2016].

Roelvink, D., Reniers, A., van Dongeren, A., van Thiel de Vries, J., Lescinski, J., McCall, R. (2010) Xbeach Model Description and Manual, Unesco-IHE Institute for Water Education. Deltares and Delft University of Technology, pp.106.

Roelvink, D., Reniers, A., Van Dongeren, A., Van Thiel de Vries, J., McCall, R., Lescinski, J. (2009) Modeling storm impacts on beaches, dunes and barrier islands. Coastal Engineering 56, 1133–1152.

Rogers, C.T. (1997) 18 Landslide hazard data for watershed management and development planning, Saint Lucia, West Indies. In R. Ahmad (Ed.), Natural hazards and hazard management in the Greater Caribbean and Latin America (Vol. Publication No. 3, pp. 150–164). Unit for Disaster Studies, The University of the West Indies.

Saint Lucia Meteorological Service (1994) Report on the 1994 Atlantic hurricane season: Tropical Storm Debby. National Hurricane Center, Available from: http://www.nhc.noaa.gov/archive/storm_wallets/atlantic/atl1994/debby/preloc/stlucia1.gif [Accessed 20 August 2016].

Scott, D., Simpson, M.C., Sim, R. (2012) The vulnerability of Caribbean coastal tourism to scenarios of climate change related sea level rise. Journal of Sustainable Tourism 20(6), 883-898.

Scott, S., Jean, E., Bobb, M., Mathurin, G., Chastanet, S., Tulsie, B., et al. (2006) Global Environment Outlook St Lucia: State of the Environment. Sustainable Development and Environment Section. Castries: United Nations Environment Programme (UNEP).

Short, A.D., Jackson, D.W.T. (2013) Beach Morphodynamics. In: Treatise on Geomorphology, edited by: Shroder, J., Sherman, D.J. 10, 106–129.

Simpson, M.C., Clarke, J.F., Scott, D.J., New, M., Karmalkar, A., Day, O.J., Taylor, M., Gossling, S., Wilson, M., Chadee, D., Stager, H., Waithe, R., Stewart, A., Georges, J., Hutchinson, N., Fields, N., Sim, R., Rutty, M., Matthews, L., Charles, S. (2012) CARIBSAVE Climate Change Risk Atlas (CCCRA) - Saint Lucia. DFID, AusAID and The CARIBSAVE Partnership, Barbados, West Indies.

Simpson, M.C., Scott, D., Harrison, M., Silver, N., O'Keeffe, E., Harrison, S., Taylor, M., Sim, R., Lizcano, G., Wilson, M., Rutty, M., Stager, H., Oldham, J., New, M., Clarke, J., Day, O.J., Fields, N., Georges, J., Waithe, R., McSharry, P. (2010) Quantification and Magnitude of Losses and Damages Resulting from the Impacts of Climate Change : Modelling the Transformational Impacts and Costs of Sea Level Rise in the Caribbean (Full Document). United Nations Development Programme (UNDP), Barbados, West Indies.

SLTB (2016) Economic Indicators 2016, Available from: http://www.investstlucia.com/content_manager/documents/index/16/page:2 [Accessed 28 June 2016].

Smith, D. (2014) Section 3.7 Infrastructure. Damage and loss Assessment of the Christmas Eve Trough of 2013.

SNC (2011) Second National Communication on Climate Change for Saint Lucia, December 2011, Available from: http://dipecholac.net/docs/xfiles/544-lcanc2.pdf [Accessed 10 June 2016].

Stockdon, H.F., Holman, R.A., Howd, P.A., Sallenger, J.A.H. (2006) Empirical parameterization of setup, swash, and runup. Coastal Engineering 53, 573–588.

Thomas-Louisy, L. (2014) Saint Lucia: Country Document for Disaster Risk Reduction, National Emergency Management Organisation (NEMO), UNISDR DIPECHO Project.

Taylor, K.E., Stouffer, R.J., Meehl, G.A. (2012) An overview of CMIP5 and the experiment design. Bulletin of the American Meteorological Society 93, 485-499. doi: 10.1175/BAMS-D-11-00094.1.

Torres, R.R. (2013) Sea-level variability in the Caribbean Sea over the last century. University of Southampton, Ocean and Earth Science, Doctoral Thesis, pp.216.

Torres, R.R., Tsimplis, M.N. (2014) Sea level extremes in the Caribbean Sea. Journal of Geophysical Research: Oceans 119, 4714–4731. doi:10.1002/2014JC009929.

UNCTAD (2014) Small Island Developing States: Challenges in transport and trade logistics. Multi-Year Expert Meeting on Transport, Trade Logistics and Trade Facilitation, Third Session. 24-26/11/2014.Trade and Development Commission, Available from: http://unctad.org/meetings/en/SessionalDocuments/cimem7d8_en.pdf [Accessed 9 May 2017].

UNCTAD (2017a) Climate change impacts on coastal transport infrastructure in the Caribbean: enhancing the adaptive capacity of Small Island Developing States (SIDS), JAMAICA: A case study. UNDA project 1415O.

UNCTAD (2017b) Climate change impacts on coastal transport infrastructure in the Caribbean: enhancing the adaptive capacity of Small Island Developing States (SIDS), Climate Risk and Vulnerability Assessment Framework for Caribbean Coastal Transport Infrastructure. UNDA project 1415O.

UNDP (2010) Social Implications of the Global Economic Crisis in Caribbean Small Island Developing States: 2008-2009 – Saint Lucia Country Report, Available from: http://www.bb.undp.org/content/dam/barbados/docs/projectdocs/poverty/St%20Lucia%20Country%20Report%20%2028%20September%202011.pdf [Accessed 28 June 2016].

UNECE (2013) Climate Change Impacts and Adaptation for International Transport Networks. Expert Group Report, Inland Transport Committee, United Nations Economic Commission for Europe ECE/TRANS/238, pp.223, Available from: http://www.unece.org/fileadmin/DAM/trans/main/wp5/publications/climate_change_2014.pdf [Accessed 10 June 2017].

UNECLAC (2014) An Assessment of Mechanism to Improve Energy Efficiency in the Transport Sector in Grenada, Saint Luci and St. Vincent and the Grenadines. LC/L.3915, LC/CAR/L.449, pp.43, Available from: http://repositorio.cepal.org/bitstream/handle/11362/37257/S1420560_en.pdf?sequence=1 [Accessed 10 October 2016].

UNECLAC (2011a) An assessment of the economic impact of climate change on the tourism sector in Saint Lucia. UN Economic Commission for Latin America and the Caribbean ECLAC Technical Report LC/CAR/L306, pp.46.

UNECLAC (2011b) An assessment of the economic impact of climate change on the transportation sector in Barbados. UN Economic Commission for Latin America and the Caribbean ECLAC Technical Report LC/CAR/L309, pp.44.

UNECLAC (2011c) Saint Lucia: Macro Socio-Economic and Environmental Assessment of the Damage and Losses Caused by Hurricane Tomas: A Geo-Environmental Disaster - Towards Resilience. Port-of-Spain, Trinidad and Tobago: United Nations Economic Commission for Latin America and the Caribbean (UNECLAC) - Sub-Regional Headquarters for the Caribbean.

UNECLAC (2007) Saint Lucia Macro Socio-Economic Assessment Of The Damage And Losses Caused By Hurricane Dean.

UNEP (2016) Green Economy Scoping Study for Saint Lucia. United Nations Environmental Programme, Available from: http://web.unep.org/greeneconomy/sites/unep.org.greeneconomy/files/final_green_economy_scoping_study_for_saint_lucia_1.pdf [Accessed 10 January 2017].

USAID/J-CAR (2000) Hurricane Lenny Recovery in the Eastern Caribbean. Special Objective Document.

U.S. Army Corps of Engineers (2002) Coastal Engineering Manual. U.S. Army Corps of Engineers, Washington, DC

U.S. Weather Bureau (1960) Hurricane Abby, July 10-15, 1960; Preliminary report with the advisories and bulletins issued ftp://ftp.library.noaa.gov/docs.lib/htdocs/rescue/hurricanes/QC9452A18H81960.pdf [Accessed 10 August 2017].

UWI (2005) Natural Hazards and Disasters: Landslides in Saint Lucia. University of West Indies (UWI), Unit for Disaster Studies, Available from: http://www.mona.uwi.edu/uds/Land_St_Lucia.html [Accessed 29 May 2016].

Van Westen, C.J. (2016) National Scale Landslide Susceptibility Assessment for Saint Lucia. CHARIM Caribbean Handbook on Risk Information Management, World Bank GFDRR, ACP-EU Natural Disaster Risk Reduction Program. http://www.charim.net/sites/default/files/handbook/maps/SAINT_LUCIA/SLULandslideReport.pdf.

Velegrakis, A.F., Ballay, A., Poulos, S., Radzeviˇcius, R., Bellec, V., and Manso, F. (2010) European marine aggregates resources: Origins, usage, and mining techniques. J. Coastal Res. SI 51, 1–14.

Vousdoukas, M.I., Mentaschi, L., Voukouvalas, E., Verlaan, M., Feyen, L. (2017) Extreme sea levels on the rise along Europe's coasts. Earth's Future 5, 265–353. doi:10.1002/2016EF000505.

Vousdoukas, M.I., Voukouvalas, E., Annunziato, A., Giardino, A., Feyen, L. (2016a) Projections of extreme storm surge levels along Europe. Climate Dynamics 47(9-10), 3171–3190. doi:10.1007/s00382-016-3019-5.

Vousdoukas, M. I., Voukouvalas, E., Mentaschi, L., Dottori, F., Giardino, A., Bouziotas, D., Bianchi, A., Salamon, P., Feyen, L., (2016b) Developments in large-scale coastal flood hazard mapping. Natural Hazards Earth System Science 16, 1841–1853.

Vousdoukas, M.I., Velegrakis, A.F., Karambas, T.V. (2009a) Morphology and sedimentology of a microtidal beach with beachrocks: Vatera, Lesbos, NE Mediterranean. Continental Shelf Research 29(16), 1937-1947.

Vousdoukas, M.I., Velegrakis, A.F., Dimou, K., Zervakis, V., Conley, D.C. (2009b) Wave run-up observations in microtidal, sediment-starved beaches of the Eastern Mediterranean. Journal of Marine Systems 78, 537-547

Walker, L. (2005) Towards the Development of a Coastal Zone Management Strategy and Action Plan for Saint Lucia. Research Paper for United Nations/Nippon Foundation of Japan Fellowship.

Webster, P.J., Holland, G.J., Curry, J.A., Chang H.-R. (2005) Changes in tropical cyclone number, duration, and intensity in a warming environment. Science 309, 1844–1846. doi:10.1126/science.1116448.

World Bank (2016) St. Lucia [WWW] Available from: http://data.worldbank.org/country/st-lucia [Accessed 10 May 20016].

World Bank (2014) Project Appraisal Document on Proposed Credits to Saint Lucia for a Disaster Vulnerability Reduction Project, pp.74, , Available from: http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2014/06/06/000333037_20140606112810/Rendered/PDF/870440REPLACEM0IC0disclosed06050140.pdf [Accessed May 27, 2015].

World Bank (2013) Disaster vulnerability reduction project (DVRP): Environmental assessment and environmental management framework. Saint Lucia, Available from: http://documents.worldbank.org/curated/en/697941468112492735/Environmental-assessment-and-environmental-management-framework [Accessed 10 October 2016].

WRI (2008a) Shoreline Protection by Coral Reefs, Relative Reef Contribution - St. Lucia [WWW] World Resources Institute. Available from: http://www.wri.org/resources/maps/shoreline-protection-coral-reefs-relative-reef-contribution-st-lucia [Accessed on March 21 2016].

WRI (2008b) Land Vulnerable to Wave Induced Erosion and Storm Damage - St. Lucia [WWW] World Resources Institute. Available from: http://www.wri.org/resources/maps/land-vulnerable-wave-induced-erosion-and-storm-damage-st-lucia [Accessed on March 21 2016].

WTO (1981) Technical handbook on the collection and presentation of domestic and international tourism statistics. World Tourism Organization: Madrid.

WTTC (2015) Travel & Tourism: Economic Impact 2015 St Lucia, Available from: http://www.caribbeanhotelandtourism.com/wp-content/uploads/data_center/destinations/StLucia-WTTC-EconomicImpact2015.pdf [Accessed 4 September 2016].

Zacarias, D.A., Williams, A.T., Newton, A. (2011) Recreation carrying capacity estimations to support beach management at Praia de Faro. Portugal Applied Geography 31, 1075-1081.

APPENDIX A

Beach retreat predictions methodology

Sea level rise represents the most significant threat to beaches forcing their retreat/erosion. Sea level rise *α* will result in a shoreline retreat *S* due to erosion of the beach face, the sediments of which are transported/deposited offshore, with the extent/rates of the cross-shore retreat controlled (amongst others) by bed slope, the texture and supply of beach sediments and the hydrodynamic conditions (e.g. Dean, 2002).

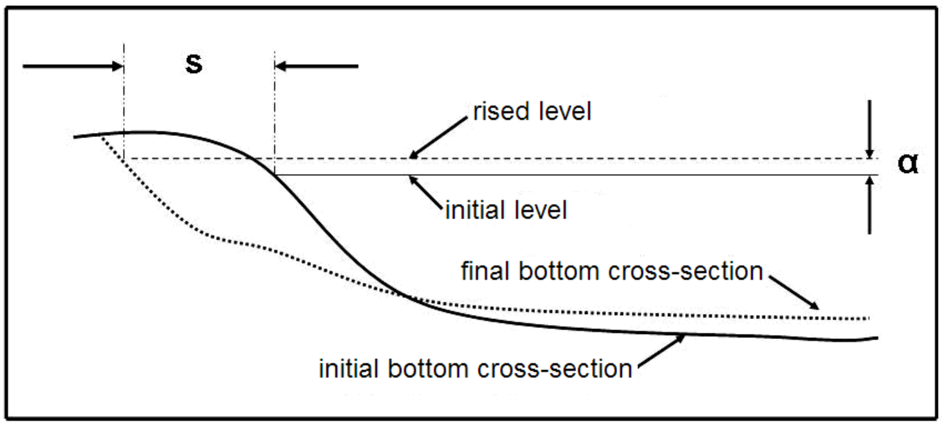


Figure A-1 Sketch of beach response to sea level rise. A rise α produces erosion of the beach face sediment which is transferred to the adjacent sea bed, resulting in a beach retreat S.

Seven cross-shore morphodynamic models were used to project beach response to SLR: the *Bruun* (Bruun, 1988), *Edelman* (Edelman, 1972) and *Dean* (Dean, 1991) analytical models and the numerical models *SBEACH* (Larson and Kraus, 1989), *Leont'yev* (Leont'yev, 1996), *XBEACH* (Roelvink et al. 2010) and a model, the hydrodynamic component of which involves high-order *Boussinesq* equations- *Boussinesq* model (Karambas and Koutitas, 2002). *The Bruun* model is a widely-used (e.g. Hinkel et al., 2010; Ranasinghe et al., 2013) analytical morphodynamic model that estimates long-term coastal retreat *S* under a SLR *α* on the basis of the equilibrium profile concept; its results are controlled by the height of the beach face and the cross-shore distance between the beach closure depth and the shoreline. The *Edelman* model estimates beach erosion/retreat using the initial height of the beach face, the water depth at wave breaking and the surf zone width, whereas the *Dean* model estimates retreats on the basis of the wave height, the water depth at wave breaking and the surf zone width.

The *SBEACH* model (Larson and Kraus, 1989) is a numerical morphodynamic model, consisting of 3 modules: a hydrodynamic, a sediment transport and a morphological evolution module. It can describe wave transformation in shoaling waters, with the coastal sediment transport controlled by the coastal wave energy fluxes; the sediment continuity equation in a finite difference scheme and a 'stair–step' beach profile discretization is used in its morphological module. The numerical model based on *Leont'yev* (1996) uses the energetic approach, with the cross-shore wave energy balance controlled by wave propagation angle and dissipation; sediment transport rates are estimated separately for the surf and swash zones. The *XBEACH* model (Roelvink et al., 2010) is an open-source, widely used numerical model of the nearshore processes intended to estimate the effects of time-varying storm conditions; it contains a time-dependent wave action balance solver and allows for variations in the wave action over time and over the directional space. Finally, the *Boussinesq* model used computes non-linear wave transformation in the surf and swash zone, based on a wave propagation module involving high-order Boussinesq equations (Karambas and Koutitas, 2002); its sediment transport module can estimate sheet flow as well as bed and suspended load over uneven sea beds (e.g. Karambas, 2006). Detailed descriptions of the models used can be found elsewhere (e.g. Vousdoukas et al., 2009a; Monioudi et al., 2016).

The models were used in an ensemble mode in order to assess the range of long- and short-term beach retreats/erosion for different beach slopes, sediment textures (grain size) and wave conditions, and under different scenarios of MSL changes and/or storm induced SLRs. Two model ensembles were created, a 'long-term' ensemble consisting of the analytical models *Bruun, Dean* and *Edelman* and a 'short-term' ensemble comprising the numerical *SBEACH, Leont'yev, XBEACH* and *Boussinesq* models; the former is used to assess beach retreat/erosion under MSLR, whereas the latter retreat due to temporary SLR (i.e. episodic storm-induced). The adopted approach was based on the proposition that as models have differential sensitivity to the controlling environmental factors, ensemble applications may provide 'tighter' prediction ranges than the individual models. With regard to combined SLRs (i.e. storm-induced SLR superimposed on MSLRs), the long-term and short-term ensembles were used consecutively.

The above approach is designed to project beach retreat/erosion, but not temporary inundation/flooding due to wave run-up. Although wave run–up is dealt within the numerical models of the ensemble, its effects are manifested in the results only if it induces sediment transport that forces morphological changes (e.g. Leont'yev, 1996). Yet, wave run up-induced temporary flooding that does not result in beach retreats is also a significant management issue (e.g. Jiménez et al., 2012; Hoeke et al., 2013); therefore, estimations of wave run up excursion/inundation were also undertaken. Run up heights were estimated for all tested conditions, using the expressions of Stockdon et al. (2006) (Vousdoukas et al., 2009b):

$$R_{2\%} = 1.1\left(0.35\beta(H_o/L_o)^{1/2} + \frac{\left[H_o L_o(0.563\beta^2 + 0.004)\right]^{1/2}}{2}\right) \quad \text{(all data)}$$

$$R_{2\%} = 0.043(H_o/L_o)^{1/2} \quad \text{for dissipative beaches } (\xi < 0.3)$$

where $R_{2\%}$, the 2 % exceedence of the peak run-up height H_o, L_o are the deep water wave height and length, β the beach slope and ξ the Iribarren number ($\xi = \beta/(H_o/L_o)^{1/2}$).

Wave run up excursions were then calculated from the wave run up heights ($R_{2\%}$) for all tested bed slopes and wave conditions and added to the beach erosion/retreat projections of the seven 1-D cross-shore morphodynamic models to project final flooding excursions (*S(i)*). The best fits of the lower and upper limits of the final projections of flooding by all models were then estimated.

A toolbox was constructed in order to simplify the developed approach. The toolbox is provided as a Guide User Interface (GUI) suite, is user- friendly, fast and requires no great expertise for its operation. This tool can bridge the gap between coastal scientists/engineers and coastal managers and stakeholders and can be used in building capacities in coastal regions with scarcity in human resources and little relevant expertise. The use of the toolbox may reduce flexibility in the use of the models; for full control in the use of the models, experience in morphodynamic modelling and scientific programming is needed.

Benefits of performing this approach

The present approach provides reasonable assessments of potential ranges of beach retreat under marine forcing (i.e. sea levels and waves) on the basis of (minimal) environmental information that can be obtained relatively easily. It provides ranges (maximum and minimum) of the horizontal excursion of cross-shore beach retreat/inundation, which could be then compared to the beach width that could be easily determined by remote-sensed imagery.

Under a variable and changing climate, projections on the future evolution of beach morphology are not easy, due to uncertainties regarding both forcing and beach response (e.g. Short and Jackson, 2013). Nevertheless, beach erosion is amongst the first issues to consider when planning for the sustainable development of the coastal zone, particularly in areas where beaches function as natural 'armour' to valuable coastal infrastructure and assets and/or as significant environments of leisure (e.g. Paula et al., 2013). Therefore, assessments of the beach morphological evolution at different spatio-temporal scales are required, based on advanced numerical, analytical, and/or empirical models constructed and applied by experienced operators, set up/validated using appropriate field data and backed by expert analysis (e.g. Roelvink et al., 2009; Bosom and Jiménez, 2010; Ding et al., 2013). However, such efforts are usually hampered by the (a) scarcity of relevant information in many coastal areas, and (b) dearth in the necessary human and financial resources (e.g. Parker et al., 2013); this is particularly true when assessments of beach erosion are carried out over larger spatial scales. All the same, it is necessary to assess future beach retreat/erosion and flood risk at large spatial scales, in order to identify 'hot spots' and plan for effective adaptation policies and efficient allocation of resources. Against this background, the present approach provides a rapid assessment of the erosion and temporary inundation/flood risks at a large spatial scale, under different scenarios of SLR.

Existing methodologies/tools for rapid assessment of coastal/beach erosion due to MSLR and extreme events at large scales (e.g. Hinkel et al., 2010; Ramieri et al., 2011; Khouakhi et al., 2013) have limitations stemming from (amongst others): (a) their requirements for coastal Digital Elevation Models (DEMs) of high resolution/accuracy; and (b) the generally limited consideration of major controls (e.g. hydrodynamics). At the same time, advanced modelling approaches (e.g. Vousdoukas et al., 2016b) in addition to detailed environmental information commonly require experienced operators and high computation costs that may make them impractical to coastal planners/managers (e.g. McLeod et al, 2010).

The present approach, which compares ranges of SLR induced beach retreat and flooding under different initial conditions and hydrodynamic forcing with beach maximum widths, is not limited by the resolution/accuracy of available coastal DEMs or the availability of detailed environmental information (e.g. Jiménez et al., 2012), and can be easily incorporated in other beach vulnerability tools (e.g. Alexandrakis et al., 2015) and used in areas with limited human resources. Nevertheless, there are also constraints. Projections are based on the assumption that beaches comprise inexhaustible sediment reservoirs, with no lateral sediment losses; cross-shore modelling obviously cannot resolve such issues. In addition, the approach is not designed to account for other erosion-controlling factors, such as: geological controls, coastal sedimentary budgets, and extreme event duration and sequencing (e.g. Gallop et al., 2012; Corbella and Stretch, 2012); the presence of artificial beach protection schemes and/or protecting nearshore ecosystems (e.g. Peduzzi et al., 2013); and the effects of coastal use (e.g. Bi et al., 2013). However, the aim of the exercise has not been to replace detailed modelling studies for individual beaches, but to provide ranges of beach erosion and flooding at a large scale.

Additional data that would improve beach retreat predictions

Models displayed differential behaviour for almost all tested conditions, showing as expected significant ranges of results due to the varying initial conditions and forcing used i.e. different bed slopes, sediment sizes and wave conditions. Generally, all model results have been found to be very sensitive to beach slope, which makes the beach slope the most responsible parameter for the wide range of the beach retreat results. The "high" predictions of that range reflect the calculations with mild beach slope (1/30), heavy wave conditions and fine beach material ("low" predictions are for the other ends). Then, high and low predictions are applied to each beach of Saint Lucia to drive the results, assuming that all beaches have either mild slope ("high" prediction) or steep slope ("low" prediction). So the predictions can be improved, if more information is available for the environmental conditions (especially for the beach slope) of each beach from previous studies or from literature, then this information can be used to narrow the envelope of the maximum and minimum retreat ranges through the interactive GUIs and apply a different range of beach retreat/inundation to each beach. If such information is not available, in situ measurements are required, which at large spatial scale are impractical to be performed, especially by coastal planners/managers.