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

# SAINT LUCIA: A case study

## EXECUTIVE SUMMARY*

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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.

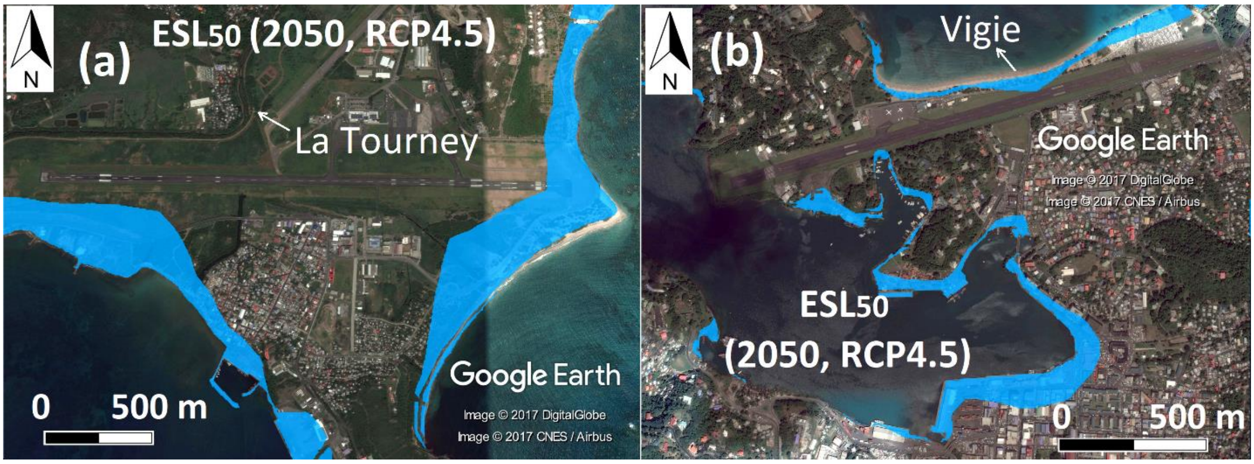


*Figure 1 Inundation maps of (a) Hewanorra Airport and Port Vieux Fort and (b) the George Charles Airport and Port Castries under 50-year ESL (cyclone effects are included) projected for the year 2050 according to RCP4.5 scenario*

## 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 at least 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 at least 20 % and the complete flooding of at least 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.