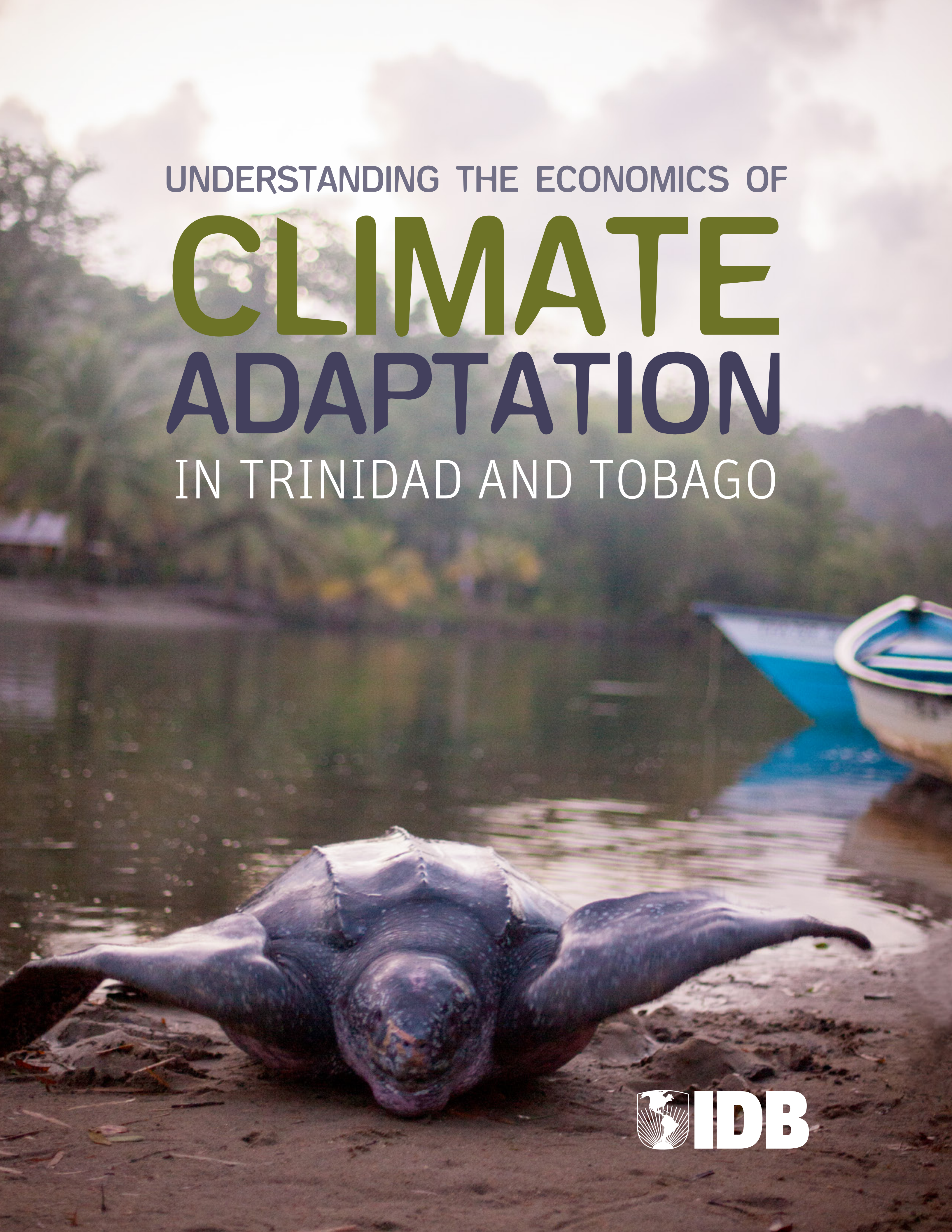
UNDERSTANDING THE ECONOMICS OF

CLIMATE ADAPTATION

IN TRINIDAD AND TOBAGO



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List of Acronyms

AIMS	Indian Ocean, Mediterranean and South China Sea
APETT	Association of Professional Engineers of Trinidad and Tobago
CARICOM	Caribbean Community
CBO	Community Based Organization
CBTT	Central Bank of Trinidad and Tobago
CCCCC	Caribbean Community Climate Change Centre
CCRIF	Caribbean Catastrophe Risk Insurance Facility
CLUE-S	Change of Land Small Use and its Effects –Scale Model
CRMI	Caribbean Risk Management Initiative
CSO	Central Statistical Office
DRM	Disaster Risk Management
EACC	Economics of Adaptation to Climate Change
ECA	Economics of Climate Adaptation
ECLAC	Economic Commission of Latin America and the Caribbean
EIA	Energy Information Agency USA
EMA	Environmental Management Authority of Trinidad and Tobago
FAO	Food and Agriculture Organization of the UN
FAOSTAT	Statistical service FAO
GDP	Gross Domestic Product
GHG	Greenhouse gas
GIS	Geographic Information System
GNI	Gross National Income
GORTT	Government of the Republic of Trinidad and Tobago
HURDAT	The North Atlantic hurricane database
IBC	International Building Code
IPCC	International Panel on Climate Change
LPC	Loan Portfolio Cover
LPP	Livelihood Protection Policy
MAC	Marginal Abatement Cost
MUSD	Million United States Dollars
M$TT	Million Trinidad and Tobago Dollars
NGO	Nongovernmental Organization

NOAA	National Oceanic and Atmospheric Administration
ODPM	Office of Disaster Preparedness and Management
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares
PETROTRIN	Petroleum Company of Trinidad and Tobago Limited
PF	Measure proposed for Petrotrin in the Pilot Case
RECCC	Review of Economics of Climate Change in the Caribbean
RRMC	Risk Reduction Management Centre
SCC	Social Cost of Carbon on the margin
SIDS	Small Islands Developing State
SODA	Simple Ocean Data Assimilation
SUDS	Sustainable Urban Drainage System
T&T	Trinidad and Tobago
T&TEC	Trinidad and Tobago Electricity Commission
TT$	Trinidad and Tobago Dollar
TTA	Measure proposed for Trinidad and Tobago
TTIA	Trinidad and Tobago Institute of Architects
TTBS	Trinidad and Tobago Bureau of Standards
TRINTOC	Trinidad and Tobago Oil Company
TRINTOPEC	Trinidad and Tobago Petroleum Company
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollars
UWI	University of the West Indies

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1. Context overview

The general objective of the project is to develop and implement an Economics of Climate Change Adaptation (ECA) study in Trinidad and Tobago that can be applied to the broader Caribbean region, together with the dissemination of the information generated and the process involved in the implementation of the study.

This project is composed by six different tasks:

1. Review of literature.
2. Identification of risks.
3. Assessment of expected loss.
4. Identification of responses.
5. Decision-making framework for action.
6. Dissemination of knowledge.

This report provides the results of all tasks 1 through 5 undertaken in this project. The report has been structured along these 5 tasks, each with their own section (3 through 7). Section 8 is a summary of the assessments and responses for the Pilot Case developed for The Petroleum Company of Trinidad and Tobago. Please note that all monetary values presented in this report are in current US Dollars.

2. Executive summary

In this report, the potential hazards due to climate change are presented, the economic effects of climate change in Trinidad and Tobago are calculated, the actions to mitigate the losses caused by climate change are proposed, and their economic costs and benefits are analyzed. Please note that all monetary values presented in this report are in current US Dollars.

In terms of climate hazards, Trinidad and Tobago will, presumably, undergo higher tropical storm (TS) frequency and the effects derived from them: coastal flooding, wind and rainfall. Additionally the island will likely experience sea level rise and more frequent and intense droughts. The table below shows a summary of the potential effects of climate change in Trinidad and Tobago:

Table 1: Potential effects of climate change by sector in Trinidad and Tobago.
Source: Prepared by the authors.

Sector	Impact
Agriculture	▪ Warmer weather from high temperature will cause soil aridity, lead to proliferation of pests and diseases, and put pressure on water resources for water for irrigation purposes. ▪ Sea level rise will cause inundation and soil desalination. ▪ The combined impact is low agricultural yields and decrease in food production.
Human Health	▪ Higher temperature will increase spread of vector diseases. ▪ Decrease in rainfall will affect potable water supply. ▪ Sea level rise will cause increases in water borne diseases.
Human settlements	▪ Increase in frequency and intensity of storm surge will cause more flooding and disrupt or destroy coastal settlements. ▪ Increase in frequency and intensity of storm surge and extreme rainfall will cause damages to infrastructure from flooding and erosion.
Coastal zones	▪ Sea level rise will lead to increased inundation, increased erosion, loss of wetlands, loss of ecosystems, and displacement of coastal communities. ▪ High temperature will result in loss of coral reefs and reduction in fish stock.
Water resources	▪ Increase in temperature will result in increased evapotranspiration and loss of available surface water. ▪ Decrease in precipitation will reduce groundwater and aquifer recharge. ▪ As an effect, available water resources will be reduced.
Energy sector	▪ Infrastructure, including field installations and offshore operations, are at risk of inundation from sea level rise, storm surges and erosion from extreme rainfall. ▪ Water shortages in the country may affect the needs of the industry in terms of energy generation. ▪ Infrastructure damages due to extreme weather events.

Since the mean sea level is a slowly changing variable, the damage associated with sea level rise is linked to that of tropical storms. In fact, sea level rise increases the effects of the tropical cyclones and hurricanes because it magnifies the coastal flooding generated by storm surge and waves. In the table below, the mean economic damage expected for tropical storms considering the different scenarios of climatic (regional sea level rise and changes in the frequency of storm events) and vulnerability conditions is shown.

Table 2: Expected annual damage for the different scenarios considered due to tropical storms.
Source: Prepared by the authors.

Scenario	Mean damage (MUSD/year)
S0	19.5953
S1	26.3465
S2	29.3377
S3	36.8614

For a better understanding of the results, it should be noted that the scenarios S0 and S1 are those in which today's vulnerability scenario is maintained, while in S2 and S3 the future vulnerability scenario is considered. Regarding the climate considered for the elaboration of the scenarios, in S0 today's climate is maintained, while in S1 and S2 a moderate change of the climate would take place and in S3 a high change.

The damage associated with the return periods of 50 and 200 years (probability of occurrence of 0.02 and 0.005) is obtained for each scenario as shown in the table below. Although changes in the mean are not very significant for S1 and S2 scenarios relating to S0, in terms of damage with low probability of occurrence the changes are more noticeable: 17% of change in the D50 for S1 scenario and 30.2% of change (almost double) for S2. In the case of S3 scenario the relative change in the D50 and D200 is up to 63%.

Table 3: Damage associated to 50 and 200 years of return period for each climate change scenario and relative change from S0.
Source: Prepared by the authors.

Scenarios	**D_{50} (MUSD)**	**D_{50}-D_{50S0} (%)**	**D_{200} (MUSD)**	**D_{200}-$D_{50\ -S0}$ (%)**
S0	170,115	0	205,883	0
S1	199,012	16,986	239,864	16,505
S2	221,607	30,268	267,098	29,732
S3	278,437	63,675	335,594	63,002

For droughts, there is only one future scenario due to the lack of historical data. In this case, the expected loss for droughts in Trinidad and Tobago is 1.815 M$TT. In terms of relative change, the damage associated with this climate change scenario represents an increase of 34% relating to historical damage due to drought events.

Regarding the identification of actions, the objective of this document is to propose measures that could reduce the effects of the hazards detected for Trinidad and Tobago. To do so, actions that cover a wide range of options are proposed. For instance, some of the included actions imply the development of important infrastructure, such as dikes, while others require a significantly less intensive financial investment such as the development of a social awareness program.

The process of the identification of actions consisted of several steps. As a first step, an analysis of the possible actions which could be developed in the country was carried out. To do so, a tailor-made prioritization methodology was designed, with which different possible adaptation actions were assessed and selected for the country level.

To do so, for the sectors included in the scope of the project - agriculture, industry, human health, human settlements and water resources - the direct and indirect consequences of the derived hazards that Trinidad and Tobago will face due to climate change were analysed.

After analyzing the direct and indirect consequences for every sector, the identification of the priorities of the country in adaptation terms was carried out. From those direct and indirect consequences, the priorities in terms of climate change adaptation for Trinidad and Tobago were defined as:

1) Prevent flooding in:
    a. Human settlements
    b. Industry
    c. Agricultural land
2) Prevent the erosion of:
    a. Coastal land
    b. Agricultural land
3) Reduce the damage caused by extreme events (tropical storms, hurricanes, droughts, heat waves), in:
    a. Human settlements
    b. Industry
    c. Agriculture
4) Guarantee water supply to:

a. Human settlements
b. Agriculture
c. Industry

The next step in the prioritization methodology was the analysis of the actions, which was carried out considering different approaches. On the one hand, the results of the country priorities were considered by determining which priorities every action would respond to. Additionally, for every action, an evaluation of specific parameters which would likely act as barriers to implementation was carried out. These parameters included: economic requirements, legal capacity, institutional capacity, technological capacity and social capacity.

Since not all the parameters have the same relevance regarding an action´s implementation, the proposed measures were classified by their importance and the action´s compliance level for the different parameters. A weighted mark was given based on the economic evaluation and the different capacities.

In the table below, a summary of the results is shown. As can be seen in the table, all the not selected actions have a lower mark than 22, which was considered the threshold which guaranteed the implementation of the action, except for the desalination technology. This measure was not included due to the fact that there is already a plant of this type in Trinidad, it is very costly, and it is environmentally less sustainable than other options.

Table 4: Summary of the action prioritization.
Source: Prepared by the authors.

Action	Weighted score	Selected
National Building Code	29	**Yes**
Construction of dikes in coastal areas	23	**Yes**
Meteorological Alert System connected to the Monitoring System	30	**Yes**
Emergency Protocols	29	**Yes**
Social Awareness Program	33	**Yes**
Institutional Training Program	33	**Yes**
Rainwater harvesting	27	**Yes**
Infrastructure and Building Reinforcement	22	**Yes**
Retention ponds	33	**Yes**
Filter Strips	32	**Yes**
Permeable pavements	23	**Yes**
Beach nourishment	26	**Yes**
Mangrove Restoration	30	**Yes**

Action	Weighted score	Selected
Parametric Insurance Scheme	30	**Yes**
Agriculture & Climate Change Research Unit	31	**Yes**
Green Roofs	26	**Yes**
Climate Change Adaptation Tool	26	**Yes**
Sustainable Drainage Systems	29	**Yes**
Coral Reef Protection and Restoration	33	**Yes**
Resettlement of population	15	**No**
Elevation of infrastructure	18	**No**
Pumping systems	20	**No**
Cover crops	21	**No**
Desalination technology	24	**No**

In order to diversify the options and maximize the applicability of the actions, a specific focus has been set on the type of investment required. Measure for which the funding would be provided by institutions, but also some measured based on a combined financial scheme or solely funded by the private sector were included in this study.

Furthermore, since the effects of climate change and, particularly, the hazards observed for Trinidad and Tobago affect different sectors, the actions identified are designed to deal with this factor, as stated in the prioritization stage. When possible, actions were designed in order to obtain a widespread impact.

In the table below, the complete list of the identified adaptation actions for Trinidad and Tobago is included along with the affected sectors and the type of investment required for every action.

Table 5: Identified adaptation actions for Trinidad and Tobago.
Source: Prepared by the authors.

Action code	Title	Type of measure	Type of investment	Sector
TTA 1	National Building Code	Technological/procedural optimisation responses	Public investment	Human settlements
TTA 2	Coastal Zone Protection in Trinidad	Infrastructure and asset-based responses	Public investment	Coastal zones
TTA 3	Meteorological alert System connected to the Monitoring System	Systemic/behavioural responses	Public investment	Human settlements
TTA 4	Emergency Protocols	Systemic/behavioural responses	Public investment	Human settlements
TTA 5	Social Awareness Program	Systemic/behavioural responses	Public investment	Human health

Action code	Title	Type of measure	Type of investment	Sector
TTA 6	Institutional Training Program	Systemic/behavioural responses	Public investment	Human settlements
TTA 7	Rainwater harvesting	Technological/procedural optimisation responses	Private investment	Water resources
TTA 8	Infrastructure and Building Reinforcement	Infrastructure and asset-based responses	Private investment	Human settlements
TTA 9	Retention ponds	Infrastructure and asset-based responses	Public and private investment	Water resources
TTA 10	Filter Strips	Infrastructure and asset-based responses	Public and private investment	Agriculture
TTA 11	Permeable pavements	Infrastructure and asset-based responses	Public investment	Human settlements
TTA 12	Beach Restoration and Protection in Tobago	Infrastructure and asset-based responses	Public investment	Coastal zones
TTA 13	Mangrove Restoration in Trinidad	Infrastructure and asset-based responses	Public investment	Coastal zones
TTA 14	Parametric Insurance Scheme	Risk transfer via insurance and alternative financial solutions	Public and private investment	Agriculture
TTA 15	Agriculture & Climate Change Research Unit	Technological/procedural optimisation responses	Public investment	Agriculture
TTA 16	Green Roofs	Infrastructure and asset-based responses	Public and private investment	Human settlements
TTA 17	Climate Change Culture Survey for the General Public	Systemic/behavioural responses	Public investment	Human settlements
TTA 18	Mangrove Restoration in Tobago	Infrastructure and asset-based responses	Public and private investment	Coastal zones
TTA 19	Coral Reef Protection and Restoration in Tobago	Systemic/behavioural responses	Public investment	Coastal zones

For this report, the economic costs and benefits of each measure were identified, calculated and analyzed in order to understand the economic viability of each action.

Economic costs were calculated by estimating the costs of implementing each measure, including construction costs, labour costs, material costs, and maintenance costs. Economic benefits were calculated by taking the probabilities of natural hazards occurring with the projections of moderate climate change, the expected damages from these natural hazards, and the impact that these measures would have in mitigating damages. In most cases, several benefits were able to be identified and calculated for each measure. However, in some cases, given the lack of environmental and social information specific to Trinidad and Tobago, and given the nature of certain benefits, some benefits to society were not able to be calculated. It should be expected that, in these cases, the total benefits to society will be larger than the benefits calculated in this study, given that not all benefits were able to be monetized for this analysis.

Several economic and multi-criteria tools were used in order to analyse the feasibility of the measures including Net Present Value, Payback Period, Benefit/Cost Ratio, "No Regret" analysis, and a Multi-Criteria Analysis. The first four tools fall into the category of cost-benefit analysis in which environmental and social costs and benefits are all given monetary values in order to understand their feasibility and compare each measure against each other. In the last tool, Multi-Criteria Analysis, each societal good is looked at independently, and not given a monetarial value. Although complex and subjective, it invites other issues related to the measures to be looked at and compared.

The table below shows a summary of the economic analysis done for this study. It includes the total costs and benefits calculated for the measure, the net present value of the project´s cash flows, the estimated payback period of each measure, and the measure's Benefit-Cost Ratio.

Table 6: Results of the Cost-Benefit Analysis of the actions.
Source: Prepared by the authors.

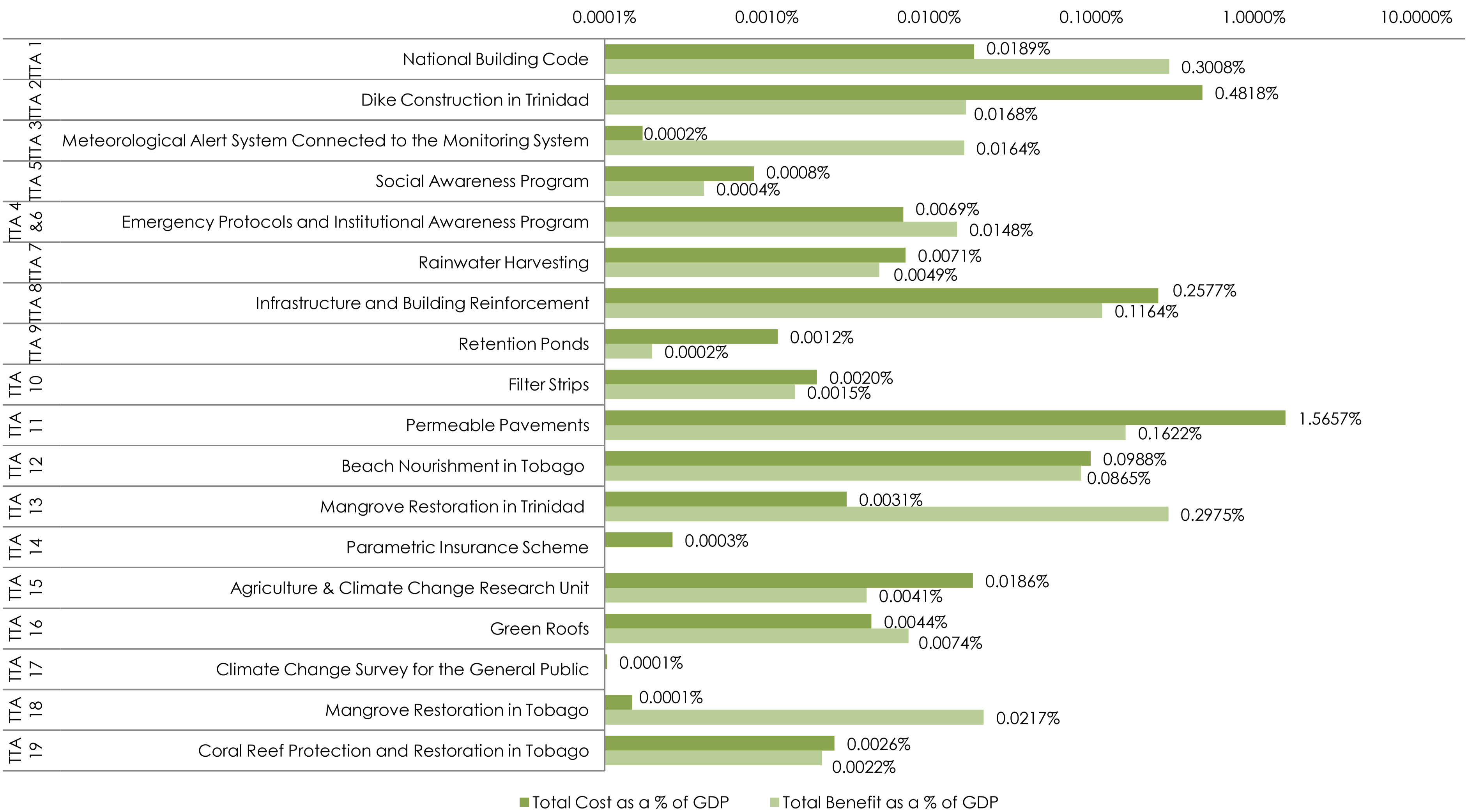
Action code	Title	Total cost	Total benefit	Net present value	Pay back (years)	Benefit-Cost Ratio
TTA 1	National Building Code	$4,529,327	$72,151,025	$43,923,883	1.9	15.9
TTA 2	Dike Construction in Trinidad	$115,554,303	$4,033,247	-$79,223,470	61.6	0.0
TTA 3	Meteorological Alert System Connected to the Monitoring System	$41,000	$3,935,834	$2,830,906	0.1	96.0
TTA 5	Social Awareness Program	$198,787	$98,240	-$83,151	∞	0.5
TTA 4 *TTA 6*	Emergency Protocols Institutional Training Program	$1,659,793	$3,545,712	$1,344,701	0.9	2.1
TTA 7	Rainwater Harvesting	$1,714,977	$1,180,476	-$500,418	24.9	0.7
TTA 8	Infrastructure and Building Reinforcement	$61,820,734	$27,911,274	-$27,646,239	35.4	0.5
TTA 9	Retention Ponds	$279,616	$47,027	-$187,075	∞	0.2
TTA 10	Filter Strips	$487,080	$356,132	-$121,338	24.9	0.7
TTA 11	Permeable Pavements	$375,536,762	$38,897,785	-$252,122,202	∞	0.1
TTA 12	Beach Nourishment in Tobago	$23,688,332	$20,736,386	-$5,522,748	19.4	0.9
TTA 13	Mangrove Restoration in Trinidad	$744,188	$71,348,613	$43,881,303	4.4	95.9

TTA 14	Parametric Insurance Scheme	$62,850	N/A	N/A	N/A	N/A
TTA 15	Agriculture & Climate Change Research Unit	$4,455,439	$986,772	-$2,661,472	∞	0.2
TTA 16	Green Roofs	$1,055,220	$1,786,554	$276,093	9.9	1.7
TTA 17	Climate Change Survey for the General Public	$24,794	N/A	N/A	N/A	N/A
TTA 18	Mangrove Restoration in Tobago	$35,325	$5,193,043	$3,402,443	4.2	147.0
TTA 19	Coral Reef Protection and Restoration in Tobago	$624,672	$523,245	-$89,772	∞	0.8

Please note: The total costs and total benefits for TTA 4 and TTA 6 were calculated together. Also, TTA 14 does not have any measureable economic benefits, as it is considered that insurance programmes do not modify the overall damage caused by the extreme events. They are useful from a cost-efficiency perspective but not from a cost-benefit approach, because the economic damage is the same even if insurance programmes are not developed. The only difference is the way in which that economic damage is covered. Therefore, from a societal cost perspective the cost-benefit analysis does not change. However, of course, from a private cost perspective it does make a difference. TTA 17 also does not have any economic benefits that can be calculated; the survey will provide information to both policy makers and practitioners, yet without knowing the results of the survey, it is impossible to determine the impact of this information in economic terms.

The graph on the next page shows the total costs and total benefits of each measure as a percentage of total GDP in Trinidad and Tobago:

Graph 1: Total Costs and Total benefits as a Percentage of GDP
Source: Prepared by the authors.



Please Note: This Graph is in Logarithmic Scale.

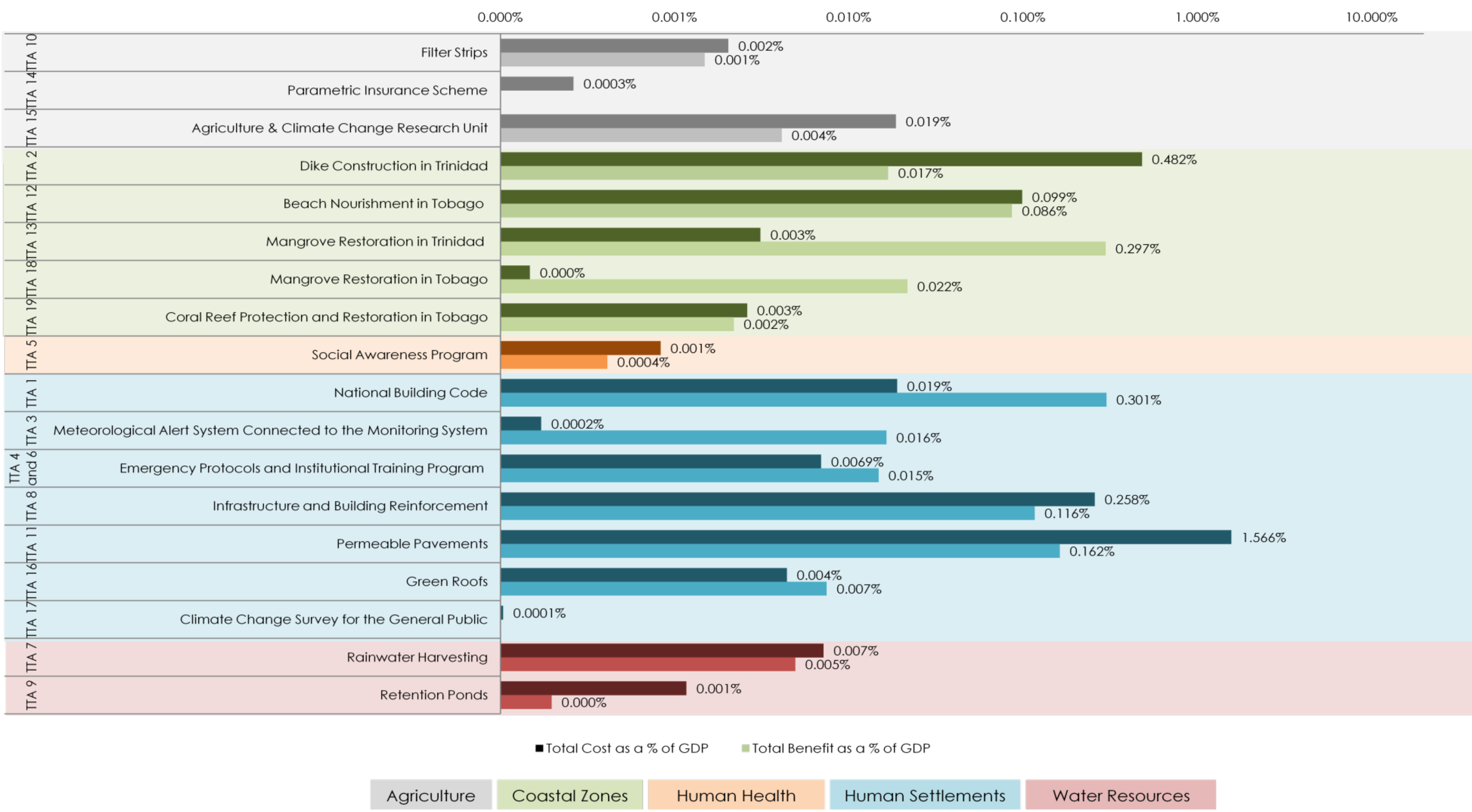
As can be seen by these measures, with the exception of permeable pavements (TTA 11) and Dike Construction in Trinidad (TTA 2) all of the measures have a total cost (not discounted) that is less than 0.3% of the GDP of Trinidad and Tobago in 2012. In terms of total benefit (not discounted), Mangrove Restoration in Trinidad (TTA 13) and National Building Code (TTA 1) have total benefits of about 0.3% of GDP. The average total cost as a percentage of GDP is 0.137% and the average total benefit as a percentage of GDP is 0.59%.

The following table and graph show the Cost Benefit Analysis organized by the sector which they correspond:

Table 7: Results of the Cost-Benefit Analysis of the actions, organized by sector.
Source: Prepared by the authors.

Action code	Title	Sector	Total cost	Total benefit	Net present value	Pay back (years)	Benefit-Cost Ratio
TTA 10	Filter Strips	Agriculture	$487,080	$356,132	-$121,338	24.9	0.7
TTA 14	Parametric Insurance Scheme		$62,850	N/A	N/A	N/A	N/A
TTA 15	Agriculture & Climate Change Research Unit		$4,455,439	$986,772	-$2,661,472	∞	0.2
TTA 2	Dike Construction in Trinidad	Coastal zones	$115,554,303	$4,033,247	-$79,223,470	61.6	0.0
TTA 12	Beach Nourishment in Tobago		$23,688,332	$20,736,386	-$5,522,748	19.4	0.9
TTA 13	Mangrove Restoration in Trinidad		$744,188	$71,348,613	$43,881,303	4.4	95.9
TTA 18	Mangrove Restoration in Tobago		$35,325	$5,193,043	$3,402,443	4.2	147.0
TTA 19	Coral Reef Protection and Restoration in Tobago		$624,672	$523,245	-$89,772	∞	0.8
TTA 5	Social Awareness Program	Human health	$198,787	$98,240	-$83,151	∞	0.5
TTA 1	National Building Code	Human settlements	$4,529,327	$72,151,025	$43,923,883	1.9	15.9
TTA 3	Meteorological Alert System Connected to the Monitoring System		$41,000	$3,935,834	$2,830,906	0.1	96.0
TTA 4	Emergency Protocols		$1,659,793	$3,545,712	$1,344,701	0.9	$2
TTA 6	Institutional Training Program						
TTA 8	Infrastructure and Building Reinforcement		$61,820,734	$27,911,274	-$27,646,239	35.4	0.5
TTA 11	Permeable Pavements		$375,536,762	$38,897,785	-$252,122,202	∞	0.1
TTA 16	Green Roofs		$1,055,220	$1,786,554	$276,093	9.9	1.7
TTA 17	Climate Change Survey for the General Public		$24,794	N/A	N/A	N/A	N/A
TTA 7	Rainwater Harvesting	Water resources	$1,714,977	$1,180,476	-$500,418	24.9	0.7
TTA 9	Retention Ponds		$279,616	$47,027	-$187,075	∞	0.2

Graph 2: Total Costs and Total benefits as a Percentage of GDP, organized by Sector
Source: Prepared by the authors.



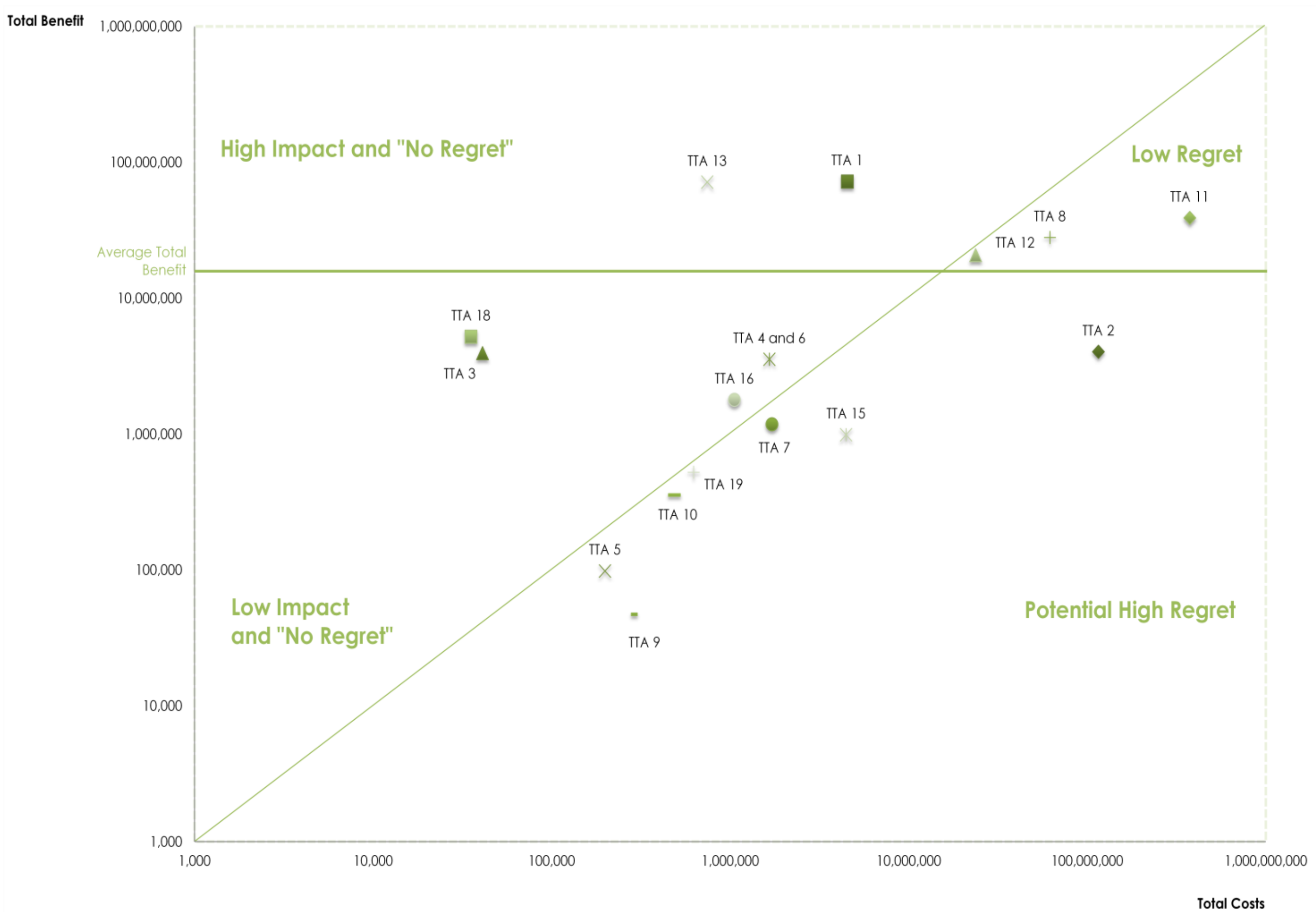
Please Note: This Graph is in Logarithmic Scale

When organized by sector, the measures for Coastal Zones and the measures for Human Settlements have relatively high benefits. Coastal Zone measures average a benefit equivalent to 0.426% of GDP and Human Settlements measures average a benefit equivalent to 0.618% of GDP. That being said, these two groups of measures also have the largest costs. Coastal Zone measures average cost is equivalent to 0.586% of GDP and Human Settlements measures average cost is equivalent to 1.854% of GDP. The next groups of measures with the highest benefits are the agriculture (with an average benefit of 0.006% of GDP) and water resources (with an average total benefit of 0.005% of GDP). However, in terms of cost; the measures for water resources have an average cost equivalent to 0.008% of GDP, while the average costs of measures for agriculture is higher, at 0.021% of GDP. Lastly, the measure for the Human Health sector has both the smallest cost (0.001% of GDP) and smallest benefit (0.004% of GDP).

The table on the following page shows the results for each measure in terms of "No Regret". "No regret" strategies are those in which the project can be justified in economic terms, even without climate change, however its benefits increase even more with climate change. For the analysis, four categories were developed:

- High Impact and "No Regret": Actions that have no regret, and also have a high impact in reducing damages due to natural hazards.
- Low Impact and "No Regret": Actions that have no regret, and offer a lower impact in terms of reducing damages.
- Low Regret: Actions that are not necessarily "No Regret" yet will produce significant benefits in the event of a natural hazard.
- Potential High Regret: Actions that are not "No Regret" yet produce lower levels of benefits in the event of a natural hazard.

Graph 3: "No Regret" Analysis
Source: Prepared by the authors.



Please note: this graph is showing the present value of the total benefits and total costs. It is also in logarithmic scale.

From this analysis, the results show that:

- The National Building Code (TTA 1) and Mangrove Restoration in Trinidad (TTA 13) fall into the category of High Impact and "No Regret"
- Meteorological alert system connected to the Monitoring System (TTA 3); Emergency Protocols (TTA 4) and Institutional Training Program (TTA 6); Green Roofs (TTA 16); and Mangrove Restoration in Tobago (TTA 18) all fall into the category of Low Impact and "No Regret"
- Infrastructure & Building Reinforcement (TTA 8); Permeable Pavements (TTA 11); and Beach Nourishment in Tobago (TTA 12) fall into the category of Low Regret
- Dike Construction in Trinidad (TTA 2); Social Awareness Program (TTA 5); Rainwater Harvesting (TTA 7); Retention Ponds (TTA 9); Filter Strips (TTA 10); Agriculture & Climate Change Research Unit (TTA 15) and Coral Reef Protection and Restoration in Tobago (TTA 19) fall into the category of Potential High Regret.

Lastly, a multi-criteria analysis was made in order to weigh the economic information against additional criteria necessary for decision-making. These criteria included:

- Importance: The importance that the measure has in regarding the ability to decrease the impacts of climate change.
- Urgency: The urgency with which the measure should be implemented in order to gain the maximum benefits from its implementation.
- No Regret: The level of "No Regret" this measure has. "No regret" strategies are those in which the project can be justified in economic terms, even without climate change, however its benefits increase even more with climate change.
- Secondary Effects: The level to which this measure would bring additional positive secondary effects to society.
- Mitigation Effects: The level to which, in addition to improving the adaptability of the country to Climate Change, the implementation of the measure also would help mitigate climate change by reducing emissions.

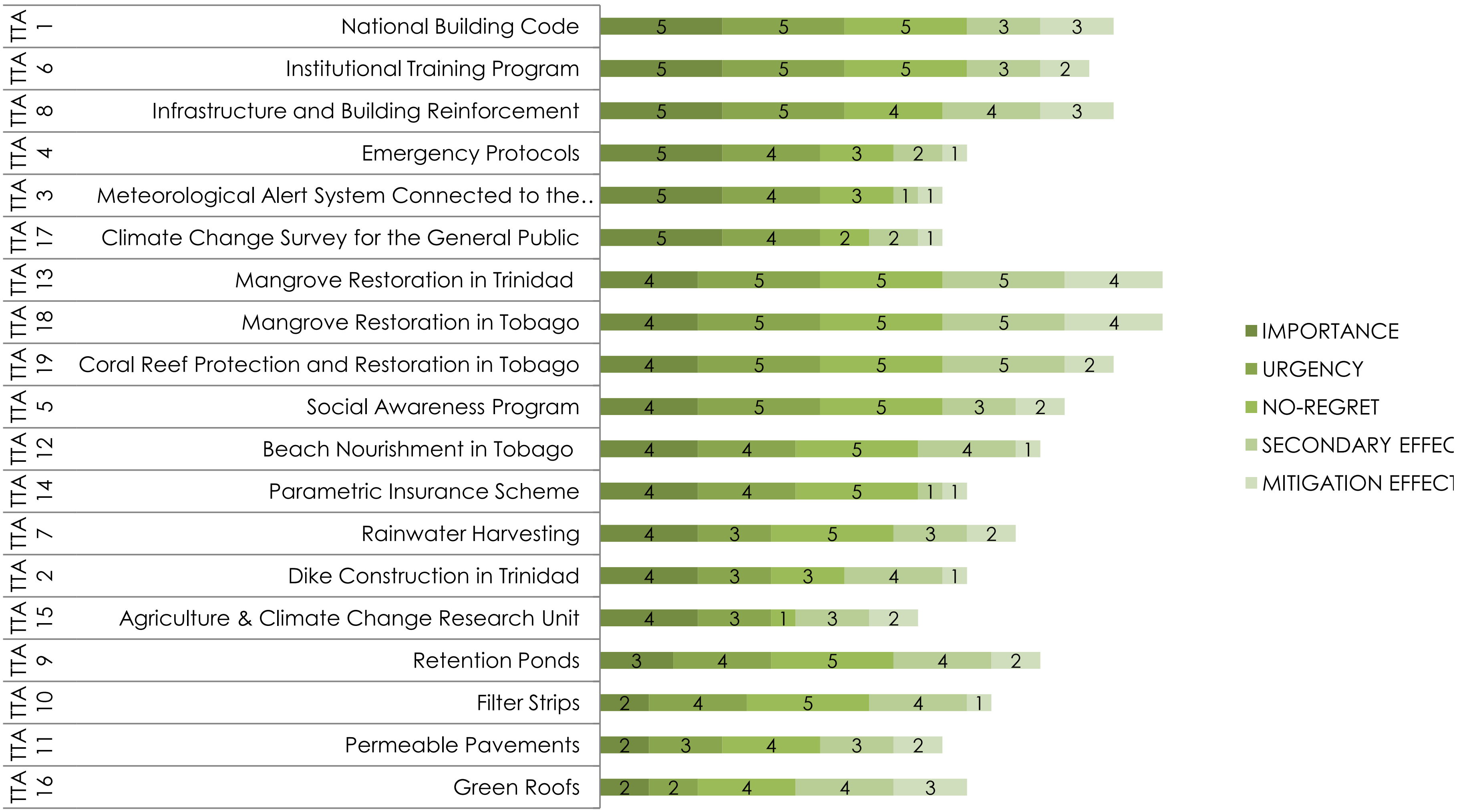
These scores have then been given a weighted score, with Importance having more weight (5) over Urgency (4), No-Regret (3), Secondary Effects (2), and Mitigation Effects (1). Therefore, in the graphs below, those measures with the largest bar are not necessarily those with the highest priority. For example, although Mangrove Restoration in Trinidad has a very high ranking in all aspects, it is not the highest in terms of priority since its weighted score was not the highest.

The measures are ordered within the table and graph below based on their score in Importance, then Urgency, then No-Regret, then Secondary Effects, and Lastly Mitigation Effects.

Table 8: Multi-criteria analysis of the actions.
Source: Prepared by the authors.

MEASURE PRIORITY	Nº	MEASURE	IMPORTANCE	URGENCY	NO-REGRET	SECONDARY EFFECTS	MITIGATION EFFECTS	WEIGHTED
1	*TTA 1*	National Building Code	5	5	5	3	3	69
2	*TTA 6*	Institutional Training Program	5	5	5	3	2	68
3	*TTA 8*	Infrastructure and Building Reinforcement	5	5	4	4	3	68
4	*TTA 4*	Emergency Protocols	5	4	3	2	1	55
5	*TTA 3*	Meteorological Alert System Connected to the Monitoring System	5	4	3	1	1	53
6	*TTA 17*	Climate Change Survey for the General Public	5	4	2	2	1	52
7	*TTA 13*	Mangrove Restoration in Trinidad	4	5	5	5	4	69
8	*TTA 18*	Mangrove Restoration in Tobago	4	5	5	5	4	69
9	*TTA 19*	Coral Reef Protection and Restoration in Tobago	4	5	5	5	2	67
10	*TTA 5*	Social Awareness Program	4	5	5	3	2	63
11	*TTA 12*	Beach Nourishment in Tobago	4	4	5	4	1	60
12	*TTA 14*	Parametric Insurance Scheme	4	4	5	1	1	54
13	*TTA 7*	Rainwater Harvesting	4	3	5	3	2	55
14	*TTA 2*	Dike Construction in Trinidad	4	3	3	4	1	50
15	*TTA 15*	Agriculture & Climate Change Research Unit	4	3	1	3	2	43
16	*TTA 9*	Retention Ponds	3	4	5	4	2	56
17	*TTA 10*	Filter Strips	2	4	5	4	1	50
18	*TTA 11*	Permeable Pavements	2	3	4	3	2	42
19	*TTA 16*	Green Roofs	2	2	4	4	3	41

Graph 4: Multi-criteria analysis of the actions.
Source: Prepared by the authors.



Based on the Multi-criteria analysis, National Building Code (TTA 1), Institutional Training Program (TTA 6), Infrastructure & Building Reinforcement (TTA 8), Emergency Protocols (TTA 4), and Meteorological alert system connected to the Monitoring System (TTA 3) came in as the top 5 in terms of priority measure to implement.

In conclusion, after looking at all of the different facets of each measure and analyzing cost/benefit results mentioned in this study, the measures that are the most favourable and feasible for Trinidad and Tobago are the implementation of a National Building Code (TTA 1), Meteorological Alert System connected to the Monitoring System (TTA 3), Emergency Protocols (TTA 4), and Institutional Training Program (TTA 6), given that they were ranked the highest priority and they are all considered "No Regret" Measures. Additionally, Infrastructure & Building Reinforcement (TTA 8) is recommended due to its high ranking in the multicriteria analysis and that it is considered Low Impact and Low Regret. Given the large benefits associated with mangroves, Mangrove Restoration in Trinidad (TTA 13) and Tobago (TTA 18) are also highly recommended for implementation. The Parametric Insurance Scheme (TTA 14) is also highly recommended, although it is not considered "No Regret", is as it will help reduce the financial risks felt by the Government, private companies and individuals in situations of Natural Hazard. Also, given the strong percentage of tourism related to the economic well-being of Tobago, it would be interesting to look into Beach Nourishment (TTA 12) and Coral Reek Protection and Restoration (TTA 19) as a possible ways to maintain the long term growth of tourism on the island.

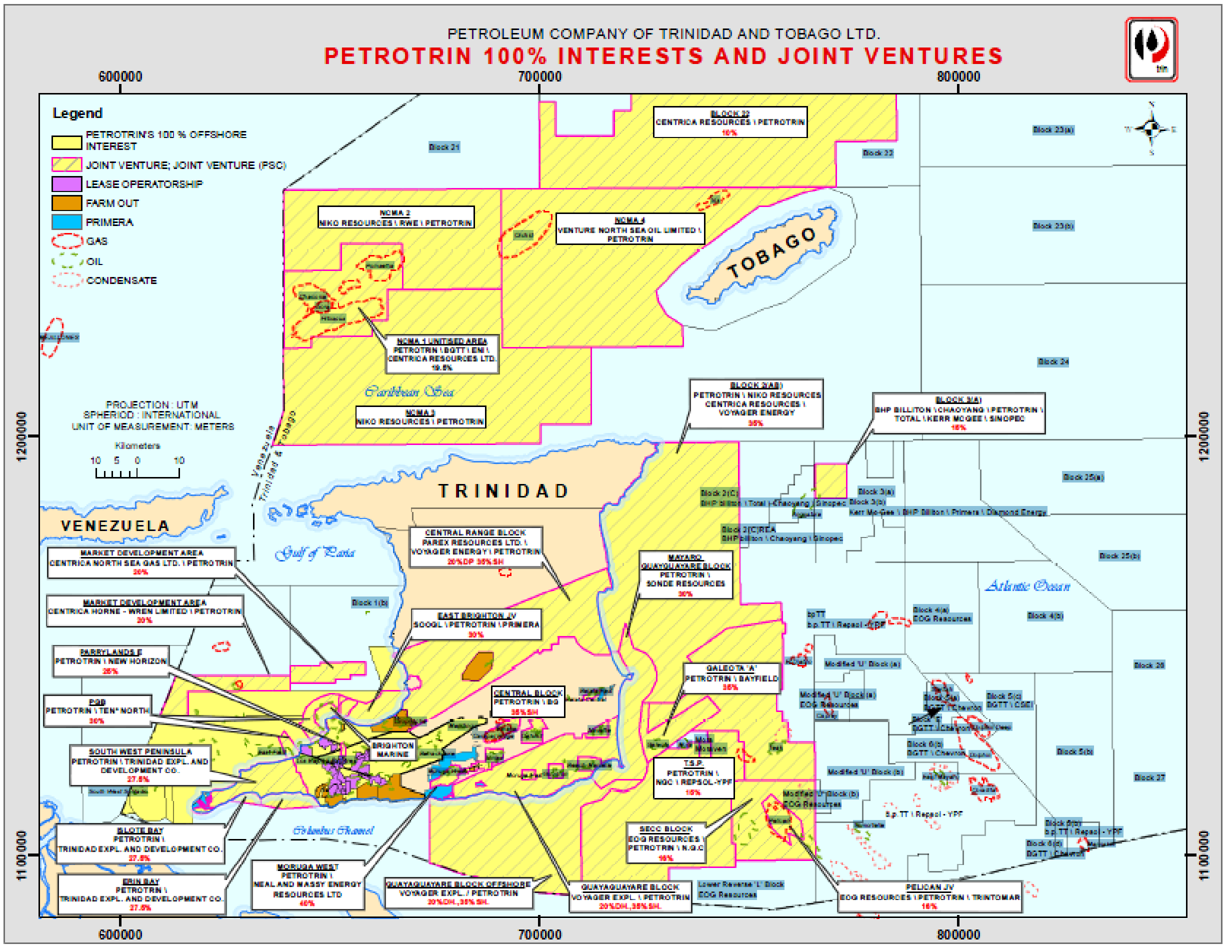
It is important to note that while all of these measures are analyzed as individual measures, many of these measures would have increased impacts if they were implemented in conjunction with other proposed measures. As an example, many of the measures regarding coastal management, including the construction of dikes (TTA 2), the restoration of mangroves (TTA 13 and TTA 18) and the protection of coral reefs (TTA 19), will have improved results if jointly implemented. The same can be said for the social awareness campaign (TTA 5), emergency protocols (TTA 4), institutional training program (TTA 6), and meteorological alert system connected to the monitoring system (TTA 3). All of the measures detailed in this report should therefore be looked at holistically and strategically when deciding which activities to implement, ensuring that possible mutual and re-enforcing benefits are captured.

Additionally, these recommendations have been made based on the information currently available. In many cases, secondary sources were used in order to determine the costs and benefits for these measures, given the lack of primary source information. It is recommended that before any of these measures are undertaken, a detailed analysis of their feasibility and impacts be done in order to decide whether or not to implement the measure.

2.1. The Pilot Case

For this analysis, the pilot case study has been focused on the Petroleum Corporation of Trinidad and Tobago (Petrotrin). This case study was chosen given the importance of the petroleum sector in the country's economy, and Petrotrin's importance within the sector. The Petroleum Industries sector accounts for over 43% of the GDP of Trinidad and Tobago in 2012, based on the GDP statistics provided by the Central Statistics Office (CSO) of Trinidad and Tobago. Petrotrin was incorporated in 1993 to consolidate the interests of the Trinidad and Tobago Oil Company (Trintoc) and the Trinidad and Tobago Petroleum Company (Trintopec), but its roots can be traced to the first years of the 20th century. They play a leading role in the development of the energy sector in Trinidad and Tobago, being the nation's largest crude oil producer. This in terms of production is expressed by the full capacity of the refinery, of up to 168,000 barrels per day and average of approximately 127,650 barrels per day. A map showing the extent of Petrotrin's operations in the country is shown in the figure below.

Figure 1: Map showing Petrotrin's Areas of Operations
Source: Petrotrin, Energy Map Feb 2013



The table below describes how each of these measures is defined along these categories.

Table 9: Proposed actions for the pilot study.
Source: Prepared by the authors.

Action code	Title	Type of measure	Type of investment	Sector
PT 1	Climate Change Adaptation Tool	Technological/procedural optimisation responses	Private investment	Energy sector & industry
PF 1	Coastal Zone and Guaracara River Protection	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PF 2	Retention Ponds in Point Fortin	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PF 3	Construction of Swales and Berms in Point Fortin	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PF 4	Mangrove Protection in Point Fortin	Infrastructure and asset-based responses	Private investment	Energy sector & industry

Action code	Title	Type of measure	Type of investment	Sector
PF 5	Relocation of Infrastructure in Point Fortin	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PF 6	Infrastructure Elevation in Point Fortin	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PAP 1	Dike Construction in Pointe-à-Pierre	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PAP 2	Construction of Retention Ponds at Pointe-à-Pierre	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PAP 3	Sustainable Drainage Systems in Pointe-à-Pierre	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PAP 4	Mangrove Restoration in Pointe-à-Pierre	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PAP 5	Relocation of Infrastructure in Pointe-à-Pierre	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PAP 6	Infrastructure Elevation in Pointe-à-Pierre	Infrastructure and asset-based responses	Private investment	Energy sector & industry

As with the measures analysed for the country, the economic costs and benefits of each measure designed for Petrotrin have been identified, calculated and analyzed in order to understand the economic viability of each action. The table below shows a summary of the economic analysis done for this study. It includes the total costs and benefits calculated for the measure, the net present value of the project´s cash flows, the estimated payback period of each measure, and the measure's Benefit-Cost Ratio.

It is important to note that costs and benefits were not estimated for PF 6 and PAP 6 due to the lack of information about the specific infrastructure in these areas.

Table 10: Results of the Cost-Benefit Analysis of the pilot project actions.
Source: Prepared by the authors.

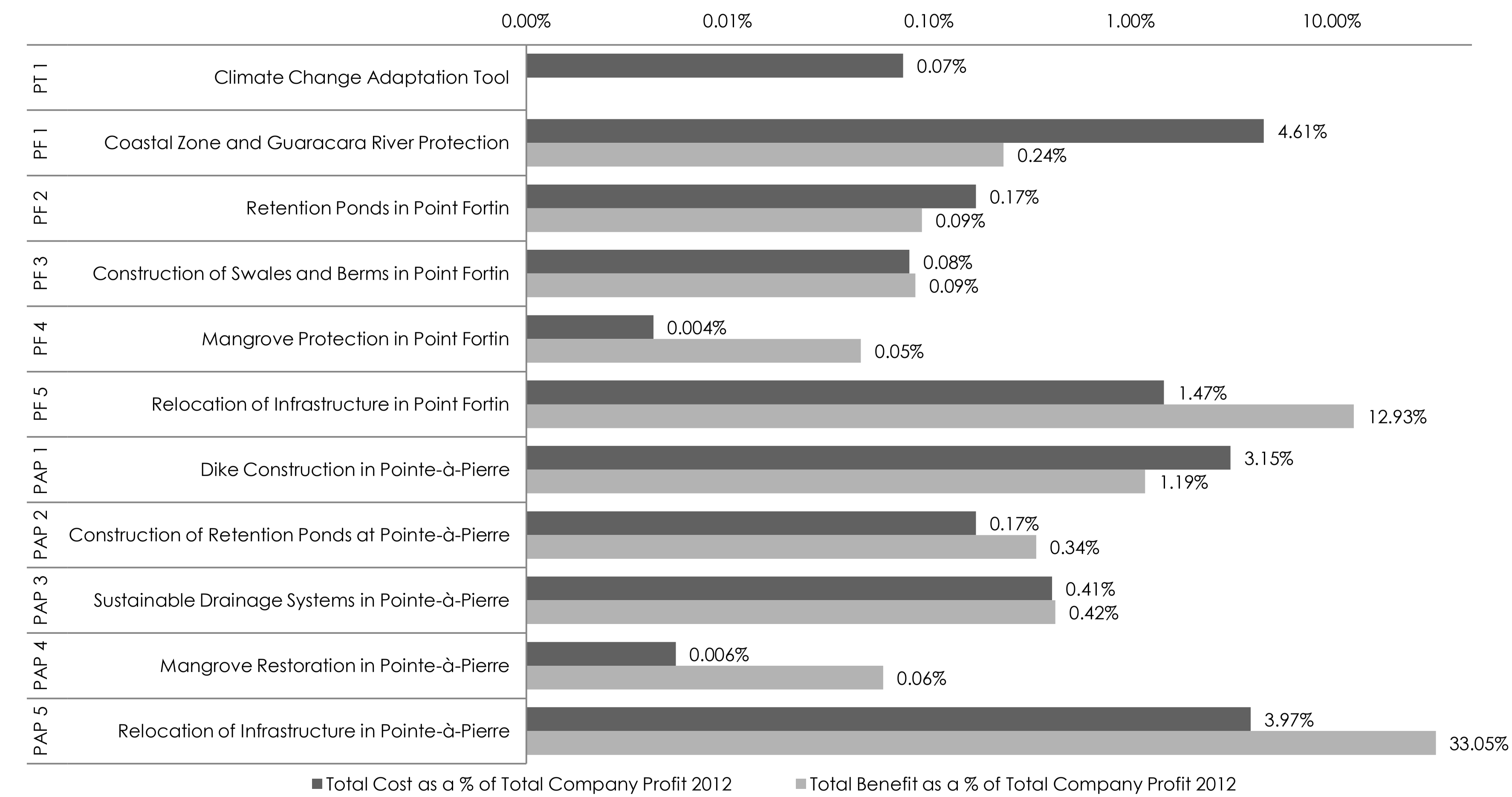
Action code	Title	Total cost	Total benefit	Net present value	Pay back (years)	Benefit/Cost Ratio
PT 1	Climate Change Adaptation Tool	$117,500	N/A	N/A	N/A	N/A
PF 1	Coastal Zone and Guaracara River Protection	$7,267,721	$370,635	-$3,927,621	∞	0.1
PF 2	Retention Ponds in Point Fortin	$269,900	$145,574	-$173,446	24	0.5
PF 3	Construction of Swales and Berms in Point Fortin	$126,194	$134,871	-$52,703	15.4	1.1
PF 4	Mangrove Protection in Point Fortin	$6,750	$72,391	$26,285	7.8	10.7
PF 5	Relocation of Infrastructure in Point Fortin	$2,317,739	$20,375,901	$9,987,274	0	8.8
PF 6	Infrastructure Elevation in Point Fortin	N/A	N/A	N/A	N/A	N/A

Action code	Title	Total cost	Total benefit	Net present value	Pay back (years)	Benefit/Cost Ratio
PAP 1	Dike Construction in Pointe-à-Pierre	$4,961,914	$1,869,243	-$2,011,884	27.8	0.38
PAP 2	Construction of Retention Ponds at Pointe-à-Pierre	$269,900	$537,769	$37,866	9.3	2.0
PAP 3	Sustainable Drainage Systems in Pointe-à-Pierre	$644,715	$669,062	-$223,766	15.6	1.04
PAP 4	Mangrove Restoration in Pointe-à-Pierre	$8,708	$93,384	$33,907	7.8	10.7
PAP 5	Relocation of Infrastructure in Pointe-à-Pierre	$6,260,578	$52,076,889	$24,548,353	0	8.3
PAP 6	Infrastructure Elevation in Pointe-à-Pierre	N/A	N/A	N/A	N/A	N/A

Relocation of infrastructure in both Point Fortin and Pointe-à-Pierre both have significantly high positive Net Present Values, given the fact that the infrastructure built will provide the company benefits during their entire use life and remove the risks of inundation. For the actions restoring mangroves in both Point Fortin (PF 4) and Pointe-à-Pierre (PAP 4), the costs of the action are much lower than the potential benefits. The actions related to improving drainage in both Point Fortin (PF 2 and PF 3) and Pointe-à-Pierre (PAP 2 and 3) have Payback Periods of less than three years, making these measures interesting for consideration in terms of reducing the risk of inundation in both locations. Lastly, the measure related to building dikes in Point Fortin (PF 1) has rather high costs relative to its benefits. This is partly due to the fact that the benefits due to Petrotrin's use of the port area and terminalling stations were not able to be included in the study due to lack of specific information regarding the use of this port by the company. It should be mentioned that Point Fortin is considered and an important terminalling station for the company, and therefore if this benefit were able to be included, this measure's results would likely improve.

The graph below shows the measures' total costs and total benefits as a percentage of the company's net profit in 2012.

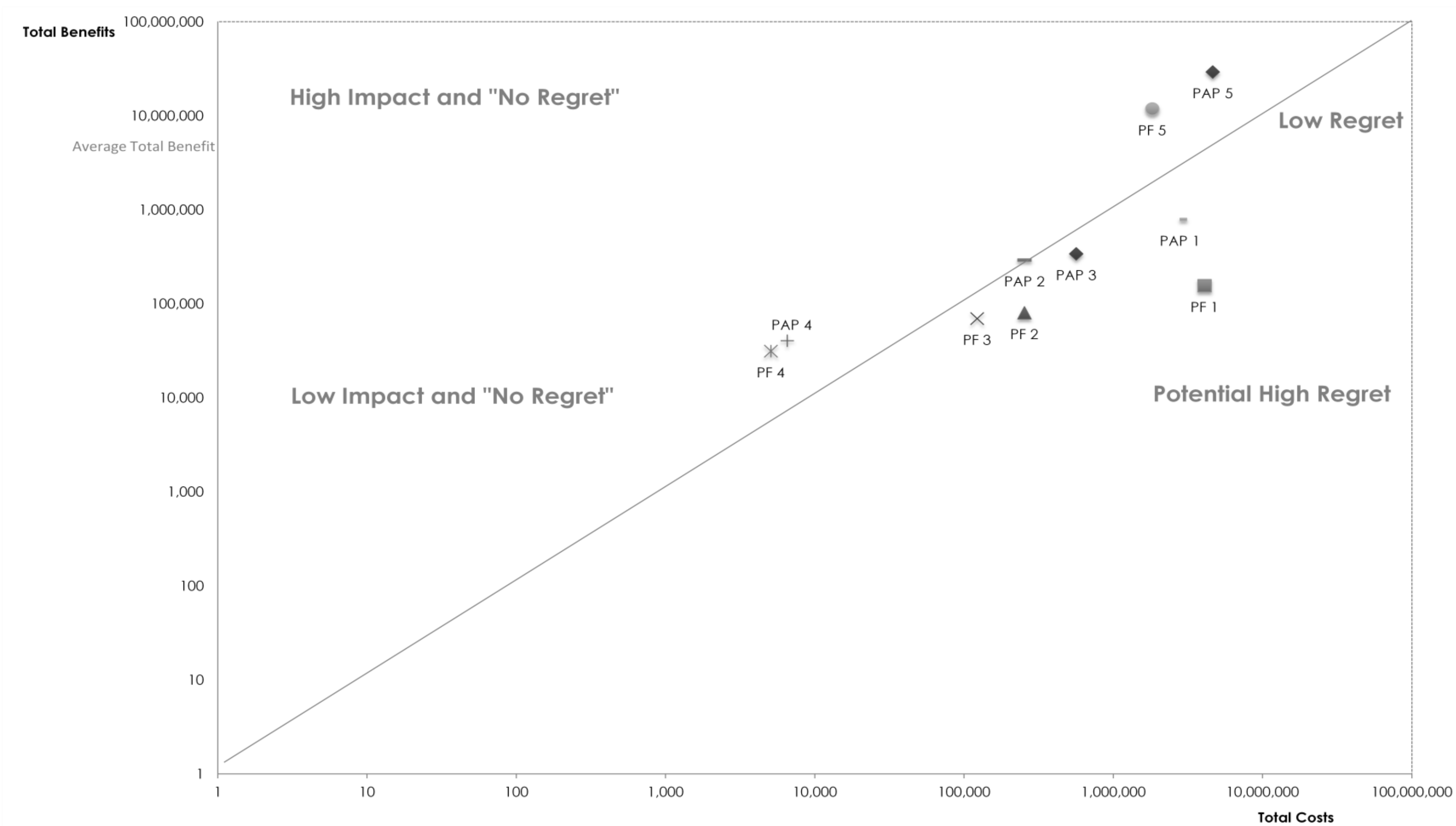
Graph 5: Total Cost and Total Benefits of each measure as a percentage of Petrotrin's Net Profit in 2012.
Source: Prepared by the authors.



Please note, this graph is in logarithmic scale

The graph below shows what the analysis has determined for each analysis in terms of "No Regret". Please note that this graph is showing the present value of the total benefits and total costs and both the x and y axes are represented in a logarithmic scale.

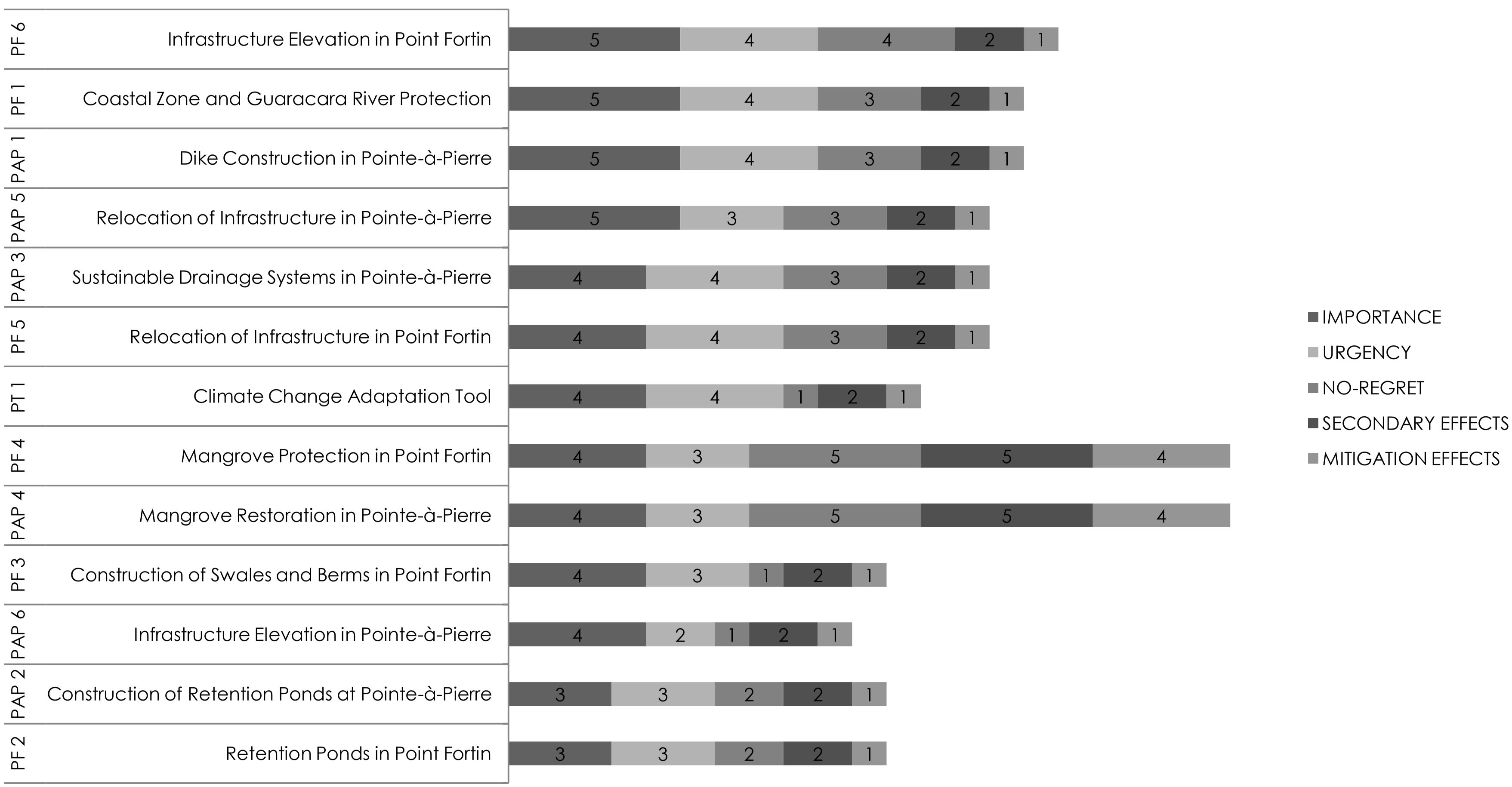
Graph 6: "No Regret" analysis of the pilot project actions.
Source: Prepared by the authors.



Both measures related to the relocation of infrastructure in Point Fortin (PF 5) and Pointe-à-Pierre (PAP 5) fall under the category of High Impact and "No Regret". As mentioned previously, this is due to the fact that the infrastructure built will provide the company benefits during their entire use life and remove the risks of inundation. The measures involving mangrove restoration in Point Fortin (PF 4) and Pointe-à-Pierre (PAP 4) are considered Low Impact and "No Regret" due to their high Benefit/Cost ratio. Retention Ponds in Pointe-à-Pierre is between Potential High Regret and Low Impact and "No Regret", as its costs are similar to its benefits. Lastly, the rest of the measures, fall under the category of Potential High Regret. The measures in Pointe-à-Pierre have slightly better results than those for Point Fortin. This is due partially to the fact that more of the benefits related to the productive value of Pointe-à-Pierre were able to be estimated and included in the analysis. However, this result also makes sense given that Pointe-à-Pierre has the country's only oil refinery, and is of relatively higher strategic importance for Petrotrin.

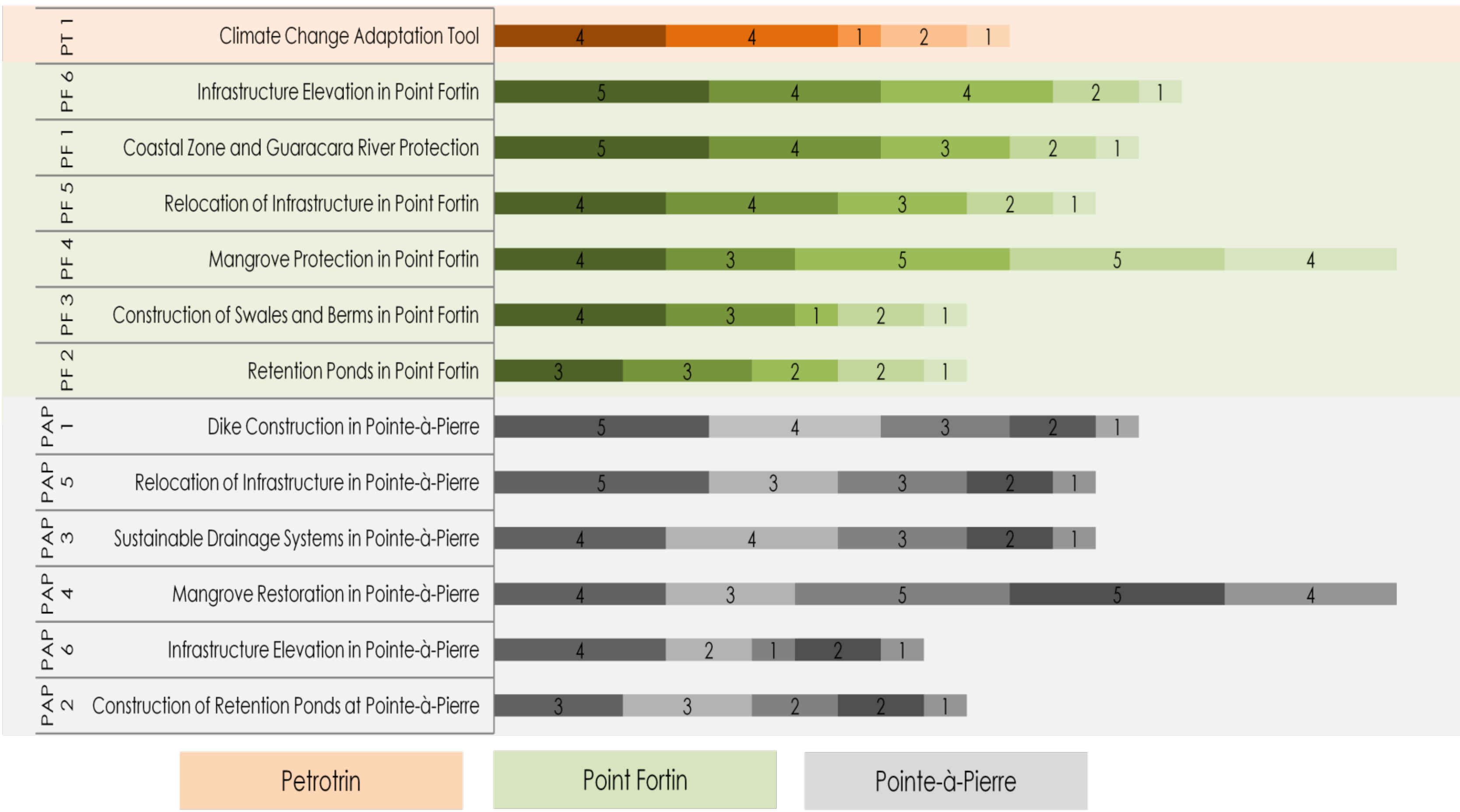
Similar to the country level actions, a multi-criteria analysis was carried out as well for the actions of the pilot study. The results of this Multi-Criteria Analysis exercise are shown in the graphs below.

Graph 7: Multi-criteria analysis of the pilot project actions.
Source: Prepared by the authors.



The scores in each bar in order from left to right: Importance, Urgency, No-Regret, Secondary Effects, and Mitigation

Graph 8: Multi-Criteria Analysis of the pilot project actions by type of action
Source: Prepared by the authors.



The scores in each bar in order from left to right: Importance, Urgency, No-Regret, Secondary Effects, and Mitigation Effect

As shown in the first graph, the elevation of the Port in Point Fortin is the classified as highest, by weighted score. This is due to the fact that the port and terminalling stations are strategic for Petrotrin. The actions focused on reinforcing the coastal areas in both Point Fortin and Pointe-à-Pierre are also highly classified in the Multi-Criteria Analysis. The Relocation of Infrastructure and improvement of drainage systems in Pointe-à-Pierre also have high importance and urgency due to the significance of the infrastructure in Pointe-à-Pierre to Petrotrin. The climate change action adaptation tool obtains better results than mangrove restoration, mainly due to its urgency compared to that of the mangrove restoration.

When the actions are classified by type, actions in both Point Fortin and Pointe-à-Pierre are both relatively equal in terms of scoring, with actions in Point Fortin having slightly higher urgency. This is due to the fact that flooding in Point Fortin is expected to occur before 2031, whereas flooding in Pointe-à-Pierre - although affecting more infrastructure for the company - is not projected to occur until 2051.

As a conclusion, if the results of the different assessments conducted are analysed in conjunction, it can be seen that, for different reasons, all the actions proposed might be helpful and interesting from a climate change adaptation perspective. In terms of Mangrove Restoration in both Point Fortin (PF 4) and Pointe-à-Pierre (PAP 4), the results of the multi-criteria analysis related to importance and urgency are lower, but it has a good benefit-cost ratio and offers many positive secondary effects. Second, the climate change adaptation tool does not offer any economic benefits itself, but it would be very useful for the company to obtain a comprehensive view of its current and future situation in terms of climate change adaptation. Furthermore, it would include all the climate change adaptation information already developed by the company and would facilitate the development of complex adaptation assessments in the different sites in which the company is located - taking into account the vulnerability of those sites and any other relevant factors. It would therefore facilitate the decision-making by including the climate change factor in the assessments of the company.

Lastly, it is important for Petrotrin to look at the remaining measures holistically, and determine its best strategy for the company, and then for both Point Fortin and Pointe-à-Pierre. As can be seen by the projections done for both areas by Singh and El Fouladi (2006 for Pointe-à-Pierre and 2007 for the Point Fortin area), both locations are at risk of inundation and land erosion due to sea level rise and storm surge in the future. Both areas are also strategically important for the company, as Point Fortin facilities deliver the region's best strategically located terminalling services and Pointe-à-Pierre is home to the country's only oil refinery (Petrotrin, 2013). Therefore, both areas will likely need investments made in order to adapt to the risks of climate change and ensure their productive use in the future. Petrotrin will need to look strategically at the options and decide what is best for the company. As an example, they may decide to improve the drainage systems in both locations in the short term (PF 2 and 3, PAP 2 and 3), while working to acquire the financial investments required for larger projects such as Port and Infrastructure Elevation in Point Fortin (PF 6) and Dike Construction in Pointe-à-Pierre (PAP 1).

It is important to mention that while all of these measures are analyzed as individual measures, many of these measures would have increased impacts if they were implemented in conjunction with other proposed measures. As an example, all of the measures, with the exception of relocation and elevation of infrastructure, are designed to help reduce the risk of flooding and storm surge, and therefore could help improve the protection of the industrial area if jointly implemented. All of the measures detailed in this report should therefore be looked at holistically and strategically when deciding which activities to implement, ensuring that possible mutual and re-enforcing benefits are captured.

Also, these recommendations have been made based on the information currently available. In many cases, secondary sources were used in order to determine the costs and benefits for these measures, given the lack of primary source information. It is recommended that before any of these measures are undertaken, a detailed analysis of their feasibility and impacts be done in order to decide whether or not to implement the measure. Additionally, it is recommended that Petrotrin complete a multi-criteria analysis similar to the one done in this study in order to include their knowledge and experience regarding their business practices into the results.

3. Literature Review

3.1. Introduction

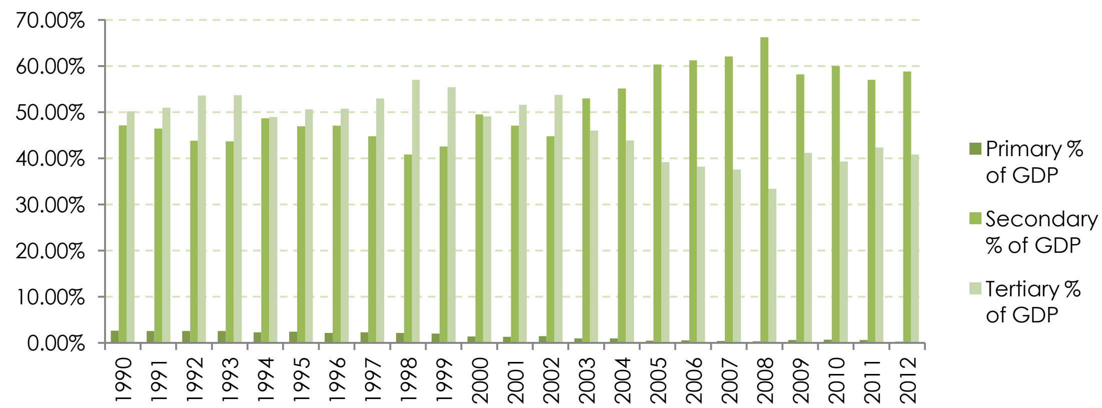
The Republic of Trinidad and Tobago is a twin-island nation of about 1.33 million people and land area of 5,127 sq km. Trinidad is the larger of the two islands with a population of 1.27 million and land area of 4,827 sq km. Tobago has a land area of 300 sq km and a population of less than 61,000 (CSO, 2012a). The country is an archipelagic state located in the southern Caribbean, with Trinidad located to the southwest of Tobago.

Even though in November 2011 the Organization for Economic Co-operation and Development (OECD) removed Trinidad and Tobago from its list of developing countries, the country is included in the Small Islands Developing States (SIDS) group. This group was recognized at the Earth Summit held in Rio de Janeiro, Brazil, in 1992 and includes developing countries facing specific social, economic and environmental vulnerabilities.

There are three geographical regions in which SIDS are located: the Caribbean, the Pacific and the Atlantic, Indian Ocean, Mediterranean and South China Sea (AIMS). In general, they face the same constraints for sustainable development. These constrains include: a narrow resource base depriving them of the benefits of economies of scale; small domestic markets and heavy dependence on a few external and remote markets; high costs for energy, infrastructure, transportation, communication and servicing; long distances from export markets and import resources; low and irregular international traffic volumes; little resilience to natural disasters; growing populations; high volatility of economic growth; limited opportunities for the private sector and a proportionately large reliance of their economies on their public sector; and fragile natural environments.

Trinidad and Tobago has slightly different characteristics to other SIDS, mainly because of its rich energy resources. The country has oil and gas. In fact, instead of having to pay high costs for energy imports, Trinidad and Tobago exports oil and gas. This also affects the industrial development of Trinidad and Tobago compared to that of other SIDS, giving industry a major role in the economy of the country. In fact, in Trinidad and Tobago, apart from the extraction and processing of oil and natural gas, there are other industries which have an important effect on the economy of the country, such as the production of methanol, fertilizer production and steel.

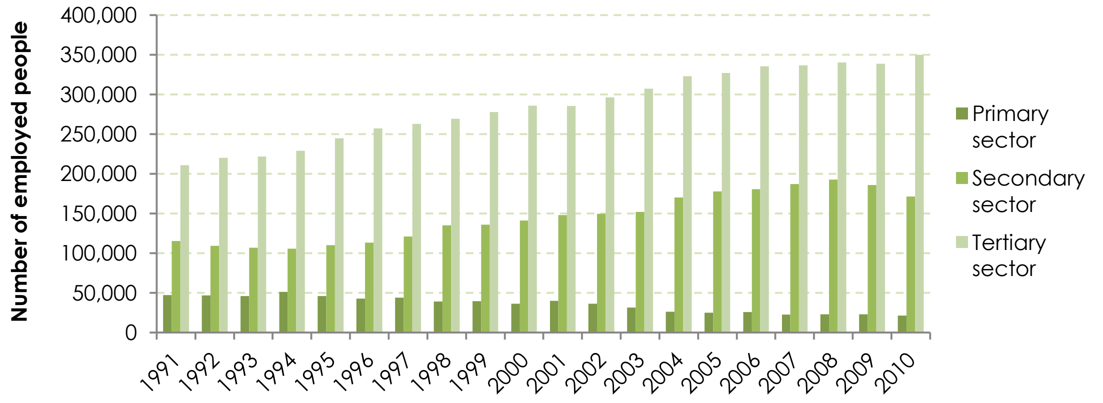
Graph 9: Evolution of the GDP share by sector in Trinidad and Tobago.
Source: World Bank.



The primary sector refers to the extraction or harvest of raw materials from the earth. The secondary sector refers to all manufacturing, processing, and construction. Lastly, the tertiary sector is a service industry, which includes activities such as retail, transportation and distribution, restaurants, tourism, and banking. As shown in the graph above, the secondary and tertiary sectors account for most of the Gross Domestic Product (GDP) of Trinidad and Tobago. The contribution of the primary sector has decreased since 1990 from less than 3% to less than 0.5%. Another interesting trend that can be observed in the graph is the increase of the contribution of the secondary sector, which in 1990 had a lower contribution compared to that of the tertiary sector, while in 2012 the situation was the opposite, raising the secondary sectors contribution to almost 60% of the total GDP of Trinidad and Tobago.

However, this GDP sectoral share is not consistent with the sectoral employment share, for which the contribution of agriculture is higher than the contribution of the oil sector, according to the data provided by the Central Bank of Trinidad and Tobago.

Graph 10: Evolution of the employment by sector in Trinidad and Tobago.
Source: Central Bank of Trinidad and Tobago.



As shown in the graph above, even if the relevance of the primary sector has decreased since 1991, it is still higher than its contribution in terms of GDP. In 1991, 13% of the total labour force of Trinidad and Tobago was employed in the primary sector, a value that decreased until reaching 4% in 2010. Furthermore, in the graph shows that in terms of employment, the secondary sector has historically employed less of the labour force than the tertiary sector.

If, instead of analyzing the country as a whole, the two islands are viewed separately, clear differences can be found between the features of Trinidad compared to Tobago. The previously stated importance of industries in the economy is derived from the characteristics of Trinidad, where all the industrial sites are located. On the other hand, the economy of Tobago is primarily based on tourism. Due to these differences in the economy of each island, the consequential environmental issues are also different. While in Tobago, preserving biodiversity is key for development, in Trinidad the efforts need to be more focused on dealing with densely populated areas and the effects of industry on the environment.

In terms of vulnerability to the effects of climate change, Trinidad and Tobago's effects and possible impacts have been well documented (Government of the Republic of Trinidad and Tobago, 2013; Ministry of Planning and the Economy, 2012). As a Small Island Developing State (SIDS), the country is vulnerable to temperature increases, changes in precipitation and sea level rise (Government of the Republic of Trinidad and Tobago, 2011). Other vulnerabilities include increased flooding, increased frequency and intensity of hurricanes, hillside erosion and loss of coastal habitats (Government of the Republic of Trinidad and Tobago, 2013). These vulnerabilities are projected to have consequential effects on the agriculture, human health, human settlements and infrastructure, coastal zones, water resources and tourism sectors.

As the world gets warmer, the risk of extreme weather events heightens. In the period between 1930 and 2008, about 248 extreme weather events that can be linked to climate change and hydro-meteorological phenomena were registered in the Central America region. Floods, storms, mudslides and landslides accounted for over 85% of these registered events. To a lesser magnitude, forest fires related to extreme temperatures and droughts accounted for 9%. The most frequently occurring event is floods. The frequency of floods has doubled in the past twenty years affecting the most vulnerable areas of riverbanks, low-lying areas and coastal zones (ECLAC, 2010).

In the Caribbean region, the average temperature has increased for the past three decades. This warming trend extends to the lower part of the Caribbean's atmosphere (Taylor et al., 2007). It is projected that the Caribbean will get even warmer within the range of 0.48 to 1.06 °C during 2010 -2039, 0.79 to 2.45 °C during 2040-2069 and 0.94 to 4.18 °C for the 2070-2099 periods (Pulwarty et al., 2010). The result will likely be an increase in the number of hot days, warm to hot nights and warmer seas. These warmer nights are expected to be more prevalent in the Caribbean and deep tropics. Projected impacts to accompany warmer days and warmer seas include sea level rise (thermal expansion), changing distribution of disease carriers, change in the patterns of rainfalls and more acidic oceans (Tompkins et al., 2005).

In Trinidad and Tobago, the average ambient temperature increased by 0.6 °C between 1961 and 1990 and by 1.7 °C from 1961-2008. Although no significant increase in mean rainfall was observed over the same period, variations in pattern of rainfall was recorded. The largest change occurred during the wet season (June-August) when mean rainfall decreased by 6.1 mm per month per decade. In the eight-year period between 1984 and 1992, rise in sea level was observed to be in the range of 1.6mm - 3.0mm per year (Government of the Republic of Trinidad and Tobago, 2011).

The Caribbean as a whole has a history of natural disasters, particularly those caused by hurricanes, in fact, in general, in the Caribbean the most significant natural hazard risk is tropical storm and hurricane risk (CCRIF, 2010). With rising temperatures, the intensity and frequency of hurricanes are projected to increase. Changes in weather patterns are compounded by socio-demographic changes such as increasing population growth, poverty, urbanization, deforestation and lack of land to heighten the vulnerability of SIDS to natural disasters (Pielke et al., 2003; Pulwarty et al., 2010).

By comparing historical hurricane losses to what they would be under current societal conditions, Pielke et al. (2003) concluded that population growth, wealth, and inflation can all affect the outcomes of natural disasters along with climate change. The results implied that each storm in the Caribbean since 1960 would have caused more damages if they had occurred in 1998.

Even though Trinidad and Tobago is not in the main Atlantic hurricane belt, the potential to be hit by hurricanes still remains and it is considered one of the main natural hazards (CCRIF, 2013a). In fact, in the past a number of tropical cyclones and two hurricanes have affected the country since 1850.

The Economic Commission for Latin America and the Caribbean (ECLAC) conducted similar economic assessments for Central America. These assessments showed that for Costa Rica, El Salvador, Guatemala, Honduras and Nicaragua, losses totalling US$13.6 billion were caused by hurricanes. Hurricane Mitch caused the most damages, amounting to about $8 billion. More than half of these damages represented loss to the productive sector, mainly the agricultural sector. Infrastructure loss accounted for a quarter of losses owing to the damages to the telecommunications and transportation sectors. About four-fifth of the losses from the social sectors was due to damages to houses. This was not surprising since, in the urban areas, people live "in precarious dwelling and only 43% of homes are subjected to established and legal ownership" (ECLAC, 2010, p 69). In the rural areas, homes are made of dirt floor (43%), roofs are made of provisional material (12%) or walls are made of light disposable material (20%). All of which increase the vulnerability of people's dwellings to extreme weather events such as hurricanes.

It should be noted that the latest Representative Concentration Pathways (RCP) scenarios being used in the 5th assessment of the Inter-Governmental Panel on Climate Change (IPCC) in the final report of working group I gave a global sea level rise projection of 0.32-0.62 metres for the period 2081-2100 for the mid-range RCP 4.5 scenario compared to 1986-2005. By comparison, the high-range RCP8.5 scenario projection showed a sea level rise range of 0.53-0.97 metres by 2100. Only the collapse of the Antarctic Ice Sheet is likely to substantially alter this range during the 21st century; however, this additional contribution cannot be precisely quantified at this time. Sea level rise in Trinidad and Tobago has so far matched the global average and is not expected to differ substantial from the global range in the future. Trinidad and Tobago's median seal level rise by 2100 might be 0.52 metres based on RCP4.5 and 0.73 metres based on RCP8.5. Therefore, planning for sea level rise of about 1 metre by the year 2100, although on the high side of projections, might be prudent as it incorporates a safety factor. Other projections for the Caribbean by the year 2100 using RCP4.5 includes a median annual temperature increase of 1.4 ^{O}C. Precipitation is projected to decrease in the southern Caribbean and increase in the north consistent with observed trends.

Simpson et al. (2010) made some projections of the potential economic impact of 1 metre sea level rise on Caribbean Community (CARICOM) member states. Countries that were suggested to suffer the greatest economic loss in absolute terms included Bahamas, Belize, Guyana, Trinidad and Tobago, and Suriname. While the bigger countries may suffer the greatest absolute losses, the smaller economies will experience greater proportional impacts since their capacity to recover and absorb losses is minimal. With a hypothetical scenario of a 1 meter rise in sea level by the year 2100, it is projected that about 1,300 km^2 of land mass may be lost and over 110,000 people displaced (Simpson et al. 2010; Scott et al 2012). Five power plants are likely to be damaged or lost and key sectors such as tourism and agriculture could lose millions in revenues. With regards to the transportation sector, 21 CARICOM countries' airports could be lost or damaged, 35 ports inundated and about 567 km of road way destroyed. The loss would increase if the effects of storm surges and the erosion to coastal beach due to sea level rise are included in the calculations.

Simpson et al. (2010) also projected future impact of sea level rise on the tourism sectors of a few Caribbean countries, including Trinidad and Tobago. The projected costs are reported in the table below. These projected effects on the tourism sector stems not only from rebuilding costs, but also from annual losses due to reduced revenue from beach loss. The overall projections for rebuilding are between US$10 – US $23.3 billion in 2050 and $23.5 and US$74 billion in 2080. For Trinidad and Tobago, sea level rise is estimated to cost the country between 1.3 – 1.4% of its Gross Domestic Product (GDP) annually and another US$1.3 to US$4.8 billion in rebuilding costs.

Table 11: Projected Annual Losses and Rebuilding Costs for Selected Caribbean Countries Due to Sea Level
Source: Simpson et al. (2010).

Country	Loss in 2050		Loss in 2080		% of GDP 2050		% of GDP 2080	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Antigua & Barbuda		36%		85%				
Bahamas	$869 m	$946 m	$2.2 b	$2.6 b				
Barbados	$283 m	$368 m	$ 850 m	$860 m	4.8%	18.7%	7.3%	42.8%
Grenada	$490 m	$1100	$1.3 b	$3.7 b	12.4%	21.5%	14%	33%
St Kitts and Nevis					60%	89%	73%	150%
Trinidad & Tobago			$1.3 b	$4.8 b			1.3%	$1.4%

Given the above estimated losses to roadways, hotels, airports, and sea ports, some countries will incur high population displacement costs. In the Bahamas, these relocation costs were estimated to be US$5.6 - US$11.3 billion in 2050 and US$11.7 to US$32 billion in 2080. These costs include relocating seaports, airports, tourist resorts, property, power plants and infrastructure. Haiti's costs are in the range of US$1.8 and US$4.3 billion in 2050 and US$4.6 – 17.2 billion in 2080 Simpson et al. (2010).

Bueno et al. (2008) developed similar cost estimates for the Caribbean region in a "business as usual" scenario. These costs were based on a methodology of comparing an optimistic scenario (rapid stabilization/low impact) with a pessimistic scenario (high impact/business as usual). The difference between the cost estimates for these two scenarios was regarded as the cost of inaction. Along with the effects of sea level rise, the cost of inaction related to hurricane damages and tourism losses were also calculated. Estimated costs of inaction for Trinidad and Tobago stood at 16% of GDP.

Caribbean islands are completely surrounded by water and development is concentrated along the coast for many of these islands. Therefore, observed rising sea levels, from 10 to 20 cm during the 20th century is of concern (Singh, 1997). With each centimetre, shoreline will retreat by several meters resulting in loss of land. The natural result could be flooding during storms for cities that are poorly drained and low-lying.

Coastal lagoons and estuaries may lose productivity due to saline intrusion and flooding. There are also possible implications on ocean acidity. With increased hydrogen ions in the ocean (about 30% increase), existing coral reefs are at risk. By 2050, a reduction of between 14 to 30% in calcification rates of corals could be experienced due to higher carbon dioxide absorption (IPCC TAR WG2, 2001). The tourism and fishery industries of some islands could be affected. Both the diving industry and the local fisheries depend on healthy reefs for their survival. According to Lewsey et al. (2004), the distinct physical effects of sea level rise includes: the emergence of low-lying wetland and dry land areas; erosion of soft shores by increasing offshore loss of sediment; increased salinity of estuaries and aquifers; rising coastal water tables and increased and more coastal flooding and storm. Along the line of this finding, ECLAC (2010) employed a Change of Land Use and its Effects – Small Scale Model (CLUE-S) and concluded that by 2100 roughly a third of forest cover will be lost, as well as up to 80% of savannahs, shrub land and natural pasture. In this case, land loss could be a factor of agricultural expansions. The loss of trees has implications for carbon stick. By 2050, the current carbon stock of 3,564 mega-tonnes will be reduced by 72%.

The infrastructural planning in most developing countries is severely lacking. Scatter settlements are becoming more common in the urban areas. Due to poor planning, these structures are vulnerable to extreme weather events such as hurricanes and rising sea level. This trend is expected to continue as long as coastal urbanization and uncontrolled development continue. Lewsey et al. (2007, p. 6) indicated that "a majority of the population centres, agricultural areas, tourism infrastructure, ports and other major sites for industrial and commercial activity are located in the coastal zone; many in low-lying floodplains that are vulnerable to flooding from hurricanes and SLR (sea level rise)". Coastal infrastructure destroys the natural buffers against weather events. The construction of harbours, channels, etc. can affect the photosynthesis process of coral reefs and sea grasses by decreasing the water quality. In some cases, mangroves are cleared for coastal development. This removes the ecosystem's natural buffer against flooding. Some beaches are mined for sand, which increases vulnerability to flooding since it erodes landforms.

The agricultural sector is a major income earner in most developing countries. Current trends indicate lowered productivity due to climate related phenomena. The growth and development of crops and even the variety of crops that can thrive are both affected. The El-Nino Southern Oscillation (ENSO) has been associated with lower precipitations that lead to a delayed rainy season, an increase mean temperature and lower cloud coverage (ECLAC, 2010). The overall impact of climate change on the agricultural sector can be manifested through increased carbon dioxide concentration, extreme weather events, availability of water resources and changes in temperature and precipitation. To empirically test these possible effects, ECLAC (2010) used an econometric method of Ordinary Least Squares (OLS) to estimate the effects of climate change on indices of the agricultural sector, crop and livestock production. The results suggest that under both A2 and B2 scenarios, the agricultural crop index could fall by 9% and 3%, respectively by 2100, implying a reduction in the value of agricultural outputs with rise in mean annual temperatures.

The agricultural sector is affected by sea level rise, intense rainfall, severe flooding, landslides and erosions which are expected effects of climate change. Simpson et al. (2010) estimated that the loss of agricultural lands will be at a cost of between $370 million in 2050 and about $2 billion in 2080. Haiti will be worst affected with costs amounting to US$700 million to US$1.8 billion in 2080. The agricultural sector will be more affected by saline intrusion than by temperature change (Lewsey et al., 2004). In terms of forestry, natural forests are at greater risk from human action than from climate change given current trends of deforestation although forests are still vulnerable to either extreme flooding or extreme drought. Also, climate change could be accompanied by increased incidents of pest and pathogens and forest fires. With the impending effects of climate change on the agricultural sector, food security is threatened. If food production is reduced, the law of demand and supply guarantees an upward pressure on prices. The poor and the most vulnerable in society will be most affected by rising food prices and reduced access to food.

Increased temperatures will have associated impacts on food, coastal settlements, health, ecosystem and water system. ECLAC (2010) noted that with rising temperatures, there may be increased water availability in moist tropics and high latitudes but decreasing water availability and drought in mid-latitudes and semiarid low latitudes. This translates to increased water stress for millions of people. Up to 30% of the region's species are at risk of being extinct while increased carbon bleaching will be experienced. With increased incidents of flood and storms, about 30% of global wetlands will be lost. This will exacerbate flooding yearly. Other "observed trends include the replacement of wet ecosystems with dry ones; the replacement of hydrophilic vegetation with no-hydrophilic species in wetlands; the displacement of montane, low-montane, and pre-montane pluvial forests; changes in the sub-Alpine, pluvial uplands and wet tropical forests, as well as the appearance of very dry tropical forests and dry pre-montane forests" (ECLAC 2010). Due to rising temperatures, growth of trees will be hampered and their ability to sequestrate carbon and produce oxygen will be hindered. This feeds into the loss of habitat for species and the emergence of new evasive species and disease vectors.

Regarding health, there is a link between respiratory diseases and temperature and moisture. Chen et al. (2008) outlined a few studies that established this link. A direct link was found between daily values of the geomagnetic index and adults receiving care for asthma crises, showing a nonlinear relationship between solar variability and such patients. Attempts have been made to show a relationship between solar activity and myocardial infarctions. Studies also sought to establish a link between dengue fever and temperature in the English speaking Caribbean. There may also be increased burden from malnutrition, diarrhoea and infectious diseases. Rising temperatures will increase morbidity and mortality from heat waves, floods and droughts. All these will present substantial burdens on the health system (ECLAC, 2010).

Climate change will affect energy demand in several ways, including an increase in energy demand due to increase use of air conditioning and cooling machinery. In addition, in terms of energy generation, impacts from climate change include decreases in the efficiency and capacity of natural gas or oil-fired combustion turbines or steam cycles due to increased temperatures. Power lines can also be affected by higher temperatures, since, under high temperatures, reinforced steel cables in power lines lose their tensile strength, expand, and begin to sag, which may put them close to obstacles that were before out of reach of these lines. In terms of variability in precipitation, thermal power plants use a significant amount of water in the electricity generation process. In periods of severe drought, the energy sector will need to compete with other sectors of the economy for the limited water resources available, causing stress on the economy as a whole. In terms of sea level rise, a significant amount of generation infrastructure in the Caribbean is located near the sea and is at risk of being damaged by flooding or erosion. Lastly, much of this infrastructure is also vulnerable to extreme weather events (Martín et al, 2013).

The table below shows a summary of the potential effects of climate change in Trinidad and Tobago:

Table 12: Potential effects of climate change by sector in Trinidad and Tobago.
Source: Prepared by the authors.

Sector	Impact
Agriculture	▪ Warmer weather from high temperature will cause soil aridity, lead to proliferation of pests and diseases, and put pressure on water resources for water for irrigation purposes. ▪ Sea level rise will cause inundation and soil desalination. ▪ The combined impact is low agricultural yields, decrease in food production and higher food process.
Human Health	▪ Higher temperature will increase spread of vector diseases. ▪ Decrease in rainfall will affect potable water supply. ▪ Sea level rise will cause increases in water borne diseases.
Human settlements	▪ Increase in frequency and intensity of storm surge will cause more flooding and disrupt or destroy coastal settlements. ▪ Increase in frequency and intensity of storm surge and extreme rainfall will cause damages to infrastructure from flooding and erosion.
Coastal zones	▪ Sea level rise will lead to increased inundation, increased erosion, loss of wetlands, loss of ecosystems, and displacement of coastal communities. ▪ High temperature will result in loss of coral reefs and reduction in fish stock.
Water resources	▪ Increase in temperature will result in increased evapotranspiration and loss of available surface water. ▪ Decrease in precipitation will reduce groundwater and aquifer recharge. ▪ As an effect, available water resources will be reduced.
Energy sector	▪ Infrastructure, including field installations and offshore operations, are at risk of inundation from sea level rise, storm surges and erosion from extreme rainfall. ▪ Water shortages in the country may affect the needs of the industry in terms of energy generation. ▪ Infrastructure damages due to extreme weather events.

Both Trinidad and Tobago face the same hazards, even if the effects of those hazards would be substantially different in each island. Therefore, the actions needed to mitigate them are the same for both.

Energy is vital for every society. Most countries heavily depend on fossil fuel based energy which makes them vulnerable to international oil price movements. Energy demand is expected to increase as a result of climate change. For Central America, a baseline scenario predicts that by 2100, hydrocarbons and other fossil fuels will dominate total demand with almost 80% used for energy generation and transportation (ECLAC, 2010).

The Government of the Republic of Trinidad and Tobago is taking the issue of climate change seriously and has taken steps to address it. A National Climate Change Policy was finalized in 2011 and Trinidad and Tobago is currently finalizing its Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC). Also, a sustainable development plan was developed for the country in 2012 (Ministry of Planning and the Economy, 2012). These documents contain policies, programmes and strategies that the government is pursing or intends to pursue to address climate change and the progress made towards the goal of achieving development within the context of sustainability. They also highlight the constraints and challenges faced by the country in relation to climate change.

The challenges confronting the government in its climate change adaptation and mitigation response are similar to those faced by other SIDS. The two major constraints are:

- Dearth of relevant climate change data
- Limited technical capacity in identifying the impacts of climate change

These constraints limit the government's ability to adequately plan its climate change adaptation and mitigation response.

In the next sections of this document, the economic implications of climate change on Trinidad and Tobago will be analyzed. As a result, an assessment of the economic losses expected in the future due to the effects of climate change in Trinidad and Tobago will be developed.

Secondly, this document also focuses on how to reduce those effects, proposing different actions for the country. These actions have been selected taking into account the previously explained characteristics of the country, the economic fabric of Trinidad and Tobago and the necessities of its inhabitants.

Lastly, this document analyses the costs and benefits of the proposed measure. These costs and benefits are then analyzed through several economic and multi-criteria tools in order to understand the in order to better understand the feasibility of each proposed action.

3.2. Methodological overview

The ECA methodology is one of many approaches available for analysing the economic impacts of climate change. Although the different approaches are based on sound economic theory, they tend to emphasize different aspect of the climate change issue depending on the primary goal of the methodology (i.e., the questions that the approach is aimed at providing answers for). When categorized according to this primary goal, the methodologies include:

Table 13: Classification of methodologies to assess the economic implications of climate change adaptation.
Source: Prepared by the authors.

Primary goal	Examples
Models of global economic cost of climate change mitigation/adaptation	▪ Stern Review, 2007. ▪ World Bank, 2010
Models of economic costs of climate change impacts at the regional, national and sectoral levels	▪ ECLAC 2009a. ▪ ECLAC 2010.
Models of economic costs of climate change adaptation at the national and sectoral levels	▪ ECA Working Group, 2009. ▪ World Bank, 2010.
Guidelines on costing of the impacts of climate change	▪ Metroeconomica, 2004. ▪ Van Beukering et al., 2007. ▪ Department of Economics, UWI, 2008.

3.2.1. *The Stern Review*

With its global perspective on the issue of climate change, the Stern Review (Stern, 2007) belongs to the first category of models. The methodology employed in the Stern Review centres on welfare economics by classifying greenhouse gases (GHGs) as an externality and the climate as a public good. GHGs in the atmosphere contribute to climate change and climate change has detrimental effects on livelihoods and the sustainability of many economies. In the current circumstance, climate is a public good that benefits everybody and no one is held accountable for the emission of GHGs. The Stern Review describes this situation as a market failure and proposes a correction to the global climate economy where market for emissions is created. This methodology involves two three main steps:

- Estimate the social cost of carbon on the margin (SCC), i.e. the cost to the society (world) now and in the indefinite future of emitting an additional unit of GHGs

- Estimate the marginal abatement cost (MAC), i.e. the cost of removing/preventing an addition unit of GHG in the atmosphere
- Find the level of emission abatement that equates SCC and MAC

The point of equality between SCC and MAC specifies the optimal level of GHGs abatement that the global community must pursue in its attempt to mitigate the effects of climate change. For any period in time, SCC is higher than MAC at lower levels of GHG abatement. As the level of abatement increases, SCC falls while MAC rises. The optimal level of abatement is that at which SCC is equal to MAC, representing a point identical to the optimal point of consumption in consumer theory where marginal cost (MAC) is equal to the marginal benefit (SCC). In this case, the cost of abating an extra unit of GHGs is equal to the benefits from having reduced concentration of GHGs in the atmosphere (equivalent to the SCC avoided). .

The Stern Review's methodology addresses climate change mitigation and noted that the optimal level of abatement will vary depending on the GHG emission scenario and the technical progress achieved in abatement. The risk and uncertainties inherent in climate change were also addressed by realizing that the costs and benefits of climate policy could not be predicted with certainty. In as much as The Stern Review emphasized the benefits of adaptation and policies that would promote the adaptive capacities of different economies, no explicit cost-benefit analysis was performed for adaptation measures given the global nature of the study and the focus on mitigation.

3.2.2. *Economics of Adaptation to Climate Change (EACC) Methodology*

The Economics of Adaptation to Climate Change (EACC) study conducted by the World Bank (2010) had dual objectives:

- Estimate adaptation costs for developing countries
- Assist decision makers in developing countries to understand and assess the risks posed by climate change so as to better design strategies to adapt to climate change

The first objective takes a global perspective in estimating costs of climate change while the second focuses on providing guidance on adaptation measures to implement. In addressing these objectives, the EACC methodology involves the following steps:

- Define a development baseline and establish a growth path till the year 2050 for each sector (and for the macro economy for the second objective) based on GDP and population forecasts for 2010-2050. This baseline represents a state without climate change

- Define two climate scenarios representing extremes of dry and wet climate projections. These scenarios represent the two climate change scenarios that will be used to assess the cost of climate change adaptation

- Use the baseline, dry and wet scenarios to predict what the world would look like under a no climate change situation and under the two climate change conditions

- Compare the state of the world under each of the two climate change scenarios with the state of the world under the baseline scenario to establish welfare change

- Identify adaptation measures that if implemented will restore welfare in a climate change scenario to the pre-climate change status

- Estimate the costs of implementing these measures and the cost of any residual damage from a changed climate

- Add the costs of implementation and residual damages to get an estimate of the cost of adapting to climate change

- Additional for the second objective, perform investment analysis to establish the net benefit of adaptation measures

The EACC methodology is developed around the Intergovernmental Panel on Climate Change (IPCC)'s projections that the global annual temperature will be 2°C above pre-industrial levels by 2050 and that with warmer atmosphere, the world will experience more intense rainfall and other weather extremes that include more frequent and more intense droughts, floods, and heat waves. These climate change effects will essentially erode social welfare and the costs of actions taken to adapt to the new world to maintain welfare or minimize welfare loss constitute the economic cost of climate change adaptation. This approach does not isolate specific hazards for analysis but involves performing vulnerability assessment of sectors when applied at the country-level.

3.2.3. *ECLAC Framework*

Most studies addressing climate change adaptation have been regional in nature and the ECLAC studies on the economics of climate change in Central America (ECLAC, 2010) and in Latin America and the Caribbean (ECLAC, 2009a) are part of this group of studies. Both of these regional studies followed the same methodology and covered selected sectors in different countries in the sub-regions. The methodology involves the following steps:

- Specify a baseline scenario of economic activity. This is based on historical trend of economic performance and involves the projection of economic growth according to this trend without taking into account the impacts of climate change (i.e., a no climate change scenario)
- Use IPCC's A2 and B2[1] emission scenarios to project economic performance of different sectors
- Compare economic performance projections under the A2 and B2 scenarios to the projected performance under the baseline scenario
- The difference in the trajectories of economic growth between the baseline scenario and A2 and B2 scenarios represents the costs (or benefits) of climate change

Using this approach, the economic impacts of changes in temperature, precipitation and sea level were estimated for different sectors in Central America, South America and the Caribbean. Although the benefit of adaptation was discussed and policy options for pursuing adaptive strategies suggested, no cost-benefit analysis of adaptation measures were presented in the two studies.

The Review of Economics of Climate Change in the Caribbean (RECCC) project executed by ECLAC addressed the gaps in the regional studies by incorporating cost-benefit analyses. Trinidad and Tobago was covered in the RECCC project with focus on the agriculture (ECLAC, 2011a), energy (ECLAC, 2011b), and health (ECLAC, 2011c) sectors. The sectoral studies followed the same methodology used in the ECLAC regional studies by specifying a baseline scenario for economic activities in each sector. The baseline trajectory was then projected to the year 2050 and compared with the trajectories under the A2 and B2 emission scenarios. The economic impacts of climate change was then estimated as the difference in the cost of operating on any

[1] The A2 scenario depicts a situation of high greenhouse gas emissions but with relatively weak global environmental concerns to curb emissions whereas the B2 scenario represents a low emissions trajectory with increased concerns for environmental and social sustainability (ECLAC 2009b).

of the climate change scenarios as opposed to following a baseline trajectory of no climate change.

The agriculture sector study looked at the impacts of temperature and precipitation on the yield and output of major crops and fisheries. The energy sector study looked at the impact of temperature on electricity demand while the health sector study looked at the effects of temperature, rainfall and humidity on the spread of diseases. All the studies provided cost-benefit analysis of adaptation measures applicable to the sector but with varying degrees of details. One limitation of these studies is the lack of any analysis on the impact of sea level rise. The studies were also not based on an assessment of the "total climate risk."

3.2.4. *The Economics of Climate Adaptation (ECA) Framework*

The ECA Working Group (2009) proposed a framework that quantifies the total climate risk faced by a nation. This involves three main steps:

- **An assessment of the total climate risk facing the country**. This entails identifying the climate hazards facing the nation, assessing the vulnerability to these hazards and estimating the value at risk in terms of human lives and infrastructure under a no climate change scenario. The impact of climate change is then assessed by examining the additional risks and vulnerability and the value at risk from a moderate and a high climate change scenarios. This provides for a comprehensive documentation of the risks that climate change presents to the economy.
- **An accurate understanding of measures or available options to address these risks**. This process involves identifying the various climate change adaptation measures available to address the risk posed by the hazards and quantifying the cost of implementing them. The benefit of putting these adaptation measures in place is also estimated and a cost-benefit analysis performed for each suggested option.
- **Prioritization of the most effective measures and integration into country's development plan**. The final step involves using the results of the cost-benefit analyses to inform decision making by itemizing adaptation measures in the order of effectiveness. This itemization allows adaptation measures to be classified as cost-saving, cost-effective or cost-ineffective. The prioritization is only an aid in decision making and decision makers may incorporate other criteria, e.g. affordability, in making decision on what options to integrate in the countries sustainable development plan.

The ECA framework has been applied by CCRIF in the Caribbean region but Trinidad and Tobago was not covered in that study.

3.2.5. *Guideline on Costing the Impacts of Climate Change*

The studies done by Metroeconomica (2004); van Beukering et al., (2007) and the Department of Economics, University of the West Indies (UWI) (2008) form another group. This group of studies is narrower in focus and geared towards providing guidelines on how to estimate costs once the impacts of climate change have already been identified. Studies in this category discuss the methodologies of estimating costs for market-based goods and non-marketed goods that may be impacted by climate change. They also discuss the important issues of discounting and offered templates for performing cost-benefit analysis. While these studies do not present a unique methodology on the Economics of Climate Adaptation per se, they provide useful tools that can be employed in the calculation of costs and benefits regardless of the methodology adopted.

A snapshot comparison of this methodology with other methodologies discussed in this review is presented in the following table.

Table 14: Classification of methodologies to assess the economic implications of climate change adapt
Source: Prepared by the au

ethodology	Objective	Level of Application	Steps	Assumptions / Information Required	Advantages	Limitati
ern Review	Determination of optimal level of global abatement of GHGs.	Global Level	1. Estimate the Social Cost of Carbon on the margin (SCC). 2. Estimate the Marginal Abatement Cost (MAC). 3. Determine the emission abatement level at which SCC=MAC.	The SCC must be identified and agreed upon. Information about the marginal costs of reducing one ton of CO_2e will need to be estimated, which will likely be different across industries and sectors, and among countries.	A single comprehensive model for estimating global cost of GHG emissions.	Methodol not design addre adaptat
orld Bank ACC)	Determination of the economic impact of climate change and identification of cost-effective adaptation measures for implementation.	Global level (Top down approach) and Country Level (Bottom up approach)	1. Define a development baseline of no climate change for 2010-2050. 2. Define two climate scenarios representing extremes of dry and wet climate projections. 3. Project state of the world for the baseline, dry and wet scenarios 4. Compare the two climate change states of the world with the baseline state. 5. Identify adaptation measures that if implemented will restore welfare to the pre-climate change state. 6. Estimate the costs of implementing these measures plus the cost of any residual damage from a changed climate. 7. Add the costs of implementation and residual damages to arrive at the cost of adaptation. 8. Perform analysis to establish the net benefit of adaptation measures.	Information regarding baseline economic activities and future projections must be available. Information regarding the impact of climate change under the chosen scenarios on the state of the world within the area of study must be available. A good understanding and methodology for estimating social welfare must be achieved.	Encourages stakeholders' participation in defining appropriate adaptation options. Identifies cost-effective adaptation options that could be considered for implementation.	Requir decision m to mak judgeme "how mu adapt
:LAC	Determination of the economic impacts of climate change on	Regional Level.	1. Define a baseline scenario of economic activities and project future economic growth based on historical trend 2. Use IPCC's A2 and B2 emission scenarios to	Information regarding baseline economic activities and future projections must be	Provides comprehensive analysis of economic impact of climate	Critical hc and clima are oft omitted.

ethodology	Objective	Level of Application	Steps	Assumptions / Information Required	Advantages	Limitati
	selected sectors or the macro economy.		project economic growth for climate change scenarios 3. Compare economic growth projections under the baseline and climate change scenarios to estimate the impacts of climate change	available. Information regarding the impact of climate change under A2 and B2 scenarios on economic activities within the area of study must be available.	change on specific sectors.	cost-ber analysis adapta measures an essentic of the methodo and not a perform
:A Framework	Determination of the economic impacts of climate change and identification of cost-effective adaptation measures for implementation	Country and Local Levels.	1. Identify climate hazards facing the country, the country's vulnerability and the value of human lives and physical assets at risk under a no climate change scenario in comparison to a medium and a high climate change scenarios. 2. Perform cost-benefit analysis of identified adaptation measures to inform decision making. 3. Prioritize cost-effective adaptation measures for implementation and integration to the nation's development plan.	Information regarding the specific hazards and vulnerabilities of the area of study must be available. Information regarding the specific costs and befits of adaptation actions chosen must be available.	Identifies specific hazards facing the country for which actions are needed. Accounts for level of risk and risk exposure in estimating cost of adaptation to climate change. Identifies cost-effective adaptation options that could be considered for implementation	The methodol data-inte and requ disaggreg country-l data whic often not r availab
etroeconomica in Beukering al. ɔE, UWI	Guidance on the appropriate procedure for costing the impacts of climate change	N/A	1. Identify if climate change impact affect market-based goods or non-marketed goods. 2. Apply appropriate costing approach based on good type. 3. Incorporate discounting as appropriate.	These tools assume that the impacts of climate change have already been identified.	Represents a good reference for costing methodology.	Only prov guideline: template costing does not guidanc how to id the impac climate ch

Due to the objectives of this project, the Economics of Climate Adaptation (ECA) methodology and the Economics of Adaptation to Climate Change (EACC) methodology were the outstanding candidates.

The Economics of Adaptation to Climate Change (EACC) study conducted by the World Bank (2010) had dual objectives:

- Estimate adaptation costs for developing countries
- Assist decision makers in developing countries to understand and assess the risks posed by climate change so as to better design strategies to adapt to climate change

The first objective takes a global perspective in estimating costs of climate change while the second focuses on providing guidance on adaptation measures to implement. The EACC methodology is developed around the Intergovernmental Panel on Climate Change (IPCC)'s projections that the global annual temperature will be 2°C above pre-industrial levels by 2050. The expected climate change effects will essentially erode social welfare; the economic cost of climate change adaptation is measured as the costs required to adapt to the new world in order to maintain welfare or minimize welfare loss. This approach does not isolate specific hazards for analysis but involves performing vulnerability assessment of sectors when applied at the country-level.

The Economics of Climate Adaptation (ECA) Framework was proposed by the ECA Working Group (2009). It is a framework that quantifies the total climate risk faced by a nation. It involves three main steps: an assessment of the total climate risk facing the country; an accurate understanding of measures or available options to address these risks; and prioritization of the most effective measures and integration into country's development plan. The ECA framework has been applied by Caribbean Catastrophe Risk Insurance Facility (CCRIF) in the Caribbean region, but Trinidad and Tobago was not covered in that study.

As can be inferred from the characteristics of the methodologies, there are several differences between the EACC and ECA methodologies. Even though both have the same objective of determining the economic impacts of climate change and identifying cost-effective adaptation measures for implementation, the process to reach that objective varies. Particularly, differences are found in two aspects. Firstly, the EACC does not analyse specific climate risk while the ECA is built around identifying those specific hazards upon which a country's vulnerability can be assessed. Secondly, under EACC, the cost of adaptation is measured based on what it will cost in adaptation expenses to restore welfare to the pre-climate change level, while, for the

ECA, cost of adaptation is the cost of implementing adaptation measures to address the risk that climate change poses.

Additionally, the ECA approach is not limited by welfare consideration. Instead, it is guided by the need to adapt to the risks that climate change poses. It is possible that, after adapting, welfare rises above or falls below the pre-climate change level; however, that should not be construed to imply having over-adapted or under-adapted. The ECA framework relieves the decision maker of the additional burden of choosing "how much to adapt" as is required under the EACC methodology. In addition, by employing the total climate risk approach, the ECA framework is able to more precisely assess the potential economic loss facing a country from identified climate hazards, geographical areas, populations and economic sectors that are most at risk. With cost-benefit analysis being an integral part of the framework, policy makers are provided with evidence-based recommendations on the adaptation measures that can be adopted and implemented to address the risks posed by and ameliorate the effects of climate change.

For these reasons, the ECA was selected at the beginning of the project as the most appropriate methodology to estimate the economic cost of climate change adaptation in Trinidad and Tobago. As shown in the diagram below, the methodology consists of five different stages.

Figure 2: Methodological development of the ECA approach.
Source: Economics of Climate Adaptation, CCRIF.

Amidst these challenges, studies of the economic impacts of climate change in select sectors have been done under ECLAC's Review of Economics of Climate Change in the Caribbean (RECCC) project. These studies covered the agriculture, energy and health sectors but are limited in the scope of vulnerability or hazards considered. Although Trinidad and Tobago is located at the southern end of the Hurricane Belt, making it at a lower risk of a direct hit by hurricanes and relatively unscathed in comparison to other Caribbean countries, it has suffered periodically from floods (and droughts) and its coastal settlements are threatened by rising sea level. These facts call for a new approach to analysing the impacts of climate change than has previously been applied. This new approach considers the total climate risk facing the economy by identifying the climate hazards and the full range of possible impacts, which may not necessarily be limited to a specific sector. The costs of these impacts on the economy are then estimated to provide a measure of the economic consequences of identified risks of climate change. The costs of implementing available and proven adaptation measures to address these impacts are then compared with the benefits to enable decision makers to prioritize options available to them in addressing climate change. This total climate risk approach to the Economics of Climate Adaptation (ECA) as proposed by the Economics of Climate Adaptation Working Group (ECA

Working Group, 2009) will be applied in the current Study of the Economics of Climate Adaptation in Trinidad and Tobago.

The ECA framework has been applied by the Caribbean Catastrophe Risk Insurance Facility (CCRIF) in assessing the impact of climate change on specific economic sectors of selected Caribbean states. Countries covered in these studies include Anguilla, Antigua and Barbuda, Barbados, Bermuda, Cayman Islands, Dominica, Jamaica, and St. Lucia with focus on impacts on infrastructure (including housing), tourism and services from wind, inland flooding and coastal flooding risks. The assessment also included the impacts of climate change on the agriculture sector of Belize and Jamaica (CCRIF, 2010).

3.3. Data Requirements and Availability in Trinidad and Tobago

The ECA framework is data-intensive and requires climate, demographic and economic data. Historical climate data and data on local weather events are essential in the assessment of the total climate risk. This includes historical data on temperature, precipitation, sea level, and wind speed. It also includes historical data on extreme weather conditions and natural disasters such as hurricanes, flooding, drought and earthquakes. Data on these variables will permit an assessment of the climate hazards facing the country and the added risks posed by these hazards due to climate change. In isolating the impact of climate change, climate change scenarios will have to be built using local data.

Demographic data on the population, density and settlement patterns as well as data on the location of important infrastructure are essential in determining vulnerability and the value of assets at risk of these hazards. Future climate change scenarios will alter the frequency and severity of these hazards and consequently modify the country's vulnerability to these hazards.

Economic data are required to aid in estimating the value at risk and the economic costs of climate change. The quantification of costs and benefits of adaptation measure also requires data on economic variables.

The variables on which data are required for each broad category are itemized in the following table. The sources of data and an indication of the availability of data are also included on the table.

Table 15: Description of Data Needs for the ECA Study in Trinidad and Tobago

Variables	Data Source(s)	Availability
Climate Data		
Temperature	Meteorological Services	Available and already sourced
Precipitation	Meteorological Services	Available and already sourced
Sea level	Meteorological Services	Available and already sourced
Wind	Meteorological Services	Available and already sourced

Variables	Data Source(s)	Availability
Extreme weather events (drought, flooding, hurricanes, earthquakes)	Meteorological Services; Office of Disaster Preparedness and Management	Available and already sourced
Demographic Data		
Population by parish	Central Statistical Office	Available and already sourced
Density by parish	Central Statistical Office	Available and already sourced
Economic Data		
Gross Domestic Product (GDP)	Central Statistical Office; Central Bank	Available and already sourced
Sector's share of GDP	Central Bank	Available and already sourced
Inflation rate	Central Statistical Office; Central Bank	Available and already sourced
Exchange rate	Central Bank	Available and already sourced
Production in each sector	GORTT Ministries	Available
Economic loss to the economy from extreme weather events	International Emergency Disasters Database	Available and already sourced
Economic loss by sector from extreme weather events	GORTT Ministries	Unavailable
GIS maps of location of major infrastructure	Ministry of Planning and the Economy	Unknown

Based on the data scoping exercise already performed, a fair amount of the required data is available but there are still data gaps that need to be addressed. These gaps relate mainly to the location of critical infrastructure and the economic loss to specific sectors due to past extreme weather events.

3.4. Sectoral Overview

3.4.1. Sectoral Analysis.

Trinidad and Tobago is a high income country with the following characteristics[2]:

- Per capita Gross National Income (GNI) of US$22,400 in 2012
- GDP of US$23.99 billion in 2012 (World Bank).
- Hydrocarbon-based economy
- Petroleum sector contributed almost 47% of the GDP and accounted for 85% of the merchandise exports in 2011
- Only 3.2% of the labour force is employed in the petroleum and gas sector.
- The highest proportion (60%) of the labour force is employed in the services sector
- The construction and agriculture sector employ 16.7% and 3.7% of the labour force, respectively
- Unemployment stood at 4.9% in 2011
- Only 5.6% of the population is reported to be below the poverty line in 2006

Although Trinidad and Tobago is a high income country with low levels of poverty, there is a geographical dimension in the distribution of poverty. The figure below shows a map of the distribution of poverty by administrative area. As shown on the map, poverty is low in Tobago and high in the eastern and southern parts of Trinidad.

Trinidad and Tobago conducted its most recent census in 2011 revealing that the twin-island nation has a population of 1,328,019 people, representing a 5.2% increase over the 2000 population census figure. Trinidad is more densely populated with a population density of 263 per sq km compared to Tobago's population density of 203 per sq km. The three most densely populated municipalities are all located in Trinidad and are:

- City of Port of Spain 3090 per Sq Km
- City of San Fernando 2570 per Sq Km
- Borough of Arima 2801 per Sq Km

[2] GNI and GDP figures are from World Banks' World Development Indicators. Other statistics are from the 2012 Annual Economic Survey of the Central Bank of Trinidad and Tobago, except the poverty statistic that is from the Human Development Atlas 2012 published by the Central Statistical Office.

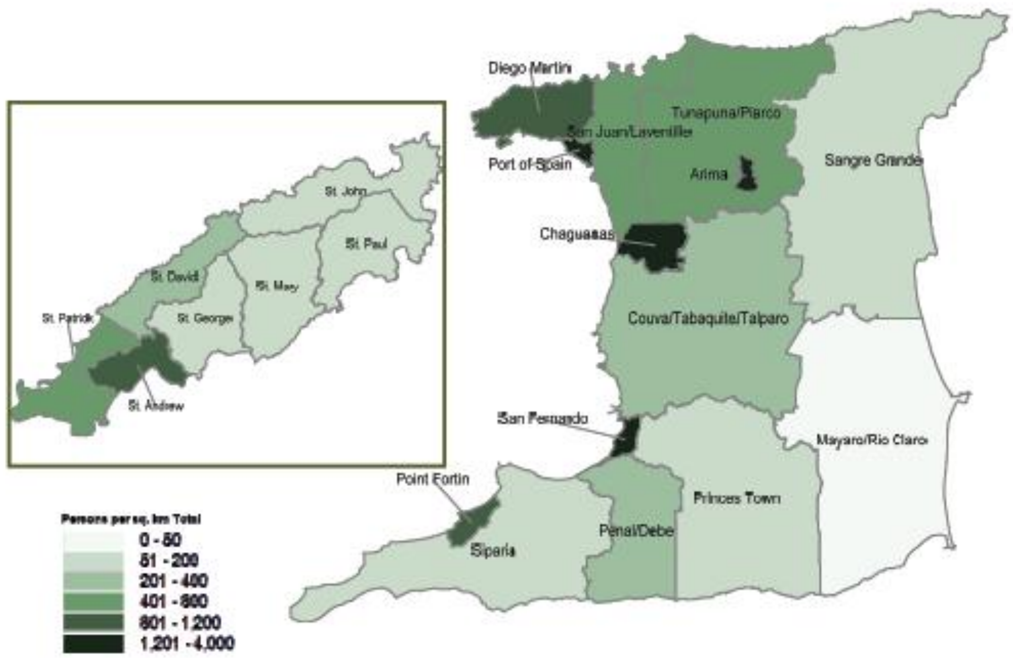
Figure 3: Distribution of Multidimensional Poverty, Trinidad and Tobago, 2006

Source: Ministry of Planning and the Economy (2010b): Human Development Atlas 2012.

Conversely, none of the parishes in Tobago has a population density above 1000 per sq km. A map of the population density by administrative area is presented in the figure below. This map provides an indication of the extent of loss that could arise from climate hazards in different areas of the country as a result of population concentration and associated economic activities at these locations.

Figure 4: Population Density by Administrative Area, Trinidad and Tobago 2011

Source: CSO (2012a): Trinidad and Tobago 2011 Population and Housing Census: Demographic Report.



3.4.2. *Determination of Sectoral and Locational Focus of Study*

As an energy-producing country, energy exports, whilst contributing to economic growth of Trinidad and Tobago, have created other developmental challenges in the form of land degradation and water and air pollution (GORTT, 2010). Although Trinidad and Tobago's total emissions of CO2 is less than 0.1% of the global emissions, according to the World Bank's World Development Indicators, the country has the second highest per capita emissions. This can be attributed to its small population and economic dependence on hydrocarbons. However, the government is implementing a number of programmes and initiatives in the energy and transport sectors to reduce its carbon footprint. In addition, the government is strengthening its adaptive capacity to cope with climate change.

With warming temperatures, climatic conditions will portray more erratic patterns in the form of increased and intensified rainfalls and tropical cyclones. Generally, the Caribbean is characterized by wet and dry seasons. The wet season, between June and December can experience up to 65% of yearly rainfalls. This is usually as a result of the weather systems such as the Inter-Tropical Convergence Zone and passing easterly waves and tropical storms. Over the past years, the Caribbean has been experiencing increased incidents of climatic incidents. In 2005, the highest ever sea surface temperature was recorded, 2004 and 2005 also had unprecedented active hurricane seasons and 2009 to 2010 saw severe and widespread drought (Pulwarty et al., 2010).

In Trinidad and Tobago, climate change is expected to impact the agriculture sector, human health, human settlements, coastal zones and water resources (Ministry of Planning and the Economy, 2012). In addition, the energy sector is expected to be impacted (Singh and El Fouladi, 2006). The specific vulnerability and anticipated impacts are highlighted as follow:

- **Agriculture sector**
    - Warmer weather from high temperature will cause soil aridity, lead to proliferation of pests and diseases, and put pressure on water resources for water for irrigation purposes
    - Sea level rise will cause inundation and soil salination
    - The combined impact is low agricultural yields, decrease in food production and higher food prices
- **Human Health**
    - Higher temperature will increase spread of vector diseases
    - Decrease in rainfall will affect potable water supply
    - Sea level rise will cause increases in water borne diseases
- **Human Settlements**
    - Increase in frequency and intensity of storm surge will cause more flooding and disrupt or destroy coastal settlements
    - Increase in frequency and intensity of storm surge and extreme rainfall will cause damages to infrastructure from flooding and erosion
- **Coastal Zones**
    - Sea level rise will lead to increased inundation, increased erosion, loss of wetlands, loss of ecosystem, and displacement of coastal communities
    - High temperature will result in loss of coral reefs and reduction in fish stock
- **Water resources**

- Increase in temperature will result in increased evapotranspiration and loss of available surface water
- Decrease in precipitation will reduce groundwater and aquifer recharge
- These will have combined effect of reducing available water resources

- **Energy sector**
  - Infrastructure, including field installations and offshore operations, are at risk of inundation from sea level rise, storm surges and erosion from extreme rainfall.
  - Water shortages in the country may affect the needs of the industry in terms of energy generation.
  - Infrastructure damages due to extreme weather events.

The risks posed by climate change in the context of these vulnerabilities could be magnified or diminished based on settlement patterns. As shown in the figure above, the western and northern coastlines of Trinidad are more densely populated than the eastern or southern coastlines. In the case of Tobago, only the south-eastern region of the island is fairly densely populated.

Another useful indicator could be the exposure databases used in the Country Risk Profile (CCRIF 2013) that were designed specifically to provide acceptable estimates for losses from hydro-meteorological and geophysical hazards suffered by physical assets in the territory. The spatial exposure distribution responds to a similar pattern of population, being the most exposed areas Port of Spain and its surroundings and the area of San Fernando, that host an important industrial activity.

This Country Risk Profile was developed at a more detailed scale, and hence a lower aggreggate methodology was developed. Instead of measuring aggregate exposure through inference of past observed damages recorded as a national aggregated value, a detailed catalogue of buildings was developed and a technical vulnerability analysis was individualliy developed and hence differences can be observed: a) multi risk analysis is offered for seismic, wind and floodings for each cathegory of asset. b) a detailed fieldwork was developed to locate this categories of assets in GIS, be it private owned or public infrastructures. However, the analysis developed for Hurricanes and wind storms may have been also different and is probably causing some quantitative discrepancies in the results. As can be read in the IDB (2013) the hurricanes damage analysis is based in the formulas provided by ATC -13 and on a "Hazard Assesment" technical report not available for this team at the moment this document is written. As a consequence the overall damages attributed to an specific Hurricane can be different due to the different return period attributed in the extremes distribution for the same hurricane severity within each population.

Another important issue to consider derives from the fact that a top down damage accounting approach represents a summary of actual damages computed, whereas a bottom up methodology may produce some double counting effect. The actual event represented by a hurricane is essentially a combination of extreme events on wind, waves and flooding and the analytic combination of the three distributions can produce some misguiding totals. First because the peak damage migth be different from the mere overlapping of the three maxima and it is the combined event the one that shoud be considered. In this study the 100 years return period event has a unique size with a joint distribution function for all the relevant consequences and hence a wind event for a specific return period might be associated with a flood event associated with a different return period.

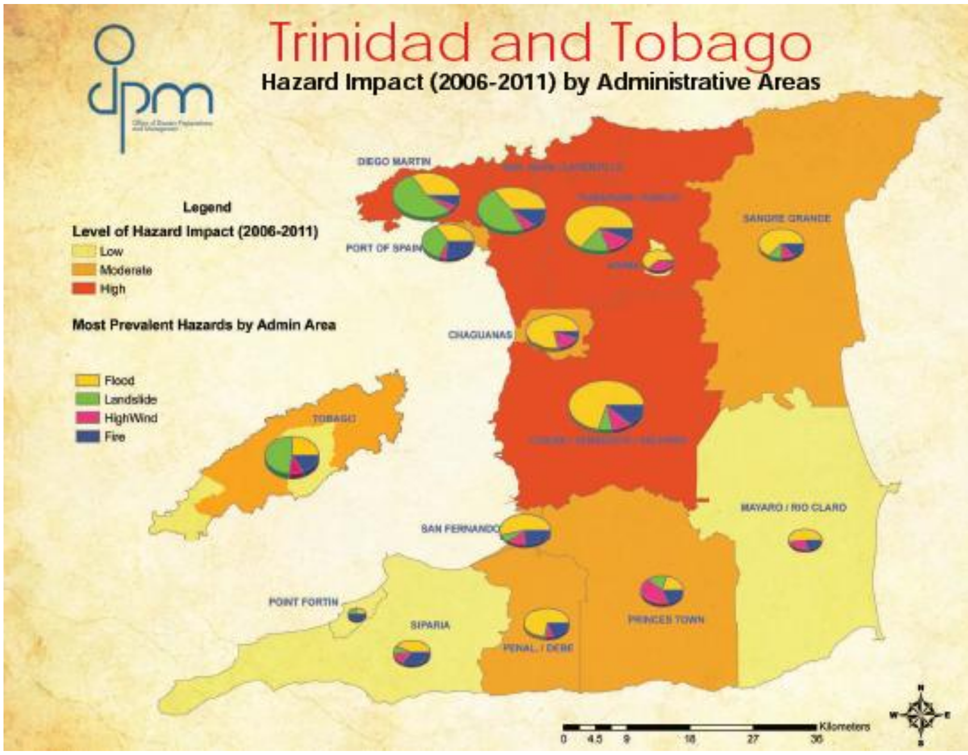
Consequently different estimates for the joint distribution may produce different results for damages return period. And finally a mere additive process for different damages may produce a double counting because the damage suffered by the asset subject to a combination of the three drivers can introduce not only a non probability equalized result (already described) but a pure double counting if some of the damages occur on an already deteriorated asset. (i.e. you cannot destroy the same house twice but distribute the asset damage over the different sources) or if the presence of one driver increases the impact of the other (i.e. the wind stops protection easures against flooding to be taken)

Nevertheless the spatial distribution of aggregated results from both analysis is essentially compatible as far as it si based in the same basic damage inventory series (CCRIF 2013) and any differences can be attributed either to the diferent methodologies (top down vs bottom up), or the inherent uncertainty of weather prediction in the long run.

When historical records of hazards in the past five years are considered, the more densely populated areas of Trinidad have been impacted more severely with flood and landslide constituting the most prevalent types of hazard. The figure below shows the map of the distribution of hazards and the level of impact by administrative areas.

Figure 5: Map showing Distribution of Hazards by Administrative Areas (2006-2011)

Source: Ministry of Planning and the Economy (2010b): Human Development Atlas 2012.



The next figure shows a map of landslide susceptibility for Trinidad while a map of flood susceptibility for Trinidad is presented in the figure provided after[3]. These maps again indicate that, in general, the more densely populated areas are more susceptible to the hazards of landslide and flood.

[3] Landslide and flood susceptibility maps for Tobago are current unavailable.

Figure 6: Map showing Landslide Susceptibility for Trinidad

Source: Ministry of Planning and the Economy (2010b): Human Development Atlas 2012.

Based on the foregoing and supported by the government's identification of the country's vulnerability, the Economic of Climate Adaptation in Trinidad and Tobago study has identified the following as the climate hazards facing Trinidad and Tobago and on which risk assessment will be performed.

- **Hurricanes**
  - Wind
  - Flooding
  - Landslide
  - Storm surge
- **Sea level Rise**
  - Inundation
  - Flooding
  - Erosion
- **Drought**

Figure 7: Map showing Flood Susceptibility for Trinidad

Source: Ministry of Planning and the Economy (2010b): Human Development Atlas 2012.

Similarly, based on available information, the locations of likely high impacts and greater value at risk as a result of dense population and of physical assets (infrastructure) are identified as follows:

- City of Port of Spain, Trinidad (high population density; concentrated economic activities; physical assets)
- City of San Fernando, Trinidad (high population density; commercial interests)
- Borough of Arima, Trinidad ((high population density; commercial interests)
- Chaguanas, Trinidad (high population density; residential assets)
- Point Fortin, Trinidad (high population density; PETROTRIN location)
- Diego Martin, Trinidad (high population density; commercial interests)
- Tunapuna/Piarco, Trinidad (International airport)
- San Juan/Laventille, Trinidad (residential assets)

- St. Andrew, Tobago (high population density; concentrated economic activities)
- St. David, Tobago (residential assets)

CCRIF (2013) presents the risk profile of Trinidad and Tobago under hurricane and earthquake hazards, providing losses for the country at different probabilities of occurrence (more precisely referred to as probabilities of exceedance). Trinidad and Tobago is prone to both hurricanes and earthquakes, with earthquakes ground shaking and liquefaction being the greatest risk. Tobago is more prone to hurricane activity, while the areas around Port of Spain in Trinidad are more prone to earthquake risks. Building codes are good but not always enforced, and may be insufficient to avoid major damage from a large quake.

3.5. Conclusions

A variety of approaches have been applied to studies of Economics of Climate Change with each methodology emphasizing either mitigation or adaptation. Methodologies that have been applied to estimate the cost of climate change adaptation have generally been regional in focus and omitting the much needed evidence-based recommendations on what adaptation measures decision makers should consider for adoption and implementation in their development planning process. The Economics of Climate Adaptation (ECA) framework proposed by the ECA Working Group addresses this limitation as well as the World Bank's Economics of Adaptation to Climate Change (EACC) methodology does. However, the EACC requires the decision maker to choose "how much" of an adaptation they would pursue. The ECA framework does impose this additional burden on the decision maker and is thus regarded as an ideal methodology for costing climate change adaptation in Trinidad and Tobago. In addition, the ECA framework uses a total climate risk approach that allows for identification of hazards from climate change, the value at risk for specific locations or sectors and the vulnerability of the location or sector within an economy to these hazards. Consequently, the ECA methodology has been adopted for the current ECA study in Trinidad and Tobago.

Based on the review of literature and evaluation of available data, the following hazards have been identified as posing climate change risks to Trinidad and Tobago:

- **Hurricanes**
    - Wind

- Flooding
- Landslide
- Storm surge

- **Sea level Rise**
  - Inundation
  - Flooding
  - Erosion
- **Drought**

The impacts of these hazards are expected to be felt in the following sectors:

- Agriculture sector
- Human Health
- Human Settlements (including infrastructure)
- Coastal Zones
- Water resources
- Energy Sector

Due to the expectation of high value of human lives and physical assets at risk in these locations, the selected areas of focus for the assessment of adaptation costs are:

- City of Port of Spain, Trinidad
- City of San Fernando, Trinidad
- Borough of Arima, Trinidad
- Chaguanas, Trinidad
- Point Fortin, Trinidad
- Diego Martin, Trinidad
- Tunapuna/Piarco, Trinidad
- San Juan/Laventille, Trinidad
- St. Andrew, Tobago
- St. David, Tobago

Upon the determination of the costs of adapting to hazards posed by climate change, cost benefits analysis of adaptation measures will be performed. Cost benefit analysis will result in the itemization and ranking of adaptation measures as cost-saving, cost-effective or cost-ineffective. The prioritized list will serve as an objective aid in assisting policy makers to make decisions on what options to integrate in Trinidad and Tobago's sustainable development plan.

3.6. Risks

The main objective of this task is the characterization of the environmental risks borne by T&T society; the exposure to climate change generated risks in the country and provide a basic framework to describe the socio-economic characteristics of this society.

- In this sub-section a specific focus is expected on "the identification, for Trinidad and Tobago, of the key economic sector in terms of GDP generation and employment as well as the identification of the main hazards and exposure to these hazards (assets at risk and their valuation For this purpose, to characterize the socioeconomic framework the demographic evolution of T&T in the last decades will be initially reviewed in order to produce a systematic scenario for the society in the coming years. At a second step focus will be put on the basic macroeconomic equilibrium for the economy and its evolution. From this point on, the situation on the main economic sectors in the economy will be reviewed, eventually developing an initial diagnosis on its susceptibility to climate change.
- To characterize the hazards and exposure a review will be developed about the environmental conditions of the islands and the eventual changes derived from climate change. For these purpose initial focus will be put on the list of hazards selected by the team, which is at present being reviewed by local experts and the IDB supervisors.
- Once this work has been completed, and depending on the availability of GIS layer data from local sources, a spatial diagnosis on vulnerability and hazards will be initially implemented so that broad estimates can be produced for relevant hazards, the risk drivers and the affected activities and assets.

3.6.1. Risk assessment approach

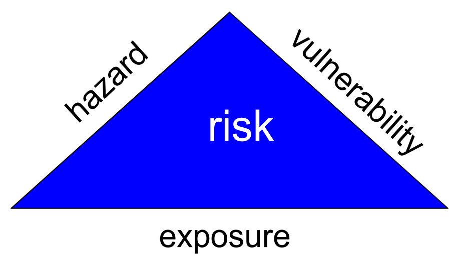
The objective of this sub-section is to provide the general framework used to determine the effects of climate change associated to different natural hazards in the Republic of Trinidad and Tobago. These effects are quantified in terms of Risk (hereafter also named Expected Consequences or Expected Damages). Several hypothesis, simplifications and definitions needed to be able to solve this complex and multidisciplinary problem are described following:

- The "time" unit to evaluate Risk, R, is the year; therefore expected annual consequences or expected annual damages (EAD) will be obtained, as is usually approached in risk analysis.

- The risk is defined in terms of hazard probability, exposure and vulnerability, following the risk triangle concept (see the figure below):

Figure 8: Triangle of Risk

Source: (Scheneiderbauer et al., 2004.)



- The definition of the concepts of the risk triangle are:
  - Natural hazard: Natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.
  - Exposure: People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.
  - Vulnerability: The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.
  - Risk: The combination of the probability of an event and its negative consequences as a result of the combination of the hazards, exposure and vulnerability characteristics.

- The conceptual S-P-R-C approach will be used to evaluate how the Sources or Threats (precipitation, temperature, heat waves, droughts, waves, tide, storm surge, mean sea level, river discharge, run-off, wind, water availability, landslides) through the Pathways (the bio-physical domain) affect the Receptor (Population, Economical Sectors, Ecosystems, Infrastructure, Health) generating Consequences (economic, social, environmental, affected population, life casualties, land losses). Some variables are direct sources (temperature, precipitation, sea level, waves), and others are indirect (heat wave index, drought index, coastal flooding extent, landslides).

- Different hazards will be analysed, i.e. flooding, landslides, wind events, water availability, droughts, etc.

- Consequences (or Damages) may have different units (quantitative values or qualitative indices): Economical damage (€); Social damage (life-loss); Environmental damage (biodiversity index); Casualties (number of people); Loss of land (Km^2); and Affected population (number of people).

- Consequently, economical, social, environmental, casualty, loss of land, and population risks, will be obtained as measures of the different dimensions of risk. All these dimensions could be aggregated using any multicriteria analysis, weighted by different experts (by means of a Delphi Panel) and decision makers.

- Consequences can also be defined in terms of Vulnerability (V) and Exposure (E), $C=V \cdot E$ (For example, this approach allows the definitions of density of damage ($€/Km^2$) for vulnerability and exposure (Km^2))

- Baseline risk of our analysis is defined as $R(\tau_0)$

- Risk for a future climate scenario is defined as $R(\tau_f)$

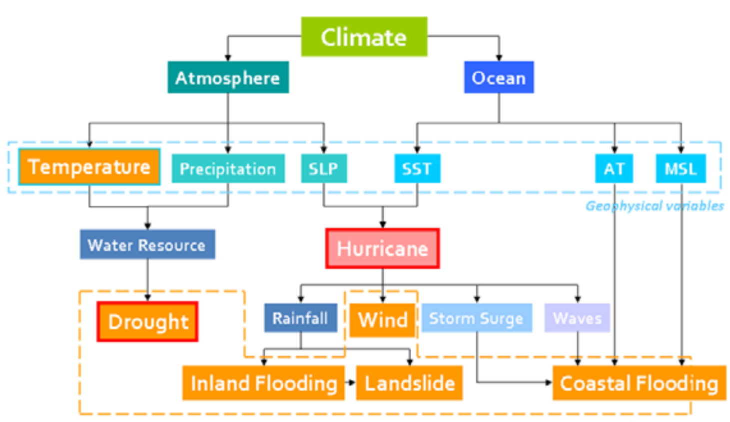
- The effects of climate change are quantified obtaining the absolute risk differences $R(\tau_f)- R(\tau_0)$ or relative risk differences $(R(\tau_f)- R(\tau_0))/ R(\tau_0)$. The uncertainty will also be quantified.

3.6.2. *Identification of the main natural hazards*

Water Cycle and extreme meteorological events are generally accepted as the main drivers for climate change impacts (Alavian et al, 2009). In order to synthesise the origin of the primary natural hazards affecting Trinidad and Tobago, in terms of geophysical variables, and the impacts associated to them the scheme shown the figure below is introduced. Concerning to droughts, geophysical variables as temperature and precipitation are considered, and focus will be made on how changes affect to the water resources deriving in drought in extreme events. Noted here that the increase of temperature due to climate change involves an impact by itself, affecting different economic sectors, In the case of hurricanes sea surface temperature (SST) and sea level pressure (SLP) will be selected as the geophysical variables driving the tropical cyclones and extreme events of hurricanes. The direct effects of the hurricane are heavy rainfall, strong winds and storm surge in the coast. The wind can directly impact on infrastructures, settlements or services, generating damages in roofs, electricity or telecommunication lines. The intense rainfall can trigger inland flooding and in combination with that landslides where the conditions of the soil are not stable. Finally, the storm surge in the coast and waves generated by the hurricane combining with the mean sea level (MSL) and the astronomical tide (AT) will generate coastal flooding. The main natural hazards considered in this study, hurricanes and droughts are shown in red boxes, while the impacts generated by these hazards are shown in orange ones.

Figure 9: Main sources of risk for T&T

Source: IH Cantabria.



Once the most at risk have been selected the most relevant hazards will be defined, answering the question on the risk they are exposed to. The aim is to identify the natural hazards susceptible to suffer the effects of climate change.

The most significant natural hazard risk in the Caribbean is hurricane risk, particularly because of the possibly large span of territories which can be impacted by any single event (CCRIF 2013). Although Trinidad and Tobago is not in the main Atlantic hurricane belt the potential to be hit by hurricanes still remain as happened in the past by a number of tropical cyclones and the direct impact of two hurricanes since 1850.

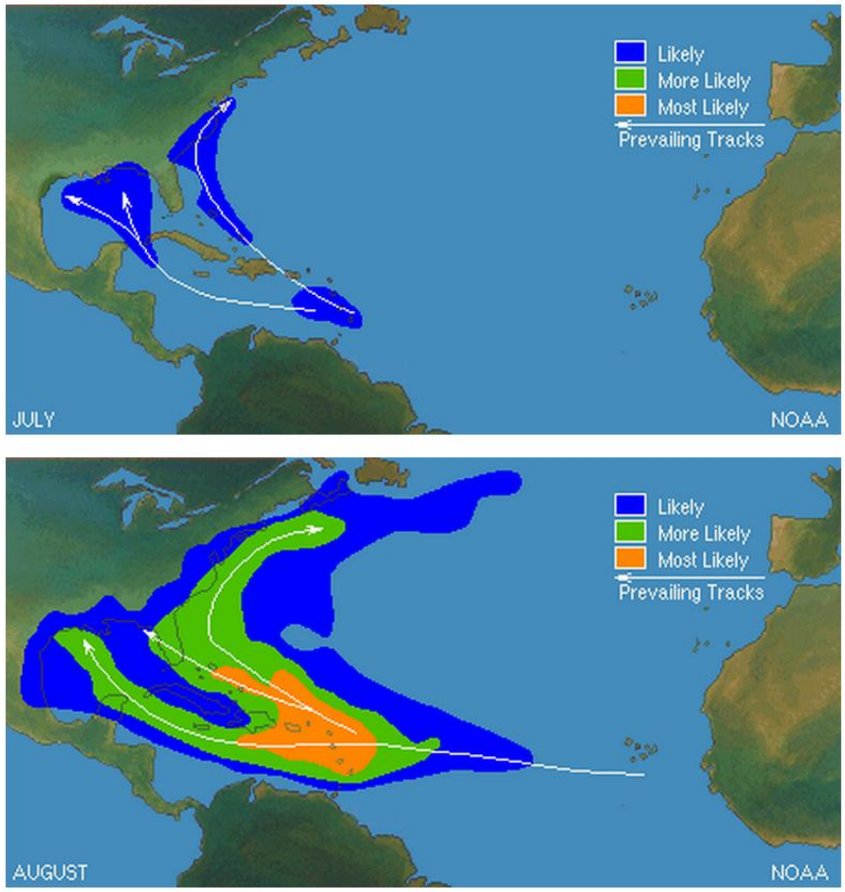
A tropical cyclone is a storm system characterized by a low-pressure centre and strong winds typically forming over large bodies of relatively warm water. The tropical cyclones affecting Trinidad and Tobago are usually formed between 9°N and 30°N in the Atlantic basin comprising the North Atlantic Ocean, Caribbean Sea and the Gulf of Mexico. Depending upon wind speed near the centre of the circulation they are classified as:

- Tropical depression: the sustained winds at the earth's surface are ≤62 km/h.
- Tropical storm: the sustained winds at the earth's surface are in the range of 63 km/h to 118 km/h.
- Hurricane: the sustained winds at the earth's surface are greater than 118 km/h.

Based on the above classification a hurricane is supposed to be an extreme event of a tropical cyclone. The Atlantic hurricane season extends from June 1st to November 30th but Trinidad and Tobago is affected generally during the months of August and September (see the figure below). However, tropical storms have been known to affect the islands outside the season, such as the cyclone "Alice" which lasted from December 30 in 1954 to January 5 in 1955 (Meteorological Services of Trinidad and Tobago, 2002).

Figure 10: Zones of origin and tracks for hurricanes

Source: NOAA.



Strong winds, heavy rainfall and storm surge are some direct hazards associated with hurricanes and tropical cyclones. In the figures below, an example can be observed of the numerical modelling that IH Cantabria is developing in the frame of this project concerning to hurricane derived hazards and impacts. In the first figure the wind field generated by hurricane Ivan (September 7th 2004) in the area of Trinidad and Tobago is shown while the second figure shows the associated storm surge and waves. Combining the information of the three panels one can see that the most intense storm surge in the island of Trinidad was found in the Gulf of Paria when the eye of the hurricane was displacing north-eastward. At 11 pm the storm surge observed in the coasts of Port of Spain, San Juan – Laventille, Chaguanas and San Fernando reached 3 m of height. On the contrary, at this time of highest storm surge level, the waves in the Gulf of Paria were insignificant, due to the sheltered natural location. At this time the highest waves were found in the northeast face of the island of Trinidad, up to 8 m of significant wave height in Diego Martin region.

Figure 11: Wind field generated by hurricane Ivan in September 7th 2004

Source: NOAA.

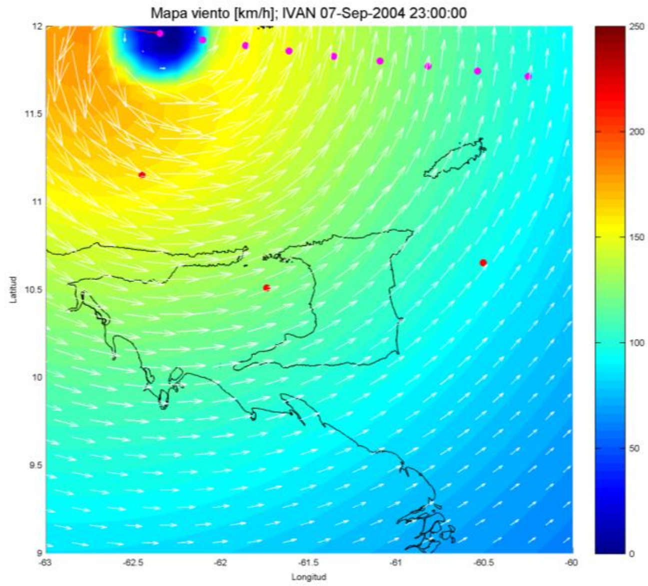
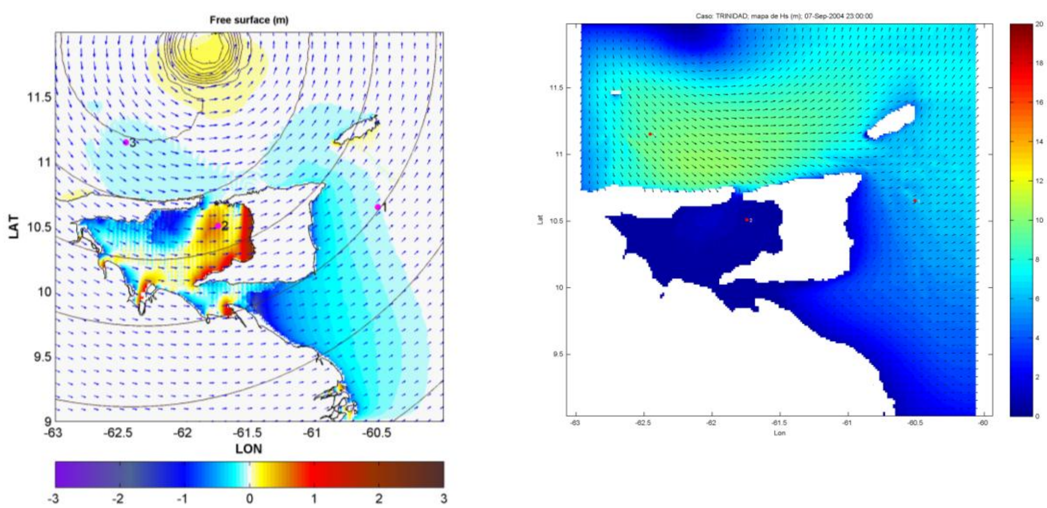


Figure 12: Free surface (left panel) generated and Waves (right panel) by hurricane Ivan in September 7th 2004 (at 23:00)

Source: NOAA.



Other secondary hazards which can generate important damages to the socio economic and natural system are also derived from these extreme events. Inland flooding generated by the intense rainfall, coastal flooding caused by the storm surge or landslides as a result of the combination of rainfall and flooding are the main impacts of hurricanes that affect the Republic of Trinidad and Tobago. Furthermore, the exposure to these hazards determines the vulnerability from some areas opposite to others. Low-lying areas such as Port of Spain, Chaguanas, San Fernando or the south of Sangre Grande are more susceptible to coastal flooding as can be seen in the flood susceptibility map.

On the other hand, unstable lands will be susceptible to landslides when heavy rainfall or flooding occurs . The landslides can affect settlements on slopes or on unstable soils.

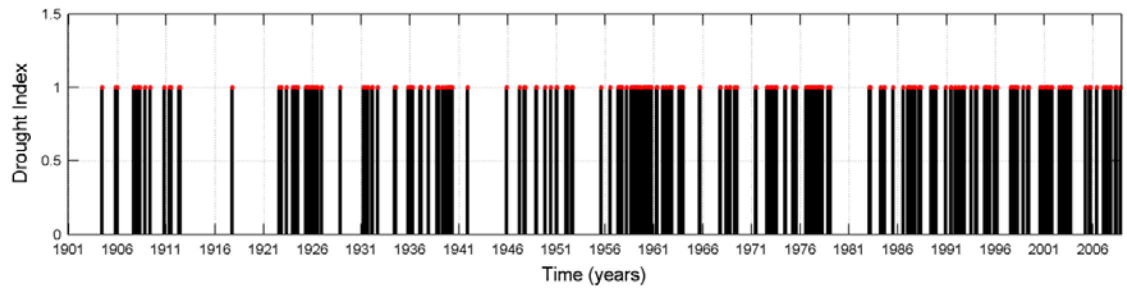
Based on the analysis of the key economic sectors for Trinidad and Tobago droughts have also been identified as a primary natural hazard susceptible to climate change that can bring severe impacts in the agriculture. When considering drought to agricultural impacts the focus is placed on precipitation shortages, soil water deficits, and reduced ground water or reservoir levels needed for crop irrigation. Besides on the agricultural sector, other impacts on society, due to famine and disease outbreak and environment, and environment, such as habitat loss due to forest fires, point at droughts as a primary natural hazard in Trinidad and Tobago.

Drought is a quiet hazard that can cover extensive areas and last for many years, with devastating impacts on agriculture, water supply and the environment. The intensity, duration and timing of droughts share characteristics with other natural hazards, such as floods, earthquakes and tornados. But in comparison to these hazards droughts tend to start slowly, last for a long time and cover vast areas of the Earth (Sheffield and Wood, 2011). The simplest definition of drought is a deficit of water relative to normal conditions that is governed by the hydrological cycle. The major components of the hydrological cycle are precipitation, evaporation, run-off and snow, soil and groundwater storage. When there is no precipitation during a period of time, the storages of water (in the land surface and in the ground) reduce and there is less water available for use. This reduce comes from evaporation back into atmosphere, drainage to lower soil layers, recharge to aquifers, export to rivers or abstraction by humans. However, in the scientific literature droughts are typically classified into four major types, depending on its impacts: meteorological drought, hydrological drought, soil moisture or agricultural drought and socio-economic drought.

The last severe drought experienced in Trinidad and Tobago lasted around seven months, starting in October 2009 and extending into the first quarter of 2010. (Office of Diaster Prepardedness T&T). During this period rainfall was reduced in the 75 % related to the average precipitation and several impacts such as bush fires, incidences of crop failure and flash flooding during some spell of post-drought rainfall were the consequences of this extreme event. Other reported drought conditions occurred during the periods 1997-1998 and 2002-2004.

Figure 13: Drought index in Trinidad and Tobago during the last century.

Source: Sheffield 2013



3.6.2.1. Data bases and information required

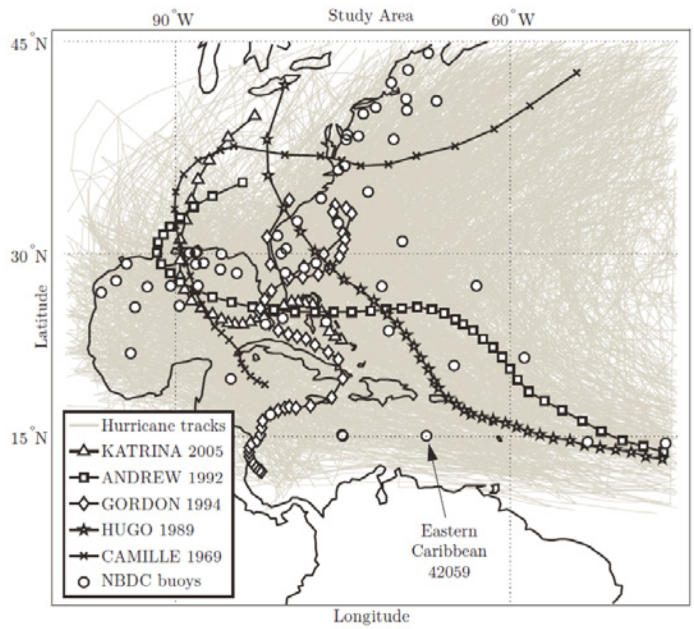
Once the natural hazards have been identified next steps imply the obtaining of a damage function for every impact defined and the definition of scenarios of change. Hurricanes and droughts are extreme natural events that involve social, economic and environmental damages, most of the times expressed as economic losses. Changes in the future conditions (intensity, frequency and duration of the event) will involve changes in the economic consequences. However, the success of the study relies on the reliability, homogeneity and long-enough data records. A description of the databases available for this study and the necessity of further information will be provided below.

The North Atlantic hurricane database (HURDAT)

The characterization of current conditions of hurricane events requires a library of historical hurricane tracks and intensities. The database used comes from the U.S. National Hurricane Center and is called the North Atlantic hurricane database (HURDAT). This database contains the 6-hourly center locations (latitude and longitude in tenths of degrees) and intensities (maximum 1-minute surface wind speeds in knots and minimum central pressures in millibars) for all Tropical Storms and Hurricanes from 1851 through 2012 (Jarvinen et al. 1984; Landsea et al. 2004, 2008). Using this information current conditions of hurricane events will be assessed in terms of intensity and frequency. Besides, the natural variability of these extreme events will be carried on trying to assess long-term trends in order to set a base for the design of future climate scenarios. The figure below shows the hurricane tracks from Atlantic HURDAT database and the tracks of some Atlantic storms.

Figure 14: Hurricane tracks from Atlantic HURDAT database and the tracks of some Atlantic storms

Source: HURDAT.



<u>Simple Ocean Data Assimilation (SODA 2.2.4)</u>

In order to properly characterize hurricane and drought hazard sea surface temperature from the Simple Ocean Data Assimilation dataset (SODA) will also be used. Hurricanes are mainly driven by the temperature gradient between the warm tropical ocean surface and the colder upper atmosphere, which means that the main geophysical variables to take into account are sea surface temperature and pressure. Climate change is affecting these variables leading to changes in the intensity and frequency of the hurricanes.

SST fields will be used as a predictor of the hurricanes, rainfall and droughts (predictand). Besides, relationships will be assessed of the predictands with primary low frequency variability patterns in the area such as El Niño or the Tropical North Atlantic. This database is a new global ocean reanalysis from 1871 to 2008 and its version 2.2.4 represents the first assimilation run of over 100 years and uses the 20Crv2 winds (Whitaker et al., 2004; Compo et al., 2006, 2008). The ocean model is based on Parallel Ocean Program physics with an average 0.25°x0.4°x40-level resolution. Observations include virtually all available hydrographic profile data, as well as ocean station data, moored temperature and salinity time series, surface temperature and salinity observations of various types, and nighttime infrared satellite SST data. The output is in monthly-averaged form, mapped onto a uniform 0.5°x0.5°x40-level grid. The reanalysis provides three types of variables, those well constrained by observations, those partly constrained by dynamical relationships to variables frequently observed, and those poorly constrained such as horizontal velocity divergence. It is worthy noting that SODA aims at improving upper ocean reanalysis, likely because data below 1000m is limited. For more information about the SODA product, see Carton et al. (2005) and Carton and Giese (2008).

Rain-gauges

In order to evaluate representative rainfall in Trinidad and Tobago rain gauges will be used. After having processed the available rain gauges in the area two of them have been selected, which provide the longest and ungapped records of total daily precipitation, La Regalada and Piarco stations. La Regalada station is elevated 300 m above the sea level while Piarco is above mean sea level. The hill facing on which the gauge is located and the surrounding topography are determinant factors affecting the total precipitation that can be detected.

Table 16: Characteristics of the rain gauges used in this study

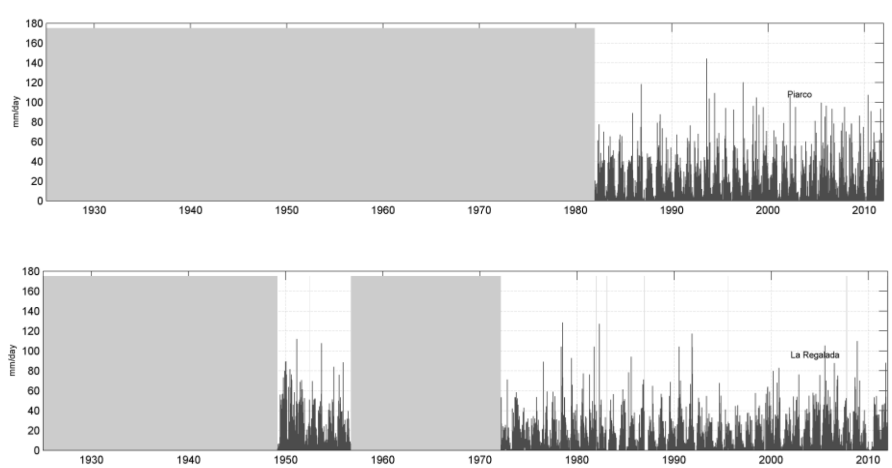
Source: CSO

Station	Time period	Long	Lat	Altitude
Piarco	1980-2011	61° 20.104'W	10° 34.569'N	13 m.a.s.l.
La Regalada	1950-2011	61° 17.760'O	10° 41.244'N	299 m.a.s.l.

The figure below shows the daily rainfall in Piarco and La Regalada rain gauges. The grey areas show the gaps in the time series.

Figure 15: Daily rainfall from Piarco (up) and La Regalada (down) rain gauges.

Source: CSO



Droughts

As described above, drought conditions depend on a range of variables such as precipitation, evaporation or soil moisture. In this study a drought index kindly provided by Dr. J. Sheffield has been considered which already includes all this information. The database consists on a boolean monthly index with 1 value for drought conditions and 0 in normal cases. The time series of the drought index spans from 1901 onwards.

This information will be used to study natural variability, duration and frequency of current drought conditions, and to set the base for the projected scenarios of climate change.

Damage function

The expected damage caused by hurricane events in T&T will be assessed through a damage or loss function that relates the wind speed, precipitation or other parameter of hurricanes with the damage. This relationship is complex and difficult to model explicitly so observed damage from past storms and its relation with meteorological parameters or impact variables will be very valuable information. Tropical cyclones affecting the islands since 1725 to 2000 have been documented and the damages caused, in some scattered cases. This valuable report shows the impacts and historical damages caused by tropical cyclones in the islands due to strong winds, rainfall, storm surge in the coast and landslides (see table below). The accuracy of the damage estimates will rely on the historical information available, which allows establishing a better loss function. As shown in the following table, only a few tropical cyclone damages are reported so, unless further information will be provided, estimated damages will require cautious interpretation.

Table 17: Summary of the historical damages caused by tropical cyclones in Trinidad and Tobago.

Source: Meteorological Service of Trinidad and Tobago.

Name/ number	Date	Intensity	Area of passage	Wind (km/h)	Rainfall (mm)	Storm surge (m)	Landslide	Damage
	1810 August 12		Trinidad		Intense rainfall			Vessels displacement out of the harbour
	1831 June 23		Trinidad and Tobago					Agitation in the Gulf of Paria, vessels displacement
2	1933 June 27	H	Cedros, Trinidad	120				13 life-losses. 1000 were rendered homeless. Damage property, especially in the south of Trinidad. Total damage of US $3 million.
Flora	1963 Sept 30	H	Tobago	195 (Tobago)		1.5 to 2.1		18 life-losses in Tobago and 2 life-losses in Trinidad. 2750 houses destroyed and 3500 houses damaged in Tobago. Damage of US $30 million (1963 US$). 50% of the coconut trees were destroyed and 16% suffered severe damage. 75% of the trees forming the forest reserve fell. The estimated damage in Trinidad was US$60.000.
Alma 4	1974 August 14	TS	Southern Trinidad		91 in Matura 147 in Savonetta	1.5 to 2.1		One indirect life-loss in Trinidad
Danielle 4	1986 Sept 8	TS	90 km NE of Tobago			1.2	27 landslides in Roxborough and Bloody Bay	4 bridges destroyed. Total damage of US $8 million in Tobago. Flooding up to 4 feet in Siparia-Erin Road, Los Bajos, Palo Seco, Rancho Quemado, Caparo, Scarboraugh.
Joan 11	1988 Oct 14	TS	70 km north of Tobago					Heavy rainfall during 4 days.
Joyce 10	2000 Oct 1	TS	Tobago	50	50	1	Yes	Heavy rainfall, flooding and landslide.

3.7. Socioeconomic analysis

3.7.1. *Demographic analysis*

The evolution of demographic variables of Trinidad & Tobago can be observed in the following table.

Table 18: Basic demographic parameters

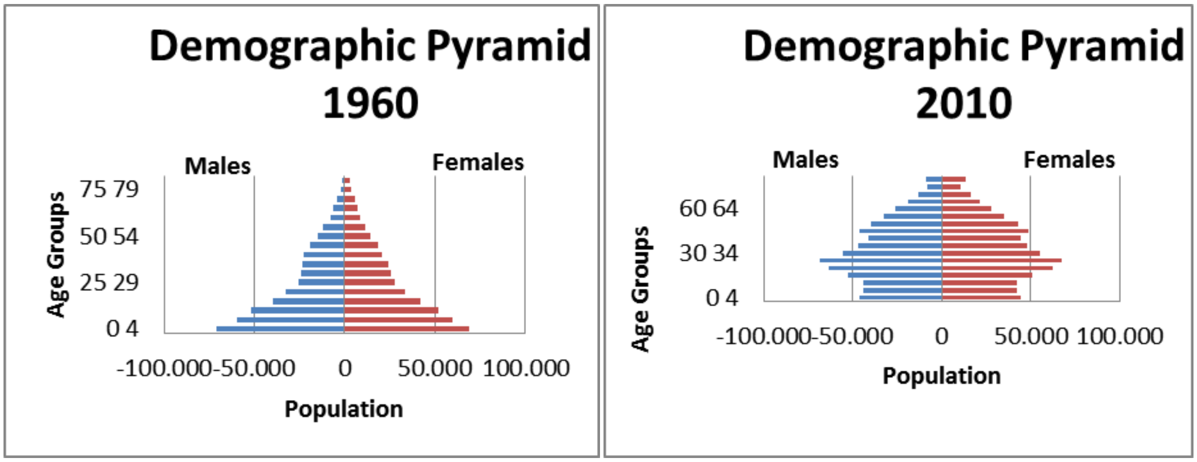
Source: ECLAC CSO.

Year	Fertility Rate	Birth Rate	Mort Rate	Mort Rate <5 years	Population	Net Migration
1960	5.24	37.62	8.8	63	843,000	+11,423
1965	4.39	35.7	7.62	56.9	896,000	-69,698
1970	3.54	26.73	7.32	51.5	971,000	-23,521
1975	3.45	27.5	7.60	46.4	1,012,000	-54,033
1980	3.34	28.88	7.59	42.4	1,082,000	-39,241
1985	3.05	27.09	7.35	39.7	1,178,700	-23,325
1990	2.45	21.44	7.04	36.8	1,215,500	-62,078
1995	1.87	16.2	7.02	34.2	1,261,400	-23,649
2000	1.64	14.54	7.57	32.1	1,289,100	-19,757
2005	1.62	13.12	7.98	29.9	1,311,400	-19,806
2010	1.64	14.59	8.12	27.7	1,331,400	-19,806

As can easily be observed, T&T society shows a clear demographic transition towards a modern society with a dramatic reduction in fertility that has dropped to a 1/3rd of the initial value from 1960 to 2000, and shows a stationary behavior from that moment on. This demographic transition anticipates the progressive slowdown in birth rate that has been divided by 2.5 in the same period. (See the figure below). As a result of this path a parallel slowdown is expected for population growth that will eventually result both in an ageing society and in a reduction in population for the future. It can be easily understood that the population previsions for the next 40 years show a reduction in the proportion of potentially active people (% 15-65 years) from a maximum in 2010 (71.9%) to a much lower value by 2050 (58.2%). At the same time the average age in population that was 20 years old by 1975, is expected to reach 44 years old by 2050. At present the society is enjoying what has been described as a demographic bonus with a peak on the potentially active labor resources, and this situation will require an increase in productivity in the economy to maintain the rent level (partially compensated by population reduction). This dramatic change in the demographic structure of the society is a key parameter to consider in any scenario for future economic performance of the society.

Figure 16: Comparative Demographic Piramides T&T

Source: ECLAC



3.7.1.1. Macroeconomic equilibrium of Trinidad &Tobago

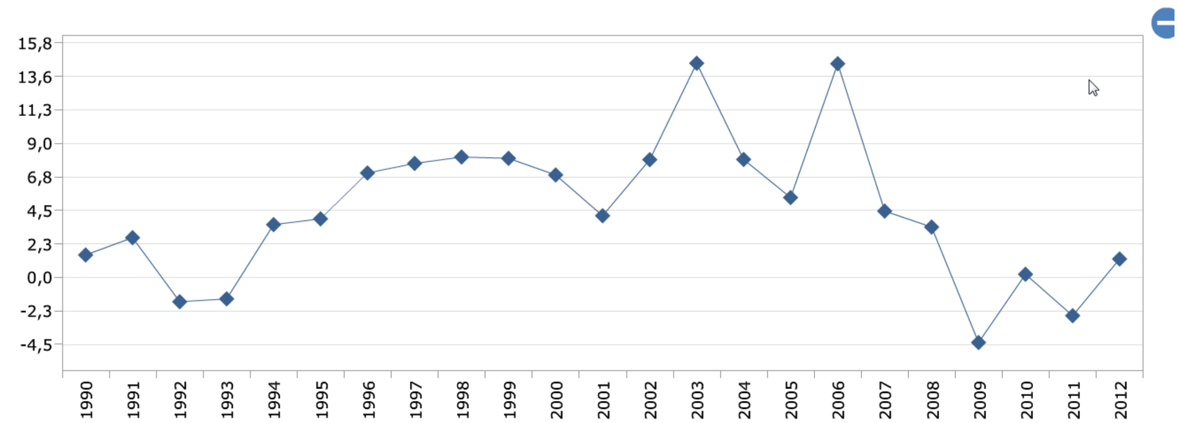
Production and Growth:

Economic growth in T& Tobago has evolved during last 20 years showing a highly variable path in the figure below:

- After 1992 crisis a sustainable growth path can be observed until 2000 reaching a top 8% in 1998
- From 2001 the economy has suffered high variability in closed connection with oil volatility market. Growth has oscillated between 14% and 4% within a period of 5 years causing high instability to income
- From 2007 , this variability has continued to exist but in more dangerous range between -4.1 and -4.5

Figure 17: Annual Growth rate T&T GDP (2005 US$)

Source: ECLAC.

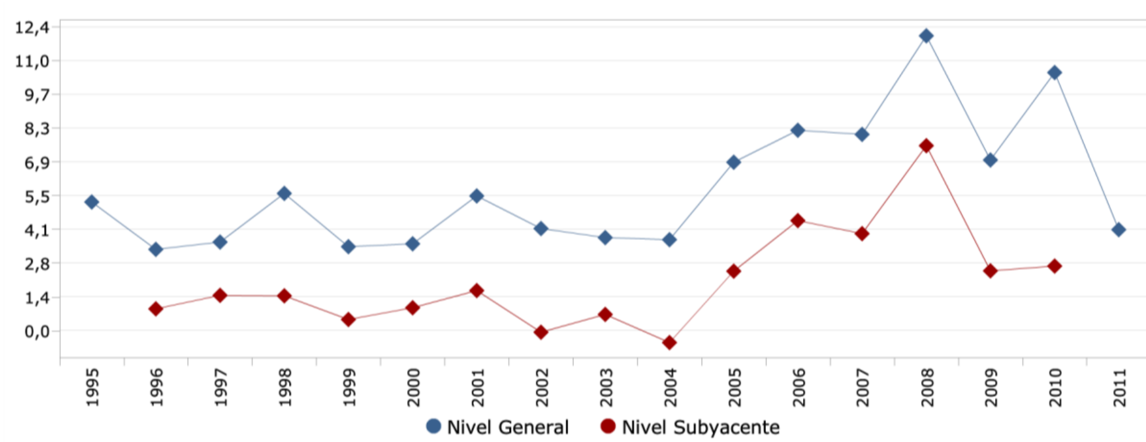


It can be concluded that this economy has increased its connection with global economies in general and in particular with energy markets, and it has been severely destabilized by global economic oscillations. The exchange rate has been stable since 1997 (6,21 TT$/US$) for a value of 6.37 TT$/US$ at present

The consequences of this situation can be observed in the evolution of inflation in the figure below.

Figure 18: Evolution of inflation and core inflation T&T

Source: ECLAC.



Three consequences can be derived from this data, first the strong impact of oil prices in the inflation rate that desestabilizes internal demand and savings. Second the high level of inflation observed (up to 12%). A six years period with rates above 7% can be observed along the last decade with an acummulated loss of 65% in purchasing capacity of savings. This represents a very weak incentive to encourage savings. And third it can be observed that the volatility of oil prices is directly transmitted to core inflation showing a high rigidity of internal sector to adapt to cost shocks. A 4% shock in global inflation produces a 3.6 % shock in core inflation. This can be the result of lack of competition in markets, and lack of scale in production firms.

From a different point of view, the aggregate macroeconomic accounts show a distribution by sectors with the trends observed in the following table that confirm our previous argument on the dependency of the economy on oil industry activity.

Table 19: Basic productive structure % GDP T&T

Source: CBTT.(2012)

SECTOR	2008	2009	2010	2011	2012
Agriculture	0.4	0.6	0.6	0.6	0.6
Petroleum	50.8	34.6	42.7	46.8	43.7
Manufacturing	4.0	5.8	5.4	5.8	6.0
Electricity and Water	0.9	1.5	1.4	1.3	1.3
Construction	8.3	11.3	7.2	5.8	5.0
Transport, Storage and Communication	4.0	5.9	5.3	4.8	5.4
Distribution	12.1	14.8	13.7	12.9	13.8
Finance, Insurance and Real Estate	8.9	11.9	11.3	11.1	11.0
Government	7.1	9.2	7.9	7.5	8.7
Other Services	4.4	6.3	6.0	6.4	0.0
FISIM	-2.9	-4.5	-4.4	-3.8	-3.9
PLUS: Value Added Tax	3.4	4.2	4.6	3.3	4.2
TOTAL	100.0	100.0	100.0	100.0	100.0

The sector with the highest contribution to GDP is the Oil and gas industry whose wedge moves in the range from 35 to 50 % of GDP. The second is the distribution industry that moves in a range between 12 and 15%, followed by Finance and insurance, Services provided by the government and Construction. Agriculture has dropped to a value below 1%

This structure shows the typical behavior for a dual economy, with an increasing wedge of Petroleum industry, that reaches 50% of GDP on 2008, and a set of ordinary industries whose demand depends on the available income whose evolution is connected with oil prices. As a consequence the GDP shows a volatile growth rate (reductions of 30% in 2008).

<u>Demand and Rent:</u>

If the demand side of GDP is reviewed, the following characteristics can be observed: (See table below)

- Private Consumption can also be quite volatile, a range of variations between 10% and -9% can be observed. Hence firms' expectations for investments face high risk levels and no estimates are expected to guarantee long term investments in the private sector.
- Public consumption is rather stable although social protection policies may force a steep rise in the future.
- Both exports and imports show a volatile trend and a rather high value so the external balance can be fragile. Internal production industries will be eventually required to deal with future shocks due to substantially different scenarios when oil and gas deposits would be finished.

Table 20: Distribution of GDP by expenses

Source: CSO (2008_1)

	2000		2001		2002		2003		2004	2005	
Government final consumption expenditure	6,140.5 11.95%	7,548.0 13.7%	+22.9%	7,652.3	1.37%	9,042.0	18.16%	9,584.5		11,884.7 12.50%	+24.00
Private final consumption expenditure	29,480.2 57.39%	26,864.4 47.8%	-8.87%	32,786.4	22.04%	33,690.5		43,869.3		48,431.5 50.94%	+10.40%
Gross capital formation	8,622.7 16.78%	14,694.2 22.7%	70.42%	12,735.7	13.32%	17,926.3		13,906.3		14,748.7 15.51%	+6.06%
Exports of goods and services	30,421.0 59.22%	30,428.4 55.3%	0.02%	28,299.0	-7.00%	36,872.1	30.29%	45,480.7		61,315.3 64.5%	+34.81%
Less: Imports of goods and services	(-)23,293.8 -45.34%	(-)24,527.8 (-)44.6%	5.29%	25,183.4 44.74%	2.67%	26,812.2 37.91%	6.47%	33,014.7 41.35%		41,323.2 (-)43.47%	+25.16%
Expenditure on Gross Domestic Product	**51,370.6**	**55,007.2**	**7.08%**	**56,290.0**	**2.33%**	**70,718.7**	**+25.63%**	**79,826.1**		**95,057.0**	**+19.08%**

If the distributional aspects of this economy are reviewed (See table below) it can be observed that the redistribution mechanisms are not working adequately, and compensation to employees is decreasing its relative value in the economy until it reaches a level that may easily compromises future economic stability.

The consequence of this structure is clear, future costs derived from climate change and required social protection as social security, should be either levied on workers or on firms. If the first alternative is adopted the impact on consumer´s income will reduce its quota even more, hence compromising social welfare (Mendelsohn, et alt 2006). It should be noted that the welfare impact of an additional cost is inversely proportional to the income level and so damage suffered by people with ½ average Income reduce people´s welfare by double than the average. If the costs are levied on the firms surplus, who are appropriating 2/3 of GDP as rent, their possibilities to move to a different area where the costs are smaller will probably be their best option.

Table 21: Distribution of GDP by perceived income

Source: CSO(2008_1)

	2000	2001		2002		2003		2004		2005	
Compensation of employees	19,177.1 37.3%	21,265.4 38.7%	10.9%	21,508.0 38.21%	1.1%	23,890.1 33.8%	11.0%	26,526.8 33.3%	11.0%	29,323.1 30.85%	10.5%
Operating surplus	23,263.9 45.3%	23,673.8 43.1%	1.8%	24,073.2 42.7%	1.7%	33,155.1 46.8%	37.7%	40,006.3 50.1%	20.7%	51,584.0 54.27%	28.9%
Consumption of fixed capital	5,692.1 11.1%	6,370.6 11.6%	11.9%	6,678.6 11.9%	4.8%	9,475.7 13.4%	41.9%	8,597.0 10.7%	-9.3%	10,025.2 10.54%	16.6%
Taxes on Production and Imports	1,931.6 3.8%	2,071.4 3.8%	7.2%	2,244.4 4.0%	8.4%	2,581.9 3.7%	15.0%	2,754.8 3.4%	6.7%	2,891.0 3.04%	4.9%
Less: Subsidies	(-)721.4 (-)1.4%	552.7 1.0%	-23.4%	615.1 1.1%	11.3%	748.4 1.1%	21.7%	1,229.7 1.5%	64.3%	1,714.7 1.8%	39.4%
Plus: Value Added Tax	2,027.3 3.9%	2,178.7 4.0%	7.5%	2,400.9 4.3%	10.2%	2,364.3 3.3%	-1.5%	3,170.9 3.9%	34.1%	2,948.4 3.1%	-7.0%
Expenditure on Gross Domestic Product	**51,370.6**	**55,007.2**	7.1%	**56,290.0**	2.3%	**70,718.7**	25.6%	**79,826.1**	12.9%	**95,057.0**	19.1%

It should be noted that the most recent data are presented for 2005, better results might easily have been obtained it the last 8 years that mitigate the situation.

3.7.1.2. Sectorial Economic Analysis

To determine the sectors that should be included in the Economic-Environmental Climate Change scenario to be built, it will be taken into account the importance of the activity, both based on size and on social impact, and the sensitivity to climate change.

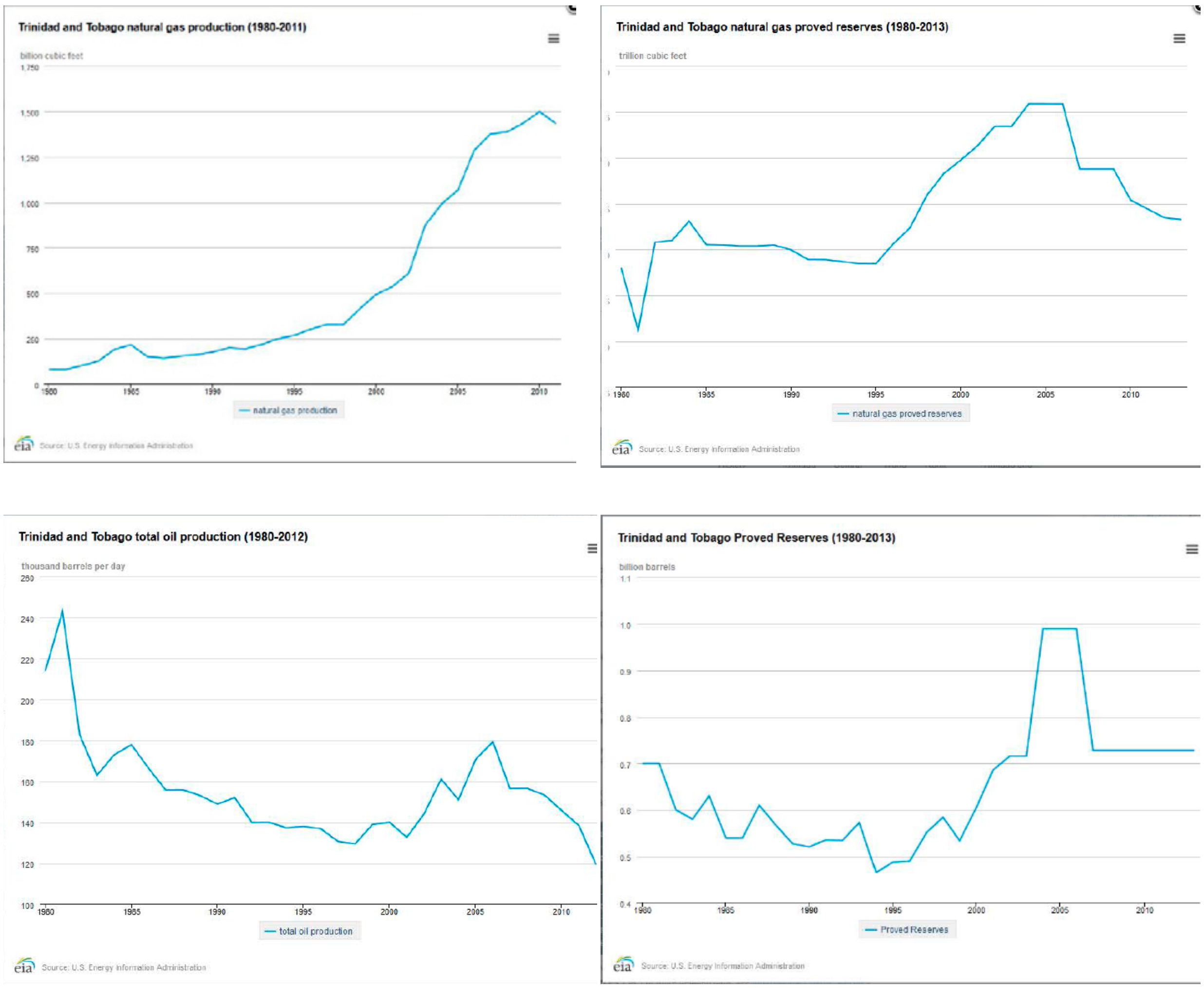
Our first analysis will focus on the Oil and Gas industry whose size (approximately 50% of GDP), instability due to evolution of prices, estimated future performance due to the increasing importance of energy in the future, and sensitivity to climate change justifies this priority.

The first comment that can be suggested points to the volatility of the income obtained. The dependence on international prices has contributed to irregular paths that may cause financial problems to T&T society.

The second point to focus on is related with the availability of reserves, as can be seen in the following graphics, the available proven reserves of Gas are decreasing steeply and hence at present extraction rate the expected horizon for the activity goes no further than 2023. For oil production the figures are slightly more optimistic but the horizon remains within the next decade (2029). Obviously these proved reserves may increase in the future due to the discovery of new deposits, but the tradition of the industry in the area and the small size of the country makes this possibility doubtful.

Figure 19: Annual consumption and proven reserves for Oil and Gas T&T

Source: EIA.



The third issue to consider relates with the sensitivity of operational costs in the oil and gas industry to extreme weather conditions. About this, the maturity of the industry and the age of the facilities have to be considered in order to take into account the climate change impact on the economic scenario of T&T.

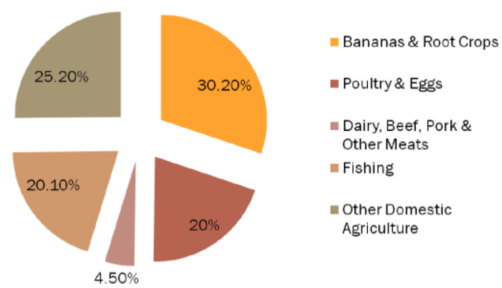
The second sector to be reviewed is agriculture, because of its sensitivity to climate change and its social importance.

As can be observed in the tables on page 92, the contribution of agriculture to GDP has decreased from an initial value of 2.1% by 1995 to a 1% 2005 and 0.6% for 2012. This relative loss Is derived on one hand from the already described growth in oil industry, and on the other for the effective decrease on the magnitudes. At current prices, 2009 agricultural GDP has the same value as used to in 1996 due to an 80% of accumulated inflation for the period (ECLAC, 2009).

The main crops to be analyzed are obtained from the Central Statistical Office and the IDB.

Figure 20: Key Commodities in agriculture

Source: CSO 2004



This reduction can derive from a reduction in the agricultural activity and the reassignment of resources to other uses, be it natural uses or economic activity.

The main "factors" that contribute to the agriculture production function are, water and temperature, available land and soil characteristics, fertilizers, capital stock and technology advances (quality of seeds…)

About temperature and water supply, an estimate has to be obtained covering both the past evolution and the future scenarios, so that future production estimates can be obtained for the main productive crops (Finger, R. and S. Schmid. 2007). See the figure and table below.

Figure 21: Evolution average rainfall and temperature T&T

Source: ECLAC.2011

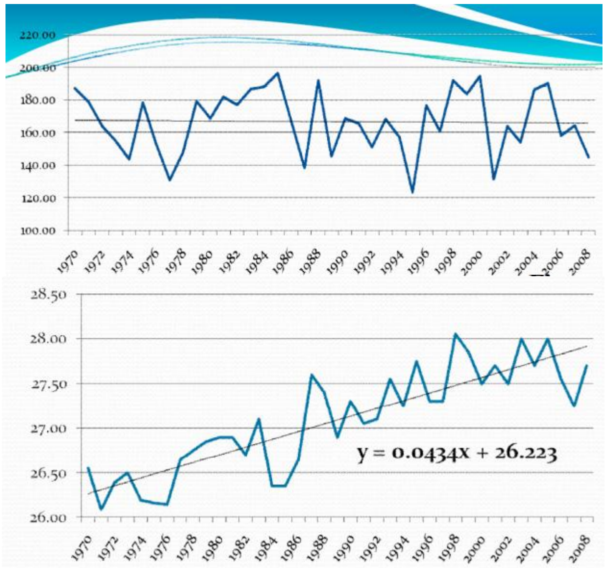


Table 22: Projected changes in climatic variables Central America

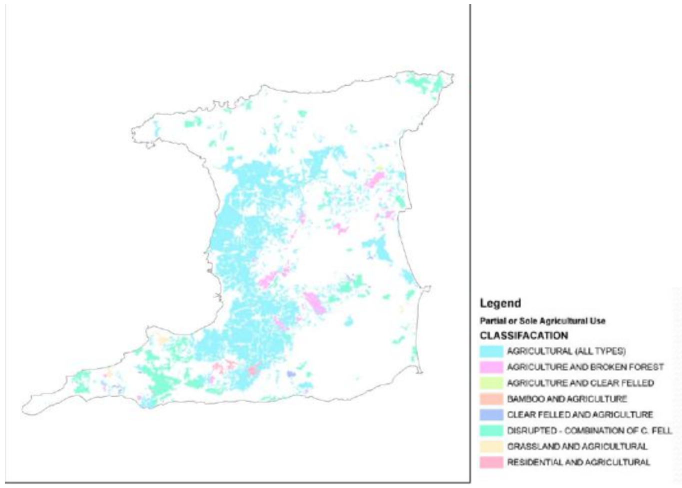
Source: IPPC.

Season	Changes in temperature (Centigrade)		
	2020	2050	2080
Dry	+0.4 to +1.1	+1.0 to +3.0	+1.0 to +5.0
Rainy	+0.5 to +1.7	+1.0 to +4.0	+1.3 to +6.6
	Changes in precipitation (Percentages)		
	2020	2050	2080
Dry	–7 to +7	–12 to +5	–20 to +8
Rainy	–10 to +4	–15 to +3	–30 to +5

The second factor is the soil used for agricultural activities. About this issue attention should be paid to three different questions. The first one is that, in order to calibrate the impact of climate change, it is critical to understand the spatial distribution of agricultural activity to discriminate spatial distribution of damages. If GIS is not available average values per departments will be used.

Figure 22: GIS Data on Agricultural activity T&T

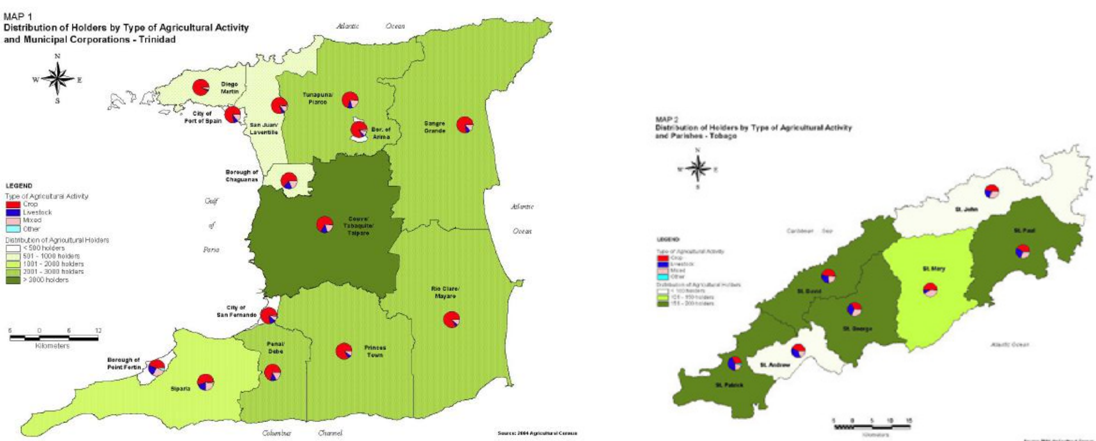
Source: ECLAC.2011



With this data, production functions will be checked against changes in the situation derived from climate change. (Finger, R. and S. Schmid, 2007)

Figure 23: GIS Data on Agricultural Holders T&T

Source: CSO(2004)



The second question is the evolution of productivity of soil that will be checked comparing the evolution land area with the evolution of crops harvested using FAO and Official statistical supplied from Trinidad & Tobago CSO (Figure above and table below).

Table 23: Agricultural land in T$T

Source: FAOSTAT.

Year	1980	1990	2000	2008
Agricultural Land Area	101,00	77,00	67,00	54,00
Arable Land Area	60,00	36,00	35,00	25,00
Permanent Crops Area	35,00	35,00	25,00	22,00
Forested Area	n\a	240,70	233,60	227,84
Total Area Equipped for Irrigation	3,00	4,00	5,00	7,00

The third question to consider is related with the topographical characteristics of harvested land that will produce different sensitivity to erosion derived from water rainfall. This will be obtained from GIS sources if available. (Baban and Sant, 2005) (Mahabir and Nurse 2007)

Other industrial activities will be analyzed and the economic structure should be reviewed (Harris 2000). Further on the identification of their specific sensitivity to climate change based on temperature sensitivity and water consumption will be analyzed.

Figure 24: GIS Data on Industrial Activities

Source: ECLAC (2011)

TABLE 8. GROSS DOMESTIC PRODUCT BY KIND OF ACTIVITY (SUB-INDUSTRY LEVEL) - TTSNA (CURRENT PRICES)
$TT million

Activity	2000	2001	2002	2003	2004	2005	2006
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
00. Export agriculture … … … …	20.9	10.6	19.4	14.1	15.8	14.4	18.1
01. Domestic agriculture … … …	377.6	413.0	469.4	426.6	471.5	479.2	484.1
Bananas and root crops … … …	121.1	158.8	179.0	132.3	134.9	145.4	152.9
Poultry and eggs … … … …	56.6	66.7	80.2	75.8	89.7	82.7	88.8
Dairy, beef, pork and other meat … …	39.3	40.8	25.2	42.5	31.9	16.5	15.5
Fishing … … … … …	80.8	83.6	98.8	81.0	87.8	119.1	100.7
Other domestic agriculture … … …	79.8	63.1	86.3	89.6	99.4	115.5	126.2
02. Sugar industry … … … …	298.7	284.0	298.4	233.9	242.0	133.1	203.2
Cane farming and cultivation … …	226.7	175.3	183.5	128.7	48.4	37.6	34.7
Sugar companies … … … …	-67.6	-64.0	-57.9	-100.0	67.6	-50.2	25.7
Distilleries … … … … …	139.6	172.7	172.8	205.2	126.0	145.7	142.8
03. Petroleum industries … … …	16,072.9	15,558.8	14,765.0	25,610.7	29,848.8	39,813.4	51,600.1
Exploration and production … … …	8,959.4	8,686.4	7,950.7	14,888.7	18,260.6	22,690.8	28,675.5
Refineries … … … … …	2,821.0	2,399.3	2,557.1	4,608.4	4,329.3	6,312.6	8,535.4
Service contractors … … …	725.7	753.3	1,087.0	1,480.7	1,752.8	2,258.0	2,879.7
Marketing and distribution … … …							
of petroleum products … … …	1,371.6	1,550.2	1,425.4	1,360.8	1,666.6	2,528.0	5,094.1
Petrochemicals … … … …	2,182.0	2,144.5	1,721.9	3,243.9	3,803.7	5,973.6	6,351.1
Asphalt … … … … …	13.2	25.1	22.9	28.2	35.8	50.4	64.3
Manufacturing … … … …	**3,625.4**	**4,074.4**	**4,494.1**	**4,495.3**	**5,330.5**	**5,955.5**	**6,491.8**
04. Food, drink and tobacco … … …	1,686.9	1,921.1	2,001.8	1,812.1	1,984.9	2,219.1	2,629.1
Meat, poultry and fish processors … …	42.7	55.2	53.4	77.4	99.0	112.2	82.1
Miscellaneous food etc. … … …	326.0	398.3	324.6	403.5	408.9	403.1	399.7
Fruit, vegetable processors and							
non-alcoholic beverages … … …	152.4	253.0	229.6	213.0	295.5	317.8	435.3
Grain and feed mills … … …	231.2	211.7	229.3	206.3	222.9	234.9	264.0
Animal and vegetable oils … … …	144.7	234.8	359.0	24.7	27.5	28.4	29.0
Bakeries … … … … …	193.1	131.0	119.6	142.7	162.1	197.3	213.9
Tobacco and breweries … … …	596.8	637.1	686.3	744.4	769.0	925.4	1,205.1
05. Textiles, garments, footwear … …							
and headwear … … … …	112.3	107.0	96.6	83.6	89.4	101.5	107.4
Textiles … … … … …	14.0	13.0	14.0	13.7	14.4	15.7	8.0
Headwear and clothing … … …	91.3	87.4	79.8	66.2	69.0	79.8	94.6
Footwear … … … … …	7.0	6.6	2.8	3.7	6.0	6.0	4.8
06. Printing, publishing and paper converters	390.5	414.1	454.8	537.7	574.4	659.8	715.2
07. Wood and related products … …	127.3	125.6	116.3	136.3	146.5	162.0	170.1
08. Chemicals and non-metallic … …							
Minerals … … … … …	687.0	698.8	761.6	903.6	986.5	1,102.2	1,244.9
Industrial gases … … … …	93.5	93.1	96.3	136.0	144.3	158.1	163.3
Pharmaceuticals … … … …	47.1	86.0	122.4	156.5	155.8	178.3	193.8
Clay etc. … … … … …	43.2	37.9	73.0	100.9	113.5	122.5	154.9
Cement … … … … …	227.8	196.2	243.0	269.5	307.5	315.8	344.3
Concrete … … … … …	159.1	154.0	114.6	128.2	136.2	163.6	201.2
Glass products and							
plastic products for construction … …	116.3	131.7	112.3	112.5	129.2	163.9	187.4

Table 25: Distribution of activities at subsector Level(2)

Source: CSO(2008_1).

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TABLE 8. GROSS DOMESTIC PRODUCT BY KIND OF ACTIVITY
(SUB-INDUSTRY LEVEL) - TTSNA - Concluded
(CURRENT PRICES)
$TT million

Activity	2000	2001	2002	2003	2004	2005	2006
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
09. Assembly type and related industries ...	404.9	589.2	853.4	826.2	1,321.5	1,456.4	1,355.3
Motor vehicle assembly and related industries	22.9	41.8	41.1	85.6	61.5	54.6	49.4
Assembly of appliances and electronic items	79.3	109.8	103.5	174.0	206.2	240.2	256.4
Boat building etc.	28.2	20.4	14.6	6.2	15.3	19.0	21.8
Metal building	205.9	329.6	581.5	449.4	906.6	988.8	840.1
Metal furniture	11.0	13.3	22.3	22.5	23.6	29.1	27.9
All other metal products	57.6	74.2	90.4	88.5	108.3	124.7	159.7
10. Miscellaneous manufacturing	216.5	218.6	209.6	195.8	227.3	254.5	269.8
Services	**31,163.9**	**34,603.7**	**36,030.1**	**40,066.8**	**43,635.3**	**48,902.6**	**55,909.0**
11. Electricity and water	888.2	880.6	802.6	896.3	924.8	891.8	866.7
12. Construction and quarrying	3,833.1	4,353.3	4,092.1	5,197.0	6,184.3	7,730.5	9,585.7
Construction	3,759.5	4,276.8	4,022.4	5,109.9	6,093.9	7,640.1	9,495.3
Quarrying	73.6	76.5	69.7	87.1	90.4	90.4	90.4
13. Distribution services including restaurants	8,401.8	8,724.3	9,286.7	9,901.9	10,623.5	12,211.8	13,426.8
Trade	7,690.8	7,957.7	8,471.2	9,038.2	9,717.5	11,004.6	12,122.0
Restaurants	711.0	766.6	815.5	863.7	906.0	1,207.2	1,304.8
14. Hotels and guest houses	217.0	235.9	255.4	265.0	310.0	357.2	374.7
15. Transportation, storage and communication	4,410.4	5,571.5	5,657.9	5,668.7	5,779.9	5,707.9	5,955.4
Omnibus service	16.8	90.9	97.3	84.4	9.3	5.8	-5.9
Taxi service	857.6	864.2	923.3	919.0	937.3	990.9	1,024.9
Trucks (internal freight)	993.4	1,223.4	1,284.2	1,358.6	1,449.8	1,187.1	1,721.2
Shipping lines	5.3	23.6	16.1	16.1	25.4	31.5	41.7
Port Authority	247.7	294.4	257.1	275.9	162.1	169.2	191.8
Airlines	522.3	849.0	542.3	288.7	129.4	180.2	2.1
Airport services and Services allied to transport	309.9	415.9	613.3	634.2	599.7	663.4	634.1
Warehousing and storage	7.3	33.3	24.6	16.2	16.0	24.1	29.5
Telecommunications	1,304.0	1,579.6	1,669.7	1,807.9	2,182.0	2,142.9	2,130.9
Post-office	51.7	53.2	61.4	66.0	45.0	82.4	43.7
Radio and television broadcasting ...	94.4	144.0	168.6	201.7	223.9	230.4	141.4
16. Finance, insurance, real estate and business services	7,305.1	7,505.8	8,890.1	9,182.2	10,538.6	11,708.5	13,309.6
Central Bank	328.3	451.3	179.7	174.0	199.7	221.9	289.5
Commercial banks	1,929.3	1,500.5	1,808.4	2,032.4	2,332.6	2,591.6	2,452.0
Insurance	1,287.5	1,357.2	2,131.4	1,891.7	2,171.1	2,412.2	2,909.5
Dwellings/Imputed Rent	567.1	520.8	668.8	706.7	811.1	901.1	938.0
Other	3,192.9	3,676.0	4,101.8	4,377.4	5,024.0	5,581.8	6,720.6
17. General government	3,887.2	4,714.1	4,332.9	5,560.0	5,963.8	6,522.7	8,147.4
18. Education and cultural community services	1,411.1	1,749.1	1,810.5	2,287.7	2,165.8	2,558.1	2,982.2
Ministry of Education	949.5	1,311.2	1,251.3	1,692.6	1,535.0	1,870.8	2,220.5
Other	461.6	437.9	559.2	595.1	630.8	687.3	761.7
19. Personal services	810.0	869.1	901.9	1,108.0	1,144.6	1,214.1	1,260.5
Health	231.0	238.5	266.5	335.2	338.4	382.4	406.5
Other	579.0	630.6	635.4	772.8	806.2	831.7	854.0
20. Less: FISIM[1]	2,216.0	2,116.0	2,187.3	2,493.0	2,888.7	3,189.6	3,537.1
21. Plus: Value Added Tax	2,027.3	2,178.7	2,400.9	2,364.3	3,170.9	2,948.4	3,305.2
Gross Domestic Product	**51,370.7**	**55,007.2**	**56,290.0**	**70,718.7**	**79,826.1**	**95,057.0**	**114,474.4**

[1]Financial Intermediation Services Indirectly Measured

Table 26: Aggregate economic data for T&T(1)

Source: CBTT(2000) (2012).

SECTOR	1996	1997	1998	1999	2000	2001	2002	2003	2004
culture	721.1	777.7	783.4	830.3	838.2	707.6	787.2	674.6	729.3
oleum	10,060.4	9,130.9	7,756.5	9,656.4	13,100.8	15,558.8	14,765.0	25,610.7	29,848.8
ufacturing	2,412.5	2,792.4	3,270.2	3,509.4	3,887.9	4,074.4	4,494.1	4,508.1	5,330.5
tricity and Water	455.7	579.1	849.2	910.4	865.6	880.6	802.6	896.3	924.8
struction	2,685.0	3,228.6	3,748.7	4,479.6	4,672.4	4,353.3	4,092.1	5,197.0	6,184.3
sport, Storage and nmunication	3,206.5	3,354.4	3,608.9	4,002.3	4,438.5	5,571.5	5,657.9	5,668.7	5,779.9
ibution	5,030.3	5,653.0	6,377.1	7,152.0	8,260.3	8,724.3	9,286.7	9,901.9	10,623.5
nce, Insurance and l Estate	4,148.1	5,193.9	5,622.2	5,695.2	7,449.3	7,505.8	8,890.1	9,182.2	10,538.6
ernment	3,398.4	3,314.6	3,489.1	3,917.8	3,738.1	4,714.1	4,332.9	5,560.0	5,963.8
er Services	1,946.2	2,167.4	2,445.5	2,610.8	2,884.7	2,854.1	2,967.8	3,660.7	3,620.4
ection for Imputed ice Charge	891.5	-1,373.7	-1,645.5	-1,844.4	-1,922.3	-2,116.0	-2,187.3	-2,493.0	-2,888.7
e Added Tax	1,413.9	1,624.0	2,153.9	1,667.1	2,018.0	2,178.7	2,400.9	2,364.3	3,170.9
SS DOMESTIC DUCT AT MARKET CES	34,586.6	36,442.0	38,459.2	42,586.9	50,231.5	55,072.2	56,290.0	70,731.5	79,826.1
rowth constant prices)					4,18%	7,93%	14,44%	7,95%	6,21%
etroleum	29.1	25.1	20.2	22.7	26.1	28.3	26.2	33.9	37.1
istribution	14.5	15.5	16.6	16.8	16.4	15.9	16.5	14.7	13.8
nancial Services	12.0	14.3	14.6	13.4	14.8	13.6	15.8	13.6	12.7
anufacturing	7.0	7.7	8.5	8.2	7.7	7.4	8	7.0	6.7
griculture	2.1	2.1	2.0	1.9	1.7	1.3	1.4	1.1	1.0
tion Rate (%)	3.3	3.7	5.6	3.4	3.6	5.5	4.2	3.8	3.7
mployment Rate (%)	16.3	15.0 2	14.2	13.1	12.3	10.8	10.4	10.5	8.4
lic Sector Debt						54.1	58.3	52.7	48.0

Table 27: Aggregate economic data for T&T(2)

Source: CBTT(2000) (2011)(2012)

TOR	2005	2006	2007	2008	2009	2010	2011r	2012
riculture	626.7	705.4		640.7	721.8	816.0	902.8	888.0
roleum	39,813.4	51,600.1		89,100.3	41,965.5	56,015.3	70,313.7	67,105.4
nufacturing	5,955.5	6,491.8		7,042.6	6,973.9	7,024.2	8,661.8	9,260.3
ctricity and Water	891.8	866.7		1,526.3	1,777.9	1,809.7	2,000.1	1,930.2
nstruction	7,730.5	9,585.7		14,476.5	13,726.5	9,410.5	8,772.3	7,642.7
nsport, Storage and Communication	5,707.9	5,955.4		6,983.4	7,194.6	6,903.1	7,193.4	8,235.2
tribution	12,211.8	13,426.8		21,140.0	17,934.9	17,942.1	19,449.2	21,180.2
ance, Insurance and Real Estate	11,708.5	13,309.8		15,681.3	14,453.8	14,812.5	16,710.2	16,936.3
vernment	6,522.7	8,147.4		12,495.1	11,167.9	10,423.9	11,219.8	13,302.8
ner Services	4,129.4	4,617.4		7,683.3	7,695.7	7,840.2	9,564.6	0.0
rrection for Imputed Service Charge	-3,189.6	-3,537.1		-5,090.7	-5,459.6	-5,812.5	-5,721.8	-5,950.6
lue Added Tax	2,948.4	3,305.2		5,933.0	5,147.3	6,032.3	4,917.0	6,497.6
OSS DOMESTIC PRODUCT AT MARKET PRICES	95,057.0	114,474.6		175,287.2	121,281.3	131,289.4	150,373.2	153,587.7
Growth constant prices (TT$)	6,21%	13,51%	4,62%	2,29%				
Petroleum	42.9	45.1		50.8	34.6	42.7	46.8	43.7
Distribution	12.6			12.1	14.8	13.7	12.9	13.8
Financial Services	11.4			8.9	11.9	11.3	11.1	11.0
Manufacturing	6.1			4.0	5.8	5.4	5.8	6.0
Agriculture	0.8			0.4	0.6	0.6	0.6	0.6
ation Rate (%)				12.0	7.2	10.5	5.2	9.3
employment Rate (%)				4.6	5.3	5.9	4.9	4.9
blic Sector Debt				24.4	34.1	39.4	37.4	46.9

3.8. Conclusions

A review of the hazard sources that will substantially affect Trinidad and Tobago and will be affected by the process of global climate change have been presented. Further discussions emerging from this initial view may root more profound analysis along the work in the project.

Relevant data sources needed and available, have been described in the document giving a clear idea of the interdisciplinary framework and the complexity of the integrated approach involved in the project.

The methodology to be followed in the assessment both of risk levels and economic consequences has been also described in the document.

The socioeconomic basic framework and data needed to provide scenarios to describe the situation for a 2040 horizons have been introduced.

The basis for a comprehensive analysis of the socioeconomic impact of climate change has been hence established.

4. Identification of Risks

4.1. Demographic Scenario

According with the information collected in previous tasks, the global demographic situation in Trinidad by 2040 will show an image qualitatively different than the present.

For the global population according with UN Population Estimates and Projections, the population of Trinidad & Tobago will reach a relative maximum level by 2020. This result is consistent with the observed fertility rate evolution that has dramatically dropped from 5.24 in 1960 to 1.8 present results in 2011 Census. About the distribution of ages the situation age again will dramatically change, the population under 5 years that was 15.5% in 1950, will drop to a 5.5 value for the decade 2030-2040, and on the other hand population above 60 years will duplicate from the present (12% approximately) to a 24% by 2040. Hence T&T will face a completely different profile that will substantially alter both demographic vulnerability as vulnerable groups will rise their presence and carrying capacity as the economically active cohort has already overpassed its maximum between 2005 and 2010. It can also be observed that the expected population for 2040 shows a decrease from the present observed values, hence we will assume that we have already reached the permanent regime. Nevertheless, when appropriate, changes in social vulnerability will be considered.

Table 28: Demographic projections T&T 1950-2100

Source: UNITED NATIONS Department of Economic and social affairs. Population division.

	*1000 Persons >65	% >65	*1000 Persons <15	% <15	*1000 Persons 15-64	% 15-64	Total Pop *1000	>65+<15/ 15-64
1950	26	4.0	258	39,9	362	56.1	646	0,18
1955	27	3.7	312	42,2	401	54.2	740	0,17
1960	30	3.5	363	42,8	455	53.7	848	0,16
1965	31	3.4	396	43,4	486	53.2	913	0,15
1970	40	4.2	392	41,4	514	54.3	946	0,16
1975	49	4.8	381	37,6	582	57.5	1.012	0,15
1980	59	5.5	369	34	657	60.6	1.085	0,14
1985	65	5.6	401	34,3	704	60.2	1.170	0,14
1990	70	5.8	410	33,6	741	60.7	1.221	0,14
1995	76	6.1	386	30,8	793	63.2	1.255	0,13
2000	83	6.5	324	25,6	861	67.9	1.268	0,13
2005	94	7.2	283	21,8	920	70.9	1.297	0,13

	*1000 Persons >65	% >65	*1000 Persons <15	% <15	*1000 Persons 15-64	% 15-64	Total Pop *1000	>65+<15/ 15-64
2010	110	8.3	275	20,7	943	71.0	1.328	0,14
2015	129	9.6	280	20,8	937	69.6	1.346	0,16
2020	155	11.5	272	20,2	921	68.3	1.348	0,19
2025	177	13.3	249	18,7	906	68.0	1.332	0,22
2030	202	15.5	225	17,2	881	67.3	1.308	0,25
2035	211	16.5	210	16,4	857	67.1	1.278	0,27
2040	219	17.6	204	16,4	820	66.0	1.243	0,29
2045	232	19.3	199	16,5	772	64.2	1.203	0,32
2050	259	22.4	188	16,3	708	61.3	1.155	0,39
2055	270	24.4	174	15,7	661	59.8	1.105	0,43
2060	257	24.4	161	15,3	636	60.3	1.054	0,43
2065	236	23.4	154	15,3	618	61.3	1.008	0,41
2070	224	23.2	149	15,5	590	61.2	963	0,41
2075	222	24.0	145	15,7	557	60.3	924	0,43
2080	223	25.1	138	15,6	527	59.3	888	0,45
2085	220	25.6	132	15,4	505	58.9	857	0,47
2090	213	25.6	128	15,4	491	59.0	832	0,47
2095	204	25.2	126	15,6	479	59.2	809	0,46
2100	199	25.1	125	15,8	466	59.0	790	0,46

As can be seen in the table above, the estimates for >65 years population quota will jump from 110 to 209 thousands between 2010 and 2040 and at the same time the quota of potentially active population is expected to drop from 940 to 820 thousands. As a result the number of dependent people per potentially active person will duplicate from 0.14 at 2010 to 0.28 at 2040. This situation can derive in a reduction of per capita rents under the business as usual scenario that will require a change in productivity or in active population ratio to compensate.

About the availability of data, no GIS layer has been obtained at the local level and hence a specific downscaling solution has been developed within the project. The procedure has collected the available data for administrative units and for cities and communities, then average spatial population density has been computed for cities and communities and detracted from the registered population at each administrative unit calculating new spatial density values for non-urban areas. Population for communities whose data have not been made available by the census data have been calculated based on average density values.

The internal distribution of population will also suffer changes. During last decade capital cities have lost population quota and countryside areas have risen up their relative wedge in population. The estimates for spatial distribution of population rely heavily on the availability of Census information at a spatially disaggregate scale. For this purpose we have used two different scales. On one hand the available information that has been supplied focus on the following spatial units

Trinidad: (14 units) City of Port of Spain, City of San Fernando, Borough of Arima, Borough of Chaguanas, Borough of Point Fortin, Couva/Tabaquite/Talparo, Diego Martin, Mayaro/ Rio Claro Penal/Debe, Princes Town, San Juan/Laventille, Sangre Grande, Siparia, Tunapuna/Piarco

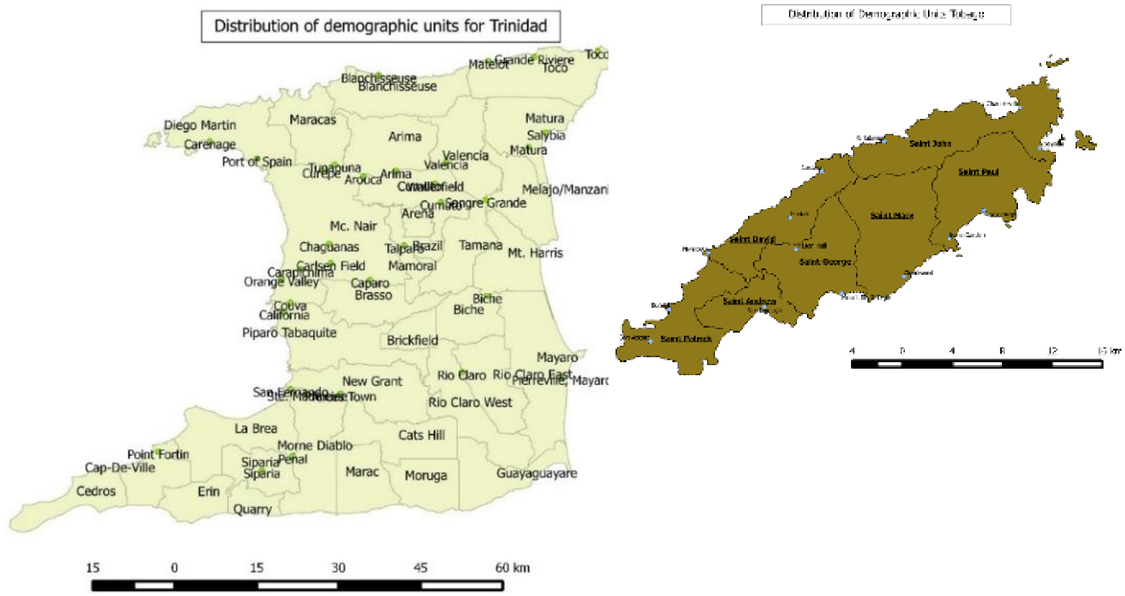
Tobago: (7 units) St Andrew, St David, St George, St John, St Mary, St Patrick, St Paul

But from a different source we have been able to work with more detailed environmental data for Trinidad, and hence a set of 34 units have been defined.

Diego Martin, Blanchisseuse, Maracas, Arima, Toco, Valencia, Matura, Melajo/Manzanilla, Mc. Nair, Cumuto, Arena, Brazil, Mamoral, Tamana, Mt. Harris, Brasso, Brickfield, Biche, Piparo Tabaquite, New Grant, Rio Claro East, Mayaro, Guayaguayare, Rio Claro West, Moruga, Marac, Cats Hill, Cedros, Cap-De-Ville, Erin, Quarry, Siparia, Morne Diablo, La Brea.

In order to downscale aggregated information 34 urban areas have been located whose population has been estimate either from census data or population density standards, so that social vulnerability can be estimate at the same scale of the available environmental hazard data.

Figure 25: Spatial Units T&T



About the definition of future spatial demographic trends we will assume a regular behavior path as no information is available to root other eventual estimates.

As a result the estimates for population used in vulnerability maps are presented in the following table for communities and spatial units.

Table 29: Estimates for Urban Population T&T (2011)

Cod	CITY NAME	SPATIAL UNIT	Pop
1	Port of Spain	Diego Martin	37.074
2	San Fernando	New Grant	48.838
3	Point Fortin	Cap de Ville	20.235
4	Chaguanas	Mc Nair	57.257
5	California	Piparo	5.479
6	Tunapuna	Maracas	13.509
7	Arima	Arima	33.606
8	Arouca	Cumuto	12.054
9	Curepe	Curupe	16.163
10	Sangre Grande	Melajo Manzanilla	14.946
11	Carenage	Diego martin	7.241
12	Biche	Biche	3.055
13	Princes Town	Morne Diablo	20.036
14	Ste. Madeleine	Morne Diablo	2.496
15	Siparia	Siparia	5.868
16	Rio Claro	Siparia	5.227
17	Pierreville, Mayaro	Mayaro	3.161
18	Carapichima	Mc Nair	4.039
19	Orange Valley	Mc Nair	1.307
20	Couva	Piparo	5.179
21	Caparo	Mc Nair	4.048
22	Cumuto	Cumuto	3.706
23	Valencia	Valencia	9.017
24	Matura	Matura	2.818
25	Salybia	Matura	1.073
26	Toco	Toco	2.219
27	Grande Riviere	Toco	2.137
28	Matelot	Toco	2.069
29	Blanchisseuse	Blanchisseuse	2.859
30	Penal	Siparia	4.899
31	Carlsen Field	Mc Nair	ND
32	Talparo	Brazil	ND
33	Wallerfield	Cumuto	ND
	Total		351.615

Table 30: Summary of Spatial Distribution of Population

COD	NAME	POP	Urban	Rural	Area	Density
1	Diego Martin	191.040	44.315	146.725	180	817
2	Blanchisseuse	75.603	2.859	72.744	179	422
3	Maracas	92.564	13.509	79.055	141	658
4	Arima	69.011	33.606	35.405	163,533	422
5	Toco	16.696	6.425	10.271	201,157	83
6	Valencia	12.672	9.017	3.655	152,675	83
7	Matura	12.550	3.891	8.659	151,204	83
8	Melajo/Manzanilla	14.946	14.946	0	137,913	83
9	Mc. Nair	239.473	82.814	156.659	443,469	540
10	Cumuto	15.760	15.760	0	145,421	83
11	Arena	2.526	0	2.526	30,4282	83
12	Brazil	3.487	0	3.487	42,0094	83
13	Mamoral	2.515	0	2.515	30,3024	83
14	Tamana	10.482	0	10.482	126,292	83
15	Mt. Harris	10.868	0	10.868	130,939	83
16	Brasso	5.562	0	5.562	126,405	44
17	Brickfield	2.478	0	2.478	56,3237	44
18	Biche	8.382	3.055	5.327	100,985	83
19	Piparo Tabaquite	54.465	10.658	43.807	207,09	263
20	New Grant	46.645	0	46.645	188,848	247
21	Rio Claro East	6.102	0	6.102	138,682	44
22	Mayaro	11.840	3.161	8.679	269,084	44
23	Guayaguayare	5.702	0	5.702	129,595	44
24	Rio Claro West	7.585	0	7.585	172,393	44
25	Moruga	18.238	0	18.238	110,535	165
26	Marac	19.366	0	19.366	117,367	165
27	Cats Hill	24.900	0	24.900	150,909	165
28	Cedros	18.286	0	18.286	103,9	176
29	Cap-De-Ville	86.309	69.073	17.236	97,9299	176
30	Erin	13.956	0	13.956	79,2951	176
31	Quarry	7.623	0	7.623	43,3115	176
32	Siparia	24.982	15.994	8.988	94,9903	263
33	Morne Diablo	66.246	22.532	43.714	182,497	363
34	La Brea	68.328	0	68.328	188,232	363
	TRINIDAD	1.267.188	351.615	915.573	4.813	
35	Saint George	6.875		6.875		88
36	Saint John	2.825		2.825		88
37	Saint Mary	3.297		3.297		88
38	Saint Paul	6.048		6.048		88
39	Saint Andrew	17.536	17.536	0		215
40	Saint David	8.733		8.733		215
41	Saint Patrick	15.560		15.560		215
	TOBAGO					

4.2. Economic Scenario

Following the trends estimates in the first interim report some general structural comments can be made about the future economic situation of T&T.

- Loss of Oil and Gas industry relevance as far as the available resources are expected to be exhausted within next decade.
- Eventual rise in industry activity assuming a process of precautionary adaptation measures, based in the availability of trained labor resources in chemical industry
- Business as Usual behavior on agricultural activity, as far as the estimates.
- Rise of services quota both tied with commerce and touristic activities

About the spatial distribution of economic activity we face again the problem of the absence of GIS layers that would locate the economic activity in the spatial framework, and again a specific approach has been developed within the project.

- Each of the spatial units previously described have been subject of expert analysis by local partners and the main socioeconomic activities and assets susceptible of been affected by environmental hazards have been identified. The categories of attributes obtained for each one have been:
    - Agricultural activity
    - Industry activity (Non oil and gas)
    - Oil&Gas Industry activity
    - Oil&Gas Fileds (Specific vulnerable asset)
    - Services
    - Critical infrastructures[4] (Motorways, Ports and Aeroports…)
    - Administrative services (public services)
- At a second step the different activities included in the menu have been wedge across the spatial units in a scale of 0 to 5 where 0 represents the absence of this activity 5 the presence of an intense activity of this nature in this specific spatial unit.
- Once this task has been made, a set of GIS Vulnerability layers have been developed to assess the eventual consequences of selected hazards at each specific area. For this purpose actual exposure and sensitivity to specific hazards have been considered.
    - Proportion of Coastal area over total area of the unit

[4] Relevant infrastructure of any kind that support the overall communities

- Sensitivity of activity to wind conditions
- Topography and sensitivity to inland flooding as defined by the Country Risk Profile for T&T (CRIF, 2013)

The result of this analysis is presented in the table below. Future steps this information will be analyzed through the lens of vulnerability

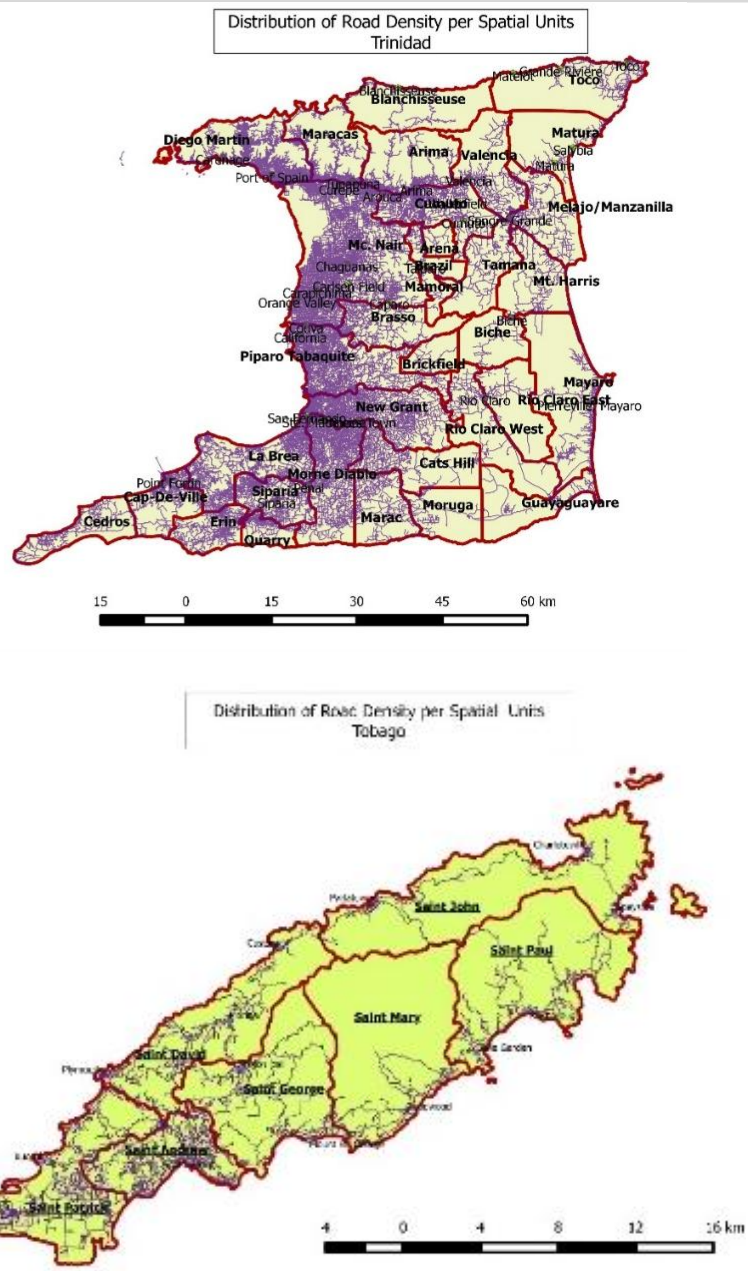
Table 31: Results for Spatial distribution of economic activity

COD	NAME	AGRIC.	SERVICES	INDUSTRY (NON OIL)	OIL INDUSTRY	OIL FIELDS	PORTS COMERCIAL	PORTS FISHING	PORTS RECRE.	ADMIN.E SERVICES	RECR.L SERVICES
1	Diego Martin	2	5	5	0	0	5	2	0	5	5
2	Blanchisseuse	5	2	0	0	0	0	5	1	2	5
3	Maracas	3	2	0	0	0	0	5	5	2	5
4	Arima	2	5	4	0	0	0	0	0	4	5
5	Toco	3	2	2	3	3	0	5	0	2	5
6	Valencia	3	2	2	0	0	0	5	0	1	1
7	Matura	3	1	2	0	0	0	5	0	1	3
8	Melajo/Manzanilla	5	1	3	0	0	0	5	0	1	3
9	Mc. Nair	4	3	3	0	0	2	0	0	1	4
10	Cumuto	5	2	5	0	0	0	0	0	1	1
11	Arena	5	2	2	0	0	0	0	0	1	1
12	Brazil	5	2	0	0	0	0	0	0	0	0
13	Mamoral	5	2	0	0	0	0	0	0	0	0
14	Tamana	5	2	0	0	0	0	0	0	1	1
15	Mt. Harris	0	0	0	0	0	0	0	0	0	1
16	Brasso	5	2	0	0	0	0	0	0	0	1
17	Brickfield	5	2	0	0	0	0	0	0	0	0
18	Biche	5	2	0	0	0	0	0	0	1	2
19	Piparo Tabaquite	5	2	0	0	0	0	0	0	0	1
20	New Grant	5	2	1	0	0	0	0	0	1	
21	Rio Claro East	5	2	0	0	0	0	0	0	1	
22	Mayaro	5	2	5	0	5	0	5	0	1	3
23	Guayaguayare	5	2	5	0	5	0	5	0	0	
24	Rio Claro West	5	2	1	0	0	0	0	0	1	

COD	NAME	AGRIC.	SERVICES	INDUSTRY (NON OIL)	OIL INDUSTRY	OIL FIELDS	PORTS COMERCIAL	PORTS FISHING	PORTS RECRE.	ADMIN.E SERVICES	RECR.L SERVICES
25	Moruga	5	2	2	0	0	0	0	0	0	2
26	Marac										
27	Cats Hill	5		2	0				0	1	
28	Cedros	5		5	0			5	0	1	4
29	Cap-De-Ville	5									
30	Erin	5	3	4	0			5	0	0	
31	Quarry										
32	Siparia	5	3	3	0				0	2	5
33	Morne Diablo	5									
34	La Brea	0	4	5	5				0	4	5
35	Chaguanas	4	5	4	0	0	0	0	0	5	5
36	Marabella	2	5	3	3					5	5
37	Point Fortin	3	5	5	5	5	5			5	5
38	Trinicity	2	5	5	0	0	0	0	0	3	5
39	Couva	3	4	5	1	0	2	2	1	4	3
40	Saint Andrew	0	5	0	0	0	5	0	0	5	4
41	Saint Patrick	0	3	0	0	0	5	4	0	0	5
42	Saint David	1	0	0	0	0	0	5	0	0	3
43	Saint George			0	0	0	0	1	0	0	1
44	Saint Mary	1	0	0	0	0	0	1	0	0	1
45	Saint John	5	0	0	0	0	0	4	0	0	3
46	Saint Paul	5	0	0	0	0	0	2	0	0	3

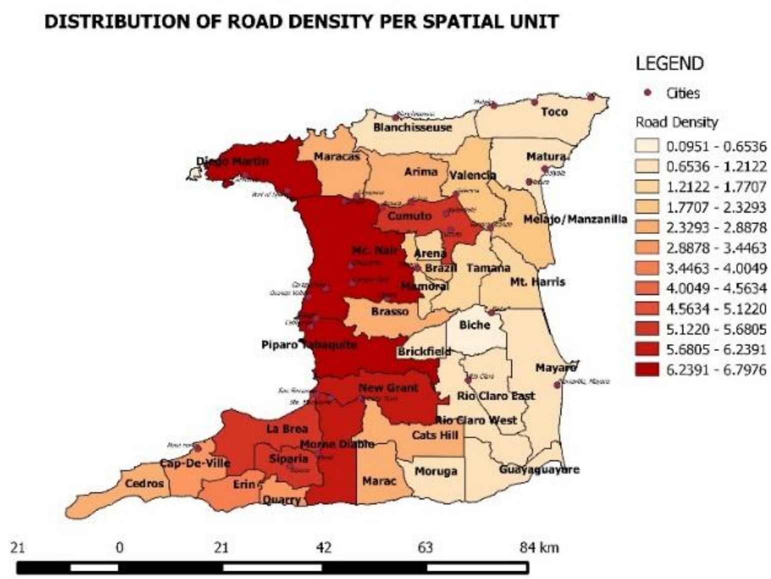
A second indicator to quantify economic vulnerability has been developed based on the available layers of road networks that will be used as proxy indicator for the location both of population and of economic activities. The basic assumption in the method is the existence of a double positive feedback between road investments and both firms and human settlements, derived on one hand from the concentration of infrastructure investments around population, and on the other from the trend in both location decisions to move close to well-connected areas.

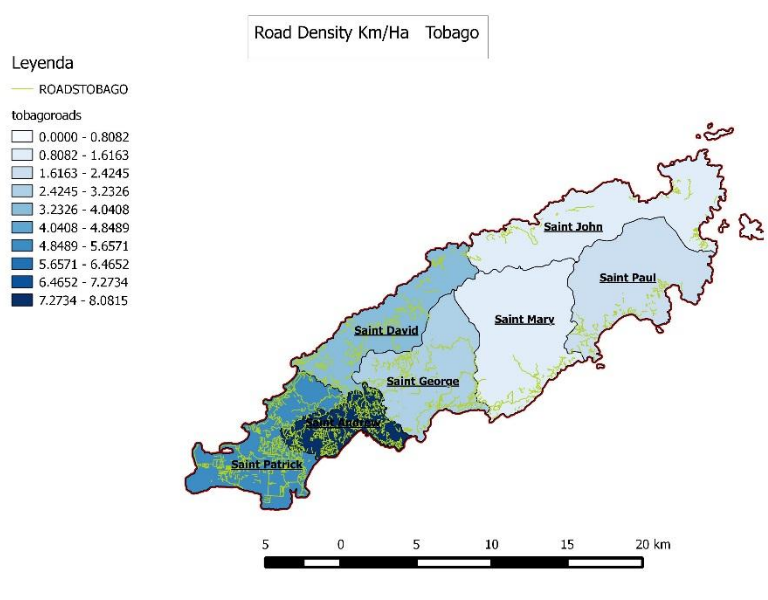
Figure 26: Spatial Distribution of Road Density



As a result of this we can observe that the eventual damage is expected to be located either close to human settlement or economic facilities

Figure 27: Spatial Distribution of Economic Activity Density[5]





[5] The quantitative indicators have been computed based on the available GIS data for roads, hence the numerical absolute value may be different according with the category of roads considered although the relative wedge is expected to remain constant.

4.3. Natural Hazards

4.3.1. Main Drivers Of Natural Hazards

The primary hazards identify for Trinidad and Tobago depend mainly on the climate variables air and sea surface temperature. However, the air surface temperature can also be identifying by itself as another primary hazard.

The climate system is a dynamical system that involves the earth's atmosphere, land surfaces, and oceans driven by energy received from the sun. Some of this energy is reflected back into space, but the rest is absorbed by the land and ocean and re-emitted as radiant heat. A crucial feature of the climate system is that the sun's energy is not distributed uniformly, but rather is most intense at the equator and weakest at the poles. This non-uniform energy distribution leads to temperature differences, which the atmosphere and ocean act to reduce by transporting heat from the warm tropics to the cold Polar Regions. This non-uniform heating and the resulting heat transport give rise to ocean currents, atmospheric circulation, evaporation, precipitation... and a natural variability and extreme events such as hurricanes or droughts.

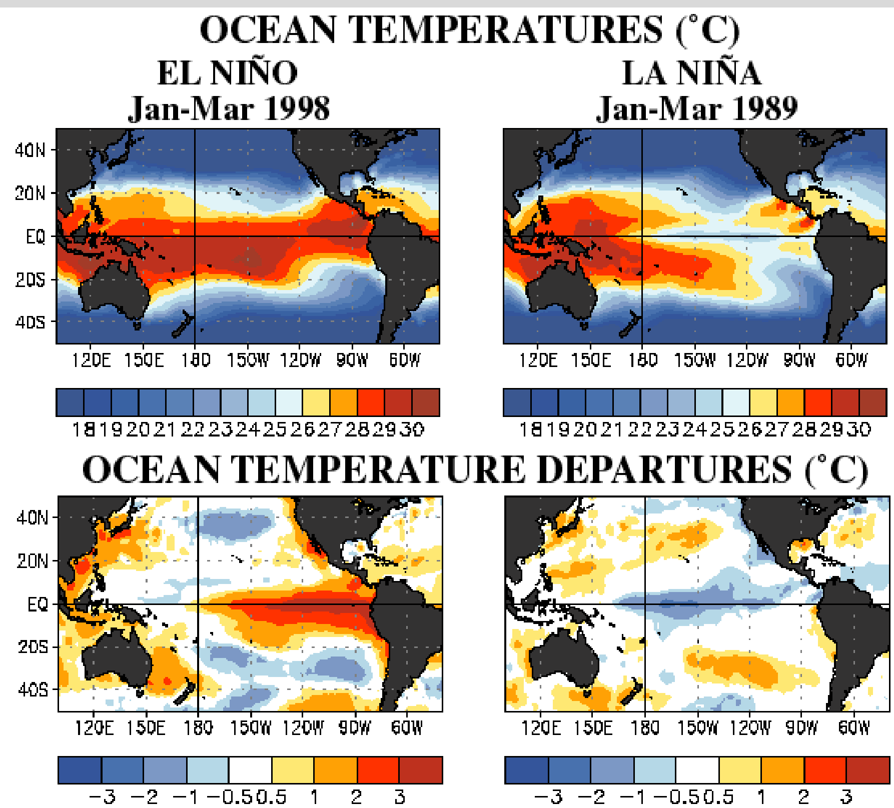
Summarizing, the main driver of global climate is the heat coming from the sun that can be expressed in terms of air and sea surface temperature. As note before, the climate variability, both temporal and spatial, is a natural feature of the climate system. Different spatial patterns of variability can be identify around the globe, being the major climate zones tropical, dry, temperate mid-latitude, cold mid-latitude, polar and high-lands. As well as varying spatially, the climate varies across multiple timescales, from hourly, to seasonal, interannual or to longer scale. The external driver of the climate system is sunlight (and human activity in the last decades), but once the heat has coming into the system internal interactions and feedbacks between ocean and atmosphere develop a complex system that varies in regular and semi-regular cycles and chaotic fluctuations. Of particular importance are variations at interannual to decadal timescales, which play a very important role in determining the variability of the Earth´s climate. Anomalies at the ocean surface interact with the overlying atmosphere to alter the transport of moisture around the globe by intensifying local convection, shifting storm tracks, and changing frequency of hurricanes, to bring flooding or drought to different regions of the globe (Sheffield and Wood 2011). Much of the large scale dynamics of the couple system ocean-atmosphere follow quasi-periodic oscillations and have been identified as predominant patterns of low frequency.

4.3.1.1. El NiñoSouthern Oscillation

The most important driver of global climate on interannual scales and well-known pattern is El NiñoSouthern Oscillation (ENSO) which is a combined oceanic-atmospheric process manifested most notably by anomalies of sea surface temperature (SST) in the tropical Pacific Ocean (Rasmussen and Carpenter 1982). The positive phase is called El Niño and characterized by positive anomalies of SST (warmer than normally) in the eastern tropical Pacific (a decrease in the easterly winds and reduce upwelling are also observing). In contrast, La Niña represents the alternate phase of the cycle characterized by colder temperature in the eastern Pacific as the thermocline tilts even further upwards towards the east. Although La Niña events do not exactly mirror the negative of each El Niño feature, they do display somewhat contrary yet variable characteristics in the ocean and atmosphere (Rosenzweig and Hillel 2008). The figure below shows sea-surface temperature (top) and departure (bottom) maps for December - February during strong El Niño and La Niña episodes.

Figure 28: Sea surface temperature (upper panels) and departure (bottom maps) during El Niño (left hand column) and La Niña (right hand column) episodes

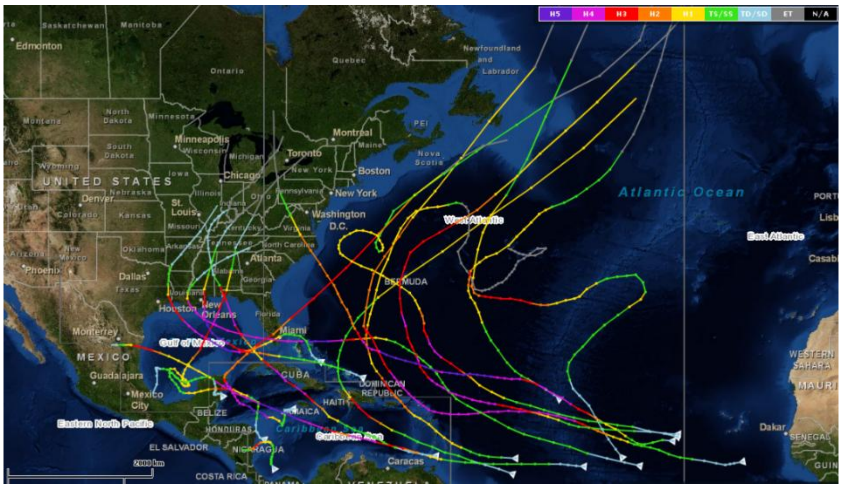
Source: NOAA



The climatic variations enhance by El Niño/La Niña phases in one part of the ocean have impacts at remote locations all over the world, called tele-connections. Thus, during El Niño phase wetter conditions are registered in the central Pacific and drier in Indonesia and northern Australia. Beside, recent investigations have identified an alternative El Niño mode called El Niño "Modoki" that leads to more hurricanes more frequently making landfall in the Atlantic (See the figure below).

Figure 29: Tracks of major (category 3, 4, or 5 at maximum strength) hurricanes in the East Atlantic, West Atlantic, Caribbean and Gulf of Mexico during hurricane seasons that followed El Niño "Modoki" winters.

Source: NOAA



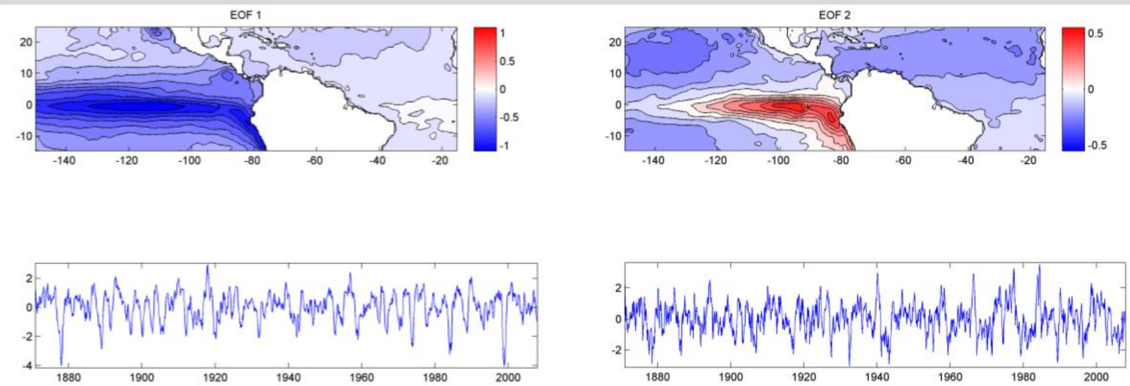
4.3.1.2. Patterns of variability of sea surface temperature

Although El Niño and La Niña phases are the primary modes of variability of SST and sea level pressure fields, other modes of variability such as El Niño Modoki are also now identifying as drivers for climatic conditions (such as hurricane events). That led into the idea of exploring climatic variability of natural hazards through primary modes of SST using a principal component analysis and synoptic climatology approach (Izaguirre et al. 2012).

The predictor SST fields come from the global database Simple Ocean Data Assimilation (SODA) which is a new global reanalysis from 1871 to 2008 and the SST data consist of monthly fields of SST on a 0.5° spatial resolution-grid. The spatial domain selected to perform the analysis spans from 15°S to 25°N and 150°W to 10°W, encompassing part of the tropical Pacific and Atlantic basins. In summary the monthly SST data consist of a record of 1656 monthly values from 1871 to 2008, each one defined at every point of the grid. This means a large amount of information difficult to process.

In order to reduce dimensionality of the problem, preserving the maximum of the sample variance, the principal component analysis (PCA) (or Empirical Orthogonal Functions decomposition, EOFs) has been applied to the SST anomaly fields. The first two spatial modes and temporal variability are shown in the figure below:

Figure 30: First and second principal components (PC) of the monthly SST anomaly over the area:150ºW-10ºW; 15ºS- 25ºN

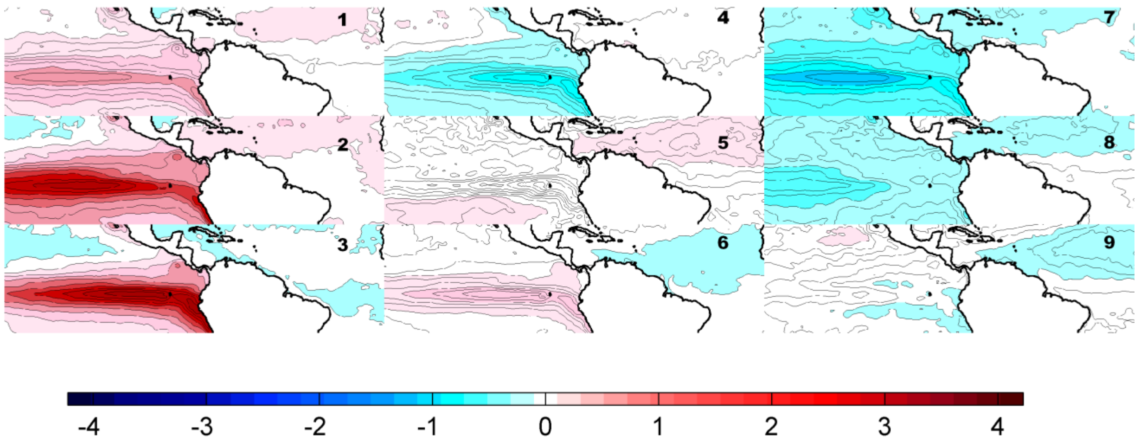


The first 10 temporal modes from the PCA, which explain more than 97% of the variance of the data, have been selected to cluster oceanic patterns using the k-means technique. Note that the first PC is highly correlated with the prominent teleconnection mode in the area, El Niño Southern Oscillation, through the climate index El Niño 3.4 (ρ=-0.91). The second PC is correlated with the Multivariate ENSO index (ρ=-0.62), while the third PC is quite similar to the Tropical Northern Atlantic Index (ρ=-0.55).

Using the first 10 PC and the k-means classification technique the objective is to obtain a lattice of representative weather types of SST anomalies. The k-means algorithm (Anderberg, 1973) is focused in minimizing the euclidian distances between classes or centroids classifying, in this case, the oceanic SST patterns in k classes. Each determined centroid represents a set of similar SST states according with the metrics used by the algorithm. This clustering technique divides the complex SST dataset in a number of subsets (n) defined by the nearest centroid into the EOF space. The algorithm initializes with a given number of subsets and iteratively moves them until minimized intra-subsets variance.

After some preliminary tests, a lattice of 3 x 3 = 9 groups, which fulfils the compromise between a significant number of weather types and the requirement of a minimum number of data per group, has been considered (see the figure below). Besides, a convenient visualization has been carried out, in order to see similar states close each to other and the most extreme state located at the corners. In the left side of the Figure (types, 1, 2, 3, 5 and 6) one can see the SST patterns with positive SST anomaly in the equatorial Pacific corresponding to El Niño events on different phases, while the right part of the figure (types, 4, 7 and 8) correspond to different strengths of La Niña.

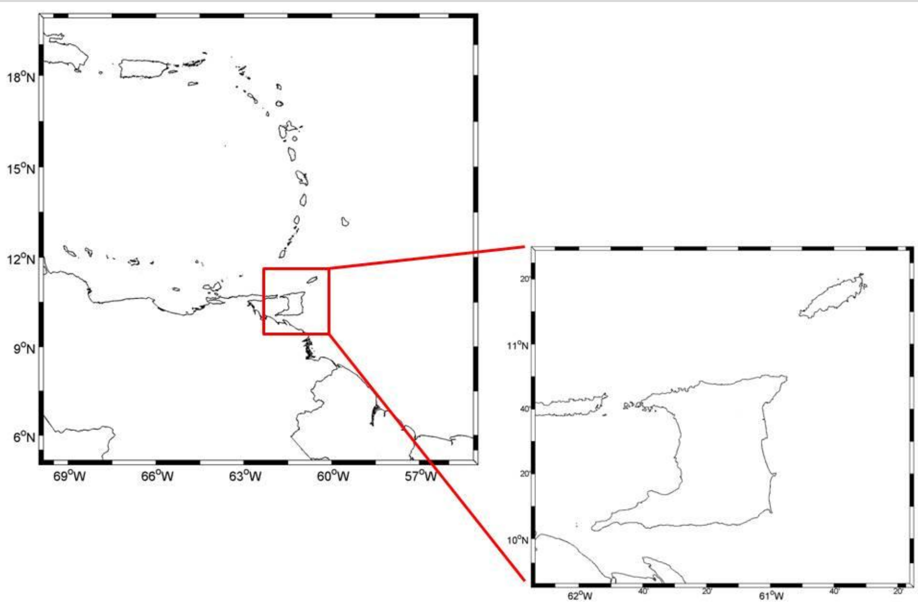
Figure 31: SST types obtained by k-means algorithm.



4.3.2. *Hurricanes And Tropical Storms*[6]

The aim of this sub-section is characterizing the hurricane natural hazard in terms of present variability, numerical modeling and associated impacts. To this fact the North Atlantic hurricane database, HURDAT, (Jarvinen et al 2004, Landsea et al 2004 and 2008) is used. HURDAT contains the 6-hourly center locations and intensities (maximum wind speed and minimum pressure) for all tropical storms (TS) and hurricanes (H) from 1851 through 2012 in the Atlantic Ocean, Gulf of Mexico and Caribbean Sea. From all this dataset the TS and H that passed through an area of influence of Trinidad and Tobago (TT) have been selected. The area spans around 200 km from a gravity center located between Trinidad and Tobago islands in the coordinates -63°W,-59°W and 9°N,13°N (See the figure below).

Figure 32: Area of influence of Trinidad and Tobago



That supposes an historical database of 102 TS and H in the area of Trinidad and Tobago with information about the position track, wind speed and pressure of each event. This dataset will be used to determine the present climate variability of hurricane events, and three of the main hurricanes that affected directly TT with effects and damages reported by the Meteorological Service of Trinidad and Tobago will be used to design and calibrate the damage function of hurricane hazard.

[6] For the purpose of this document we summarize in this chapter both hurricanes and tropical storms although we will apply the general term Hurricanes to summarize both.

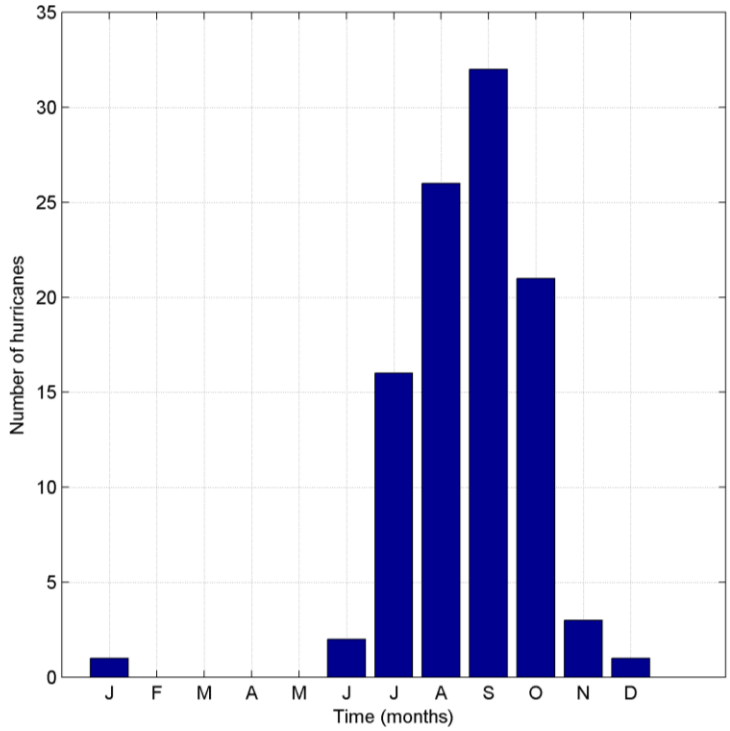
4.3.2.1. Exploring present variability

A tropical cyclone is a system of thunderstorms that shows a cyclonic rotation around a central core or eye. Tropical cyclones typically form over large bodies of relatively warm water and are not is not based on a frontal system, differing from mid-latitude cyclonic storms. The tropical cyclone derive their energy from the evaporation of water from the ocean surface, which ultimately recondenses into clouds and rain when moist air rises and cools to saturation. Each individual tropical cyclone differs, but several characteristics are common to most all tropical cyclones including a central low-pressure zone and high wind speeds of at least 34 knots. At this point, the storms are given a pre-determined storm name. Most storms are accompanied by a lot of rain and storm surges near the shore. Often, once the storms make landfall, the tropical cyclone can cause tornadoes.

When the maximum sustained surface wind of a tropical system ranges from 34 to 63 knots (39 to 73 mph) the tropical cyclone is called Tropical Storm and produce intense rainfall and, often, enough wind and waves to cause some beach erosion and minor boat damage. In the case of maximum sustained surface wind of 64 knots (74 mph) or greater the tropical cyclone is referred as hurricane, consider as the worst and strongest of all tropical systems.

The official Atlantic hurricane season extends from June 1st to November 30th, however, the location of TT makes it being more affected during August and September as shown in the figure below where the histogram of the historical TS and H in the area of influence of Trinidad and Tobago is plotted.

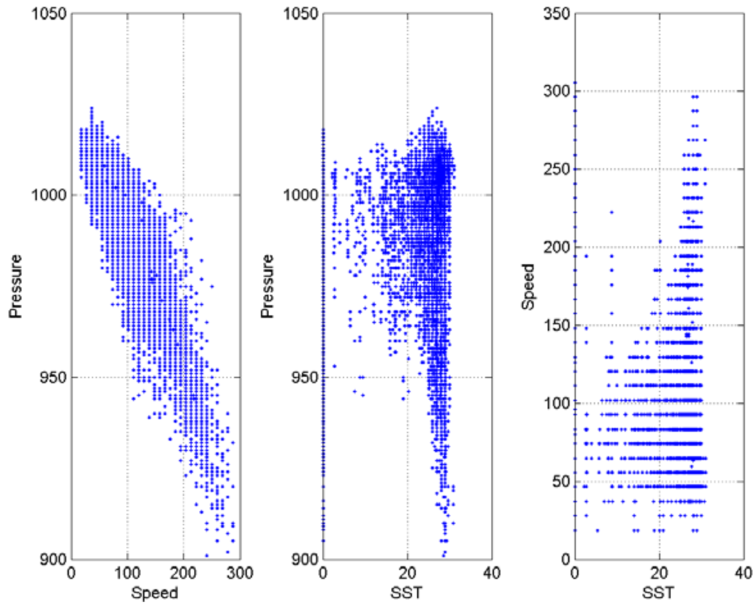
Figure 33: Histogram of the historical TS and H in the area of influence of Trinidad and Tobago.



The dataset of TS and H in Trinidad and Tobago also allows obtaining the annual rate of hurricane events corresponding to 0.7445.

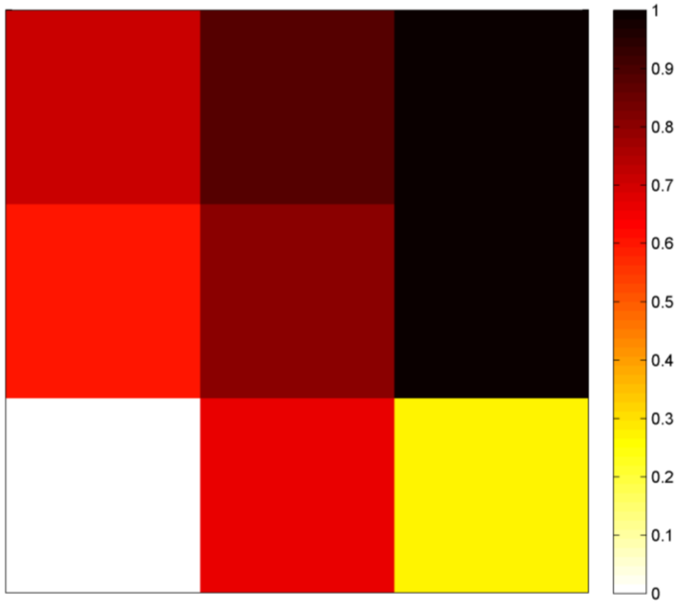
As described below, warm sea surface temperature, specially the gradient between near zones, act as a heat engine that drives the generation of hurricanes. In the figure below one can see that for higher SST, higher hurricane eye pressure and wind speeds, up to a limit of 26°C.

Figure 34: Relationship between hurricane wind speed and pressure and sea surface temperature.



A relationship between El Niño Modoki phase and hurricane events has been already reported. Therefore, using the sea surface temperature patterns of variability performed in previously, a characterization of the interannual variability of hurricanes arriving at Trinidad and Tobago is performed. Projecting the number of hurricanes into the lattice of SST patterns, a connection between oceanic variability and the occurrence of hurricane events in TT is established. First, using the SST anomaly dates, the corresponding number of hurricane events for each cluster is identified. Then, the hurricane rate in terms of annual scale is computed for each SST pattern and shown in the lattice form (See the figure below).

Figure 35: Annual rate of hurricanes associated to SST weather types



This kind of visualization establishes a direct link between the SST pattern and annual hurricane rate in TT. One can see that climatic situations similar to La Niña events, represented in cluster number 7, increases the probability of having hurricanes in TT while El Niño phase (cluster number 2) diminishes this occurrence. The annual rate of hurricane events when La Niña phase reaches 1.2 hurricane/year, and transitional states (clusters 4 and 8) reach 1 and 0.87 hurricanes/year. On the contrary, El Niño stages suppose a minor rate of occurrence. During the historical record of hurricanes, any event occurred during the most intense Niño phase, represented on cluster number 3. However, the previous stage of El Niño phase (cluster 2) characterized by a wider area of warmer water in the Pacific and warm anomalies of SST in the Atlantic suppose a rate of 0.6 hurricanes/year. Also a more primary stage of El Niño phase (cluster 1) supposes 0.7 hurricanes/year.

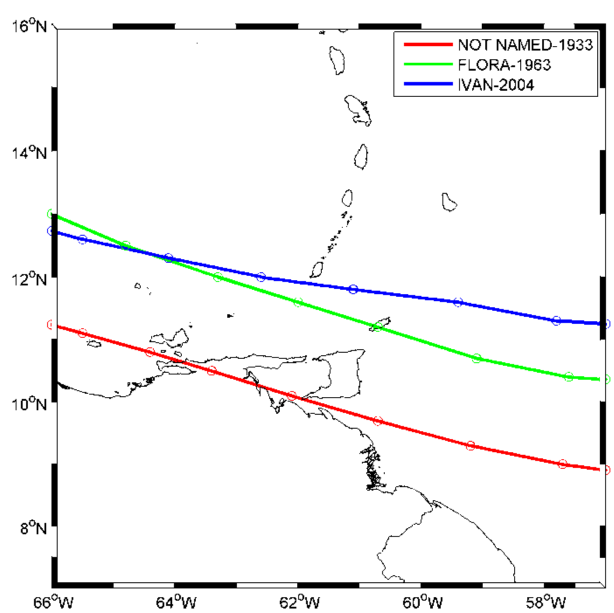
In addition to this information, the probability of occurrence of each SST pattern must be considered in order to properly interpret the variability of hurricane events. Thus, although La Niña phase supposes the higher rate of hurricane events, the probability of occurrence of this phenomenon is 0.07.

4.3.2.2. Main historical hurricanes affecting Trinidad and Tobago

Trinidad and Tobago is located in the extreme south of the Caribbean, which decreases the potential of being hit by hurricane events. However, in the last 161 years 102 TS and H passed in the surroundings of the islands, and, 5 tropical storms and 3 hurricanes impacted directly in TT. The most catastrophic events were the Flora hurricane in 1963, the hurricane event of June 1933, and hurricane Ivan in 2004. Several impacts and damages were reported by the Meteorological Service of Trinidad and Tobago and economic losses associated to this events are reported in CCRIF (2013). This information and the numerical characterization of these events will be used to define the damage functions of hurricane hazard.

The figure below shows the track for the three main historical hurricanes affecting TT. When the hurricanes passed through the area of influence of TT all of them had reached, at least, category 2.

Figure 36: Tracks of the three more catastrophic historical hurricanes affecting TT



The hurricane occurred in June 1933 was generated as a tropical storm in the area north of Surinam and displaced its center developing an eastward track and reaching hurricane category 2 in front of the coasts of Venezuela. The wind speed of each point of the track passing through the area of influence of TT can be seen in the table below.

Table 32: Physical characteristics of the hurricane affecting TT in June 1933
Source: NOAA.

Year	Month	Day	Hour	Longitude (°)	Latitude (°)	Wind Speed (km/h)
1933	6	27	0	56.2	8.8	45
1933	6	27	6	57.7	9	55
1933	6	27	12	59.2	9.3	65
1933	6	27	18	60.7	9.7	70
1933	6	28	0	62.1	10.1	65
1933	6	28	6	63.4	10.5	65
1933	6	28	12	64.4	10.8	60
1933	6	28	18	65.5	11.1	55

The center passage of the hurricane passed over the extreme southwest of Trinidad Island, hitting the region of Cedros. The impact of the hurricane caused severe social damage: 13 people died and 1000 people were rendered homeless. Besides, there were significant property damages, especially in the south of the island. The report CCRIF (2013) informs of a total loss of 54.90128 MUSD.

Hurricane Flora (1963) was the seventh tropical storm and sixth hurricane of the 1963 Atlantic hurricane season and one of the most mortal events in recorded history with a death total of over 7000. Flora arrived at TT hitting Tobago on September 30th with Category 3 hurricane status. Flora developed from a disturbance in the Intertropical Convergence Zone on September 26. After remaining a weak depression for several days, it rapidly organized on September 29 to attain tropical storm status. Flora quickly reached Category 3 and 4 hurricane status and reached maximum sustained winds of 145 miles per hour (233 km/h) in the Caribbean. The table below shows the wind speed and pressure of hurricane Flora in its track over the area of influence of TT.

Table 33: Physical characteristics of hurricane Flora (1963) when passing through the area of influence of TT.

Source: NOAA.

Year	Month	Day	Hour	Longitude (°)	Latitude (°)	Wind Speed (km/h)	Pressure (mb)
1963	9	30	0	56	10.3	70	-
1963	9	30	6	57.6	10.4	85	-
1963	9	30	12	59.1	10.7	100	994
1963	9	30	18	60.7	11.2	105	978
1963	10	1	0	62	11.6	110	981
1963	10	1	6	63.3	12	110	981
1963	10	1	12	64.8	12.5	115	974
1963	10	1	18	66	13	115	975

The Meteorological Service of Trinidad and Tobago reported several effects and damages from this hurricane event. About four hours before the eye of Hurricane Flora moved over Tobago, it began producing heavy rainfall throughout the island. Two hours later, strong winds began affecting the island, and, while moving across, Flora produced winds of up to 100 miles per hour (160 km/h). After leaving Tobago, the hurricane produced rough surf and tides 5 to 7 feet (1.5 to 2.1 m) above normal. The hurricane sunk six ships between 4 to 9 tons in Scarborough harbour and one crew member drowned while attempting to save his vessel. Heavy rainfall caused a large mudslide from Mount Dillon onto a road leading to Castara. This was considered the most well-known mudslide on the island. The strong winds caused severe damage to coconut, banana, and cocoa plantations with 50% of the coconut trees being destroyed and another 11% being severely damaged. 75% of forest trees fell, and most of the remaining were greatly damaged. The passage of Hurricane Flora destroyed 2.750 of Tobago's 7.500 houses and damaged 3.500 others. The hurricane killed 18 on the island and resulted in $30 million in crop and property damage (1963 USD). Furthermore, CCRIF (2013) reports a total loss of 299.35931 MUSD.

Finally, hurricane Ivan (2004) were the third major hurricane (in terms of damage) affecting TT. It was the fourth major hurricane of the active 2004 Atlantic hurricane season and became the 10th most intense Atlantic hurricane ever recorded. Ivan formed in early September as a tropical depression southwest of Cape Verde. As the system moved to the west, it strengthened gradually, becoming Tropical Storm Ivan on September 3 and reaching hurricane strength (on September 5) 1.150 miles (1.850 km) to the east of Tobago. Later that day, the storm intensified rapidly becoming a Category 3 hurricane with winds of 125 miles per hour (200 km/h) (Stewart 2006). Wind speed and pressure of hurricane Ivan (2004) where passing through the area of influence of TT can be seen in the table below.

Table 34: Physical characteristics of hurricane Ivan (2004) when passing through the area of influence of TT.

Source: NOAA.

Year	Month	Day	Hour	Longitude (°)	Latitude (°)	Wind Speed (km/h)	Pressure (mb)
2004	9	7	0	56.1	11.2	90	964
2004	9	7	6	57.8	11.3	95	965
2004	9	7	12	59.4	11.6	100	963
2004	9	7	18	61.1	11.8	105	956
2004	9	8	0	62.6	12	115	950
2004	9	8	6	64.1	12.3	120	946
2004	9	8	12	65.5	12.6	120	955
2004	9	8	18	67	13	120	950

Several damages were reported by the International Federation of Red Cross and Red Crescent Societies. The damage in Trinidad was minimal while in Tobago there were power outages in parts of the island mainly as a result of downed lines. Besides, 14 villages were affected and at least 23 homes lost part or all of their roofing. The Trinidad branch of the National Society deployed vehicles to Tobago to assist with relief efforts together with food and personnel (Red Cross and Red Crescent Societies, 2004). Total losses are estimated in a total number of 34.111016 MUSD (CCRIF 2013).

4.3.2.3. Numerical Modeling

In the previous sub-section the main hurricanes affecting TT have been described in terms of physical characteristics and damages reported. However, a better characterization of the hurricanes will include the spatial variability of the effects caused during each event in terms of wind, storm surge and waves. This information will provide a solid knowledge to understand the nature of the hazard and its impacts and consequences. In order to achieve this spatial characterization a numerical modeling has been carried out.

Three numerical models have been used to simulate the different effects caused by hurricanes: the large winds generated by pressure gradients, the storm surge and the waves. However, the storm surge and waves are directly related to the wind fields as derive processes. Therefore, the wind fields simulated for each instant of the hurricanes will be the inputs of the models used to simulate the storm surge and waves. Based on previous studies and bibliography, the numerical models used in this study are the Vortex Model for simulating wind fields from hurricane events, the H2D model for simulating hydrodynamic processes and the SWAN model for simulating wave fields. Following a brief description for each model is carried out.

4.3.2.3.1. Hidromet-Rankin Vortex model

The wind velocity and direction associated to each hurricane instant of the track have been calculated using a parametric model. It is based on the Hydromet-Rankin Vortex model presented by Holland (1980) and the Bretscneider (1990) approximation. This model has been implemented and validated with buoy data and satellite borne synthetic aperture radar for several historical hurricane events, Silva et. al (2002). The pressure Pr, (in mb) and wind W (above 10 m above mean sea level, in km/h), models are described with the following equations:

$$P_r = P_0 + \left(P_N - P_0\right) \cdot e^{\left(-\frac{R}{r}\right)} \qquad (1)$$

$$W = 0.886\left(F_V \cdot U_R + 0.5 \cdot V_F \cos\left(\theta + \beta\right)\right) \qquad (2)$$

$$U_R = 21.8 \cdot \sqrt{P_N - P_0} - 0.5 \cdot f \cdot R \qquad \text{for} \qquad \frac{r}{R} < 1 \qquad (3)$$

$$U_R = 21.8 \cdot \sqrt{P_N - P_0} - 0.5 \cdot f \cdot R \qquad \text{for} \qquad \frac{r}{R} \geq 1 \qquad (4)$$

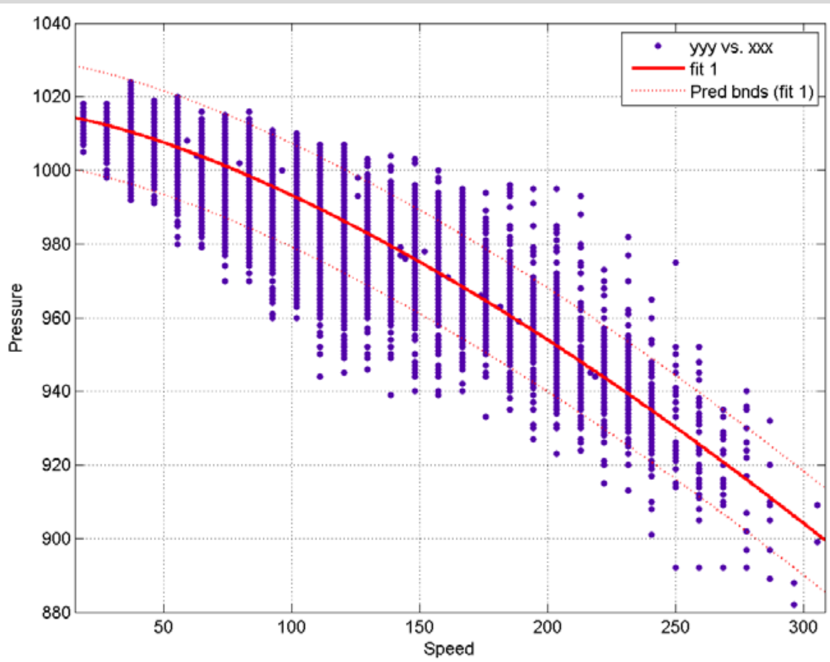
Where, P0 is the central hurricane pressure (mb); Pr is the pressure at any radial distance (km); PN is the unaltered atmospheric pressure (commonly assumed 1013 mbar); R is the cyclostrophic wind radius (km); f is the Coriolis parameter; $f = 2\omega \sin(\phi)$; ω is the angular Earth speed ($\omega = 0.2618 rad/h$); and ϕ is the latitude; r is a radial distance measured from the centre of the atmospheric perturbation; $\theta + \beta$ is the angle between the total translation speed of the hurricane VF (km/h) and the wind speed at a radial distance UR (km/h); FV is a damping factor which is calculated trough the following relations:

$$A = -0.99 \cdot \left(1.066 - \exp\left(-1.936 \cdot \left(\frac{f \cdot R}{U_R}\right)\right)\right) \qquad (1)$$

$$B = -0.357 \cdot \left(1.4456 - \exp\left(-5.2388 \cdot \left(\frac{f \cdot R}{U_R}\right)\right)\right) \quad (2)$$

In order to obtain the spatial and temporal wind maps, it is necessary to know, at each time step, the central pressure, the hurricane track and the evolution of the cyclostrophic radius. This information is obtained from the HURDAT historical database, provided by NOAA's Atlantic Oceanographic and Meteorological Laboratory, for the three historical hurricanes selected: the hurricane of June 1933, hurricane Flora in 1963 and hurricane Ivan in 2004. Since this database does not include the cyclostrophic radius, it is obtained with the relation proposed by Silva et al. (2002). Besides, in those cases when the central pressure of some points of the track is not include, a regression model (See the figure below) relating wind and pressure in the eye of the hurricane has been used.

Figure 37: Regression model used to obtain the central pressure based on the wind fields.



4.3.2.3.2. Hydrodynamic model H2D

The numerical model used to solve hydrodynamic processes is the H2D model developed by the Ocean and Coastal Research Group at the University of Cantabria. It solves the Navier-Stokes equations for an incompressible fluid, under the shallow water and the Boussinesq assumption.

The numerical model integrates the depth-averaged equations of continuity, momentum and diffusion over a finite grid. The equations, in Cartesian coordinates have the next form:

Mass conservation:

$$\frac{\partial (UH)}{\partial x}+\frac{\partial (VH)}{\partial y}+\frac{\partial \eta}{\partial t}=0 \tag{3}$$

Momentum conservation:

$$\begin{aligned}&\frac{\partial (UH)}{\partial t}+U\frac{\partial (UH)}{\partial x}+V\frac{\partial (UH)}{\partial y}=fVH-\frac{1}{\rho_0}\frac{\partial \mathrm{P_a}}{\partial x}-gH\frac{\partial \eta}{\partial x}-\frac{g}{2\rho_0}H^2\frac{\partial \rho_0}{\partial x}\\&-\frac{g}{\rho_0}\int_{-h}^{\eta}\left[\frac{\partial}{\partial x}\int_{z}^{\eta}\rho'\cdot dz\right]dz+\tau_{xz(\eta)}-\tau_{xz(-h)}\\&+H\varepsilon_h\left[\frac{\partial^2 U}{\partial x^2}+\frac{\partial^2 U}{\partial y^2}\right]+2H\frac{\partial \varepsilon_h}{\partial x}\frac{\partial U}{\partial x}+H\frac{\partial \varepsilon_h}{\partial y}\left[\left(\frac{\partial U}{\partial y}+\frac{\partial V}{\partial x}\right)\right]\end{aligned} \tag{4}$$

$$\begin{aligned}&\frac{\partial (VH)}{\partial t}+U\frac{\partial (VH)}{\partial x}+V\frac{\partial (VH)}{\partial y}=-fUH-\frac{1}{\rho_0}\frac{\partial \mathrm{P_a}}{\partial y}-gH\frac{\partial \eta}{\partial y}-\frac{g}{2\rho_0}H^2\frac{\partial \rho_0}{\partial y}\\&-\frac{g}{\rho_0}\int_{-h}^{\eta}\left[\frac{\partial}{\partial y}\int_{z}^{\eta}\rho'\cdot dz\right]dz+\tau_{yz(\eta)}-\tau_{yz(-h)}\\&+H\varepsilon_h\left[\frac{\partial^2 V}{\partial x^2}+\frac{\partial^2 V}{\partial y^2}\right]+2H\frac{\partial \varepsilon_h}{\partial y}\frac{\partial V}{\partial y}+H\frac{\partial \varepsilon_h}{\partial x}\left[\left(\frac{\partial U}{\partial y}+\frac{\partial V}{\partial x}\right)\right]\end{aligned} \tag{5}$$

Diffusion equations for temperature, T and salinity, S (here both are denoted as C):

$$\frac{\partial C}{\partial t}+U\frac{\partial C}{\partial x}+V\frac{\partial C}{\partial y}=\frac{1}{H}\frac{\partial}{\partial x}\left(HD_x\frac{\partial C}{\partial x}\right)+\frac{1}{H}\frac{\partial}{\partial y}\left(HD_y\frac{\partial C}{\partial y}\right) \tag{6}$$

where, x, y, z form the right-handed Cartesian coordinate system, U and V are the depth- averaged velocity components, H=η+h, where H is the total water column, η is the free surface and h is the depth. The term f represents the Coriolis parameter, Pa is the atmospheric pressure, εh is the horizontal (Smagorinsky, 1963) eddy viscosity coefficient, D_x and D_y are the horizontal diffusivity coefficients and $\rho = \rho_0+\rho'$ is the water density, with, ρ0 being the reference viscosity. $\tau_{XZ(\eta)}$ and $\tau_{YZ(\eta)}$ are the free surface wind-induced stresses, parameterized in terms of a quadratic law of wind speed. Density is obtained from the values of T and S using the UNESCO equation of state, as adapted by Mellor (1993).

Model equations are written on a staggered grid (Arakawa C) and are solved by means of an implicit finite difference method (Leendertse, 1970), except for non linear terms, which are treated explicitly. The finite difference algorithm is a centered, two time levels scheme, resulting in a second order approximation in space and time.

4.3.2.3.3. SWAN wave model

The model used to simulate and propagate waves into shallow waters is the SWAN model. It is a third-generation wave model for obtaining realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bottom and current conditions. The model is based on the wave action balance equation with sources and sinks and resolves the energy equation through the Eulerian approximation (Booij and Ris 1999).

The theoretical based is one of the main attractive of this model, which is the possibility of propagating waves in all directions. Besides, it is possible to apply this kind of models to large domains since it does not require a minimum number of calculating points for each wave length. Besides, the third generation of the model includes shallow water phenomena such as wave breaking and non-linear interactions (triads). Due to the fact that this is an energetic model it is possible to simulate the wind wave generation.

The equation solved by the SWAN model is:

$$\frac{\partial N}{\partial t}+\frac{\partial c_x N}{\partial x}+\frac{\partial c_y N}{\partial y}+\frac{\partial c_\sigma N}{\partial \sigma}+\frac{\partial c_\theta N}{\partial \theta}=\frac{S}{\sigma} \quad (7)$$

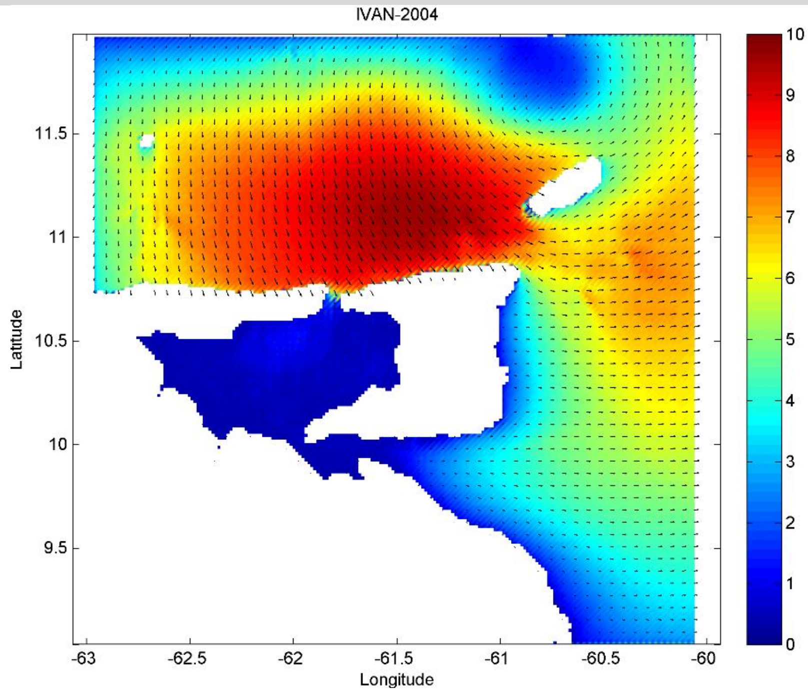
$$N(\sigma,\theta)=\frac{E(\sigma,\theta)}{\sigma} \quad (8)$$

It is an energy balance equation in which local temporal variations of spectral energy and space variations of energy flux are compensated with inputs and outputs of energy throughout the system.

In this study, the grid used to perform the model is a recti-linear structured grid with a resolution of 1500 m.

The figure below shows the wave field generated by hurricane Ivan in 2004 in one position of the track. One can see significant wave height of more than 7 m in the north coast of Trinidad Island, while the Trinidad coasts of the Gulf of Paria do not reach 1 m height.

Figure 38: Significant wave height (m) generated by hurricane Ivan in the instant of 19 pm on September 9th 2004.



4.3.2.4. Associated impacts to hurricane events

As shown before, the main effects of the hurricane events are wind, storm surge and waves, and rainfall. The storm surge and waves will develop coastal flooding, while heavy rainfall could generate inland flooding and, depending on the soil conditions, landslides. The wind, apart from a hurricane effect can be considered also as an impact. Thus, these meteorological effects will develop impacts both in the coast and in the inland territory.

4.3.2.4.1. Coastal Flooding

Coastal flooding occurs when intense, offshore low-pressure systems drive ocean water inland. The rising water level due to winds and low pressure is called storm surge. Besides, the waves also produce an elevation of the water level called set up, and other factors such as astronomical tide and sea level rise contribute also to coastal flooding.

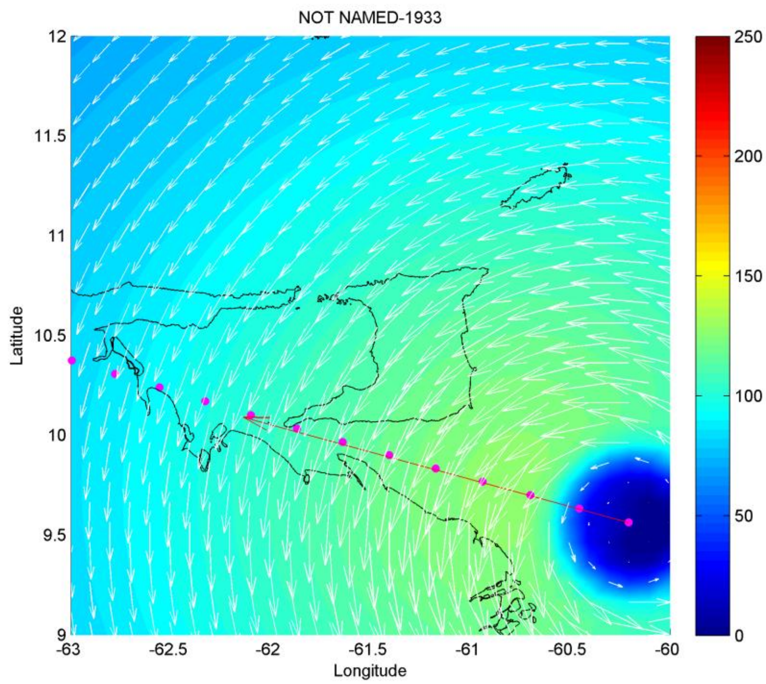
In the case of hurricane events in TT the coastal flooding is mainly driven by the storm surge and wave set up. The low pressure and heavy winds push water up generating storm surge in the coast, but, at the same time, the maintained winds blowing in a certain area of the ocean generate waves that arrive at the coast contributing to the coastal flooding. Thus, the coastal flooding has been calculating as shown in equation 13, considering a contribution of waves as a 30% of the significant wave height in the coast.

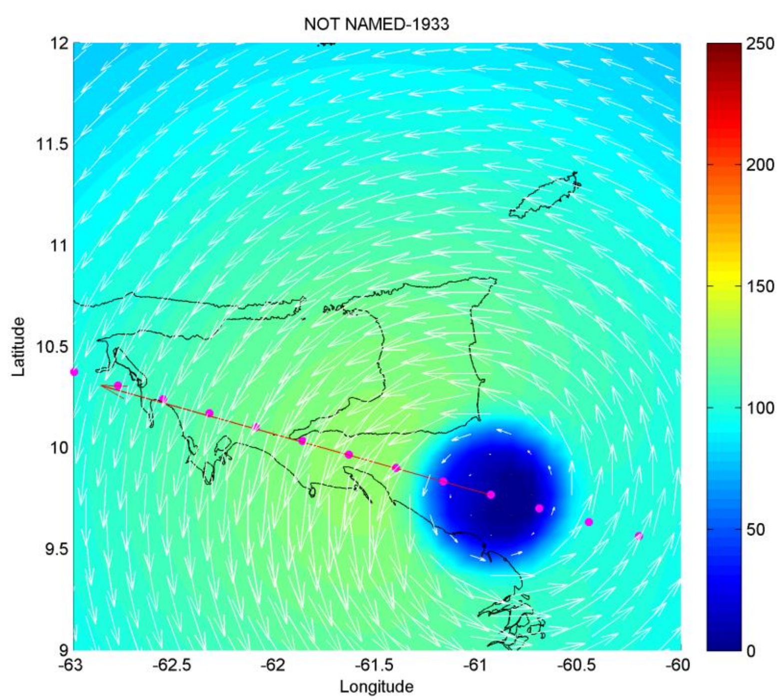
$$CF = SS + 0.3 \cdot H_s \qquad (9)$$

The coastal flooding has been calculated in the receptor points along the coasts of TT for the three historical hurricanes selected. The maps plotted in the three figures below show the maximum coastal flooding generated by each hurricane. The main differences can be appreciated between the hurricane of 1933 and the other two due to the different track followed by the hurricane.

The track followed by hurricane of 1933 passed between the coasts of Venezuela and south of TT, crossing through the narrow strait between the southwest tip of TT and Venezuela with Category 2 hurricane status. The next figure shows the wind fields generated in three instants of the track of the hurricane in its passage through TT. One can see that the most intense winds affecting TT occurred 6 hours before the hurricane hit the southwest of Trinidad Island, which corresponds to 18 pm on June 27th. The counterclockwise rotating system introduced severe winds mainly in the east coasts of Trinidad Island, generating the higher levels of coastal flooding due to both storm surge and waves (up to 2 m in the coasts of Mayaro and Melajo/Manzanilla. The accompanied movement of the hurricane along its track contributes to the storm surge generated by the low pressure in the eye of the hurricane. Therefore, high levels of coastal flooding can be also appreciated in the southwest tip of TT (between 1.5 and 2 m of coastal flooding).

Figure 39: Wind fields generated by hurricane of 1933 in its passage through TT





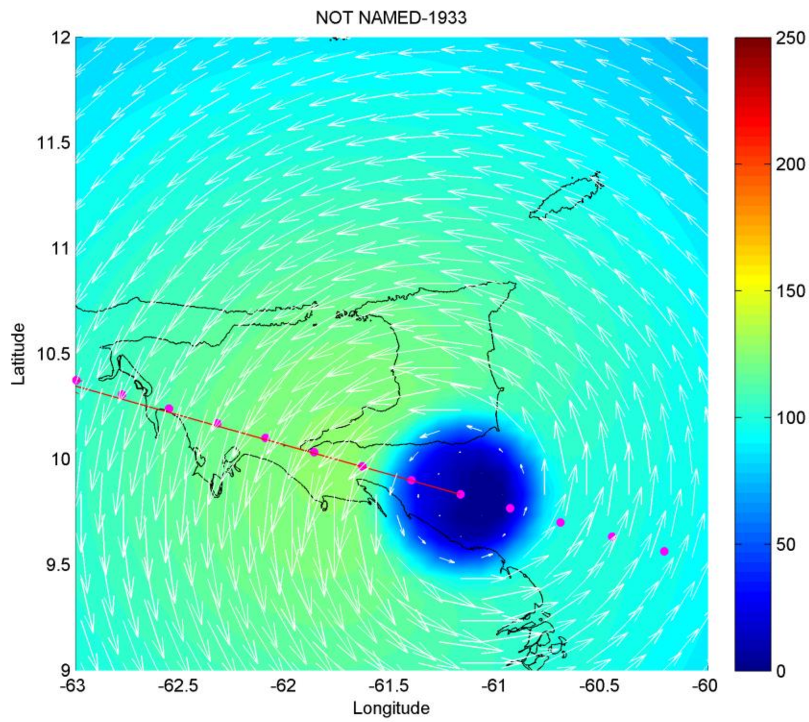
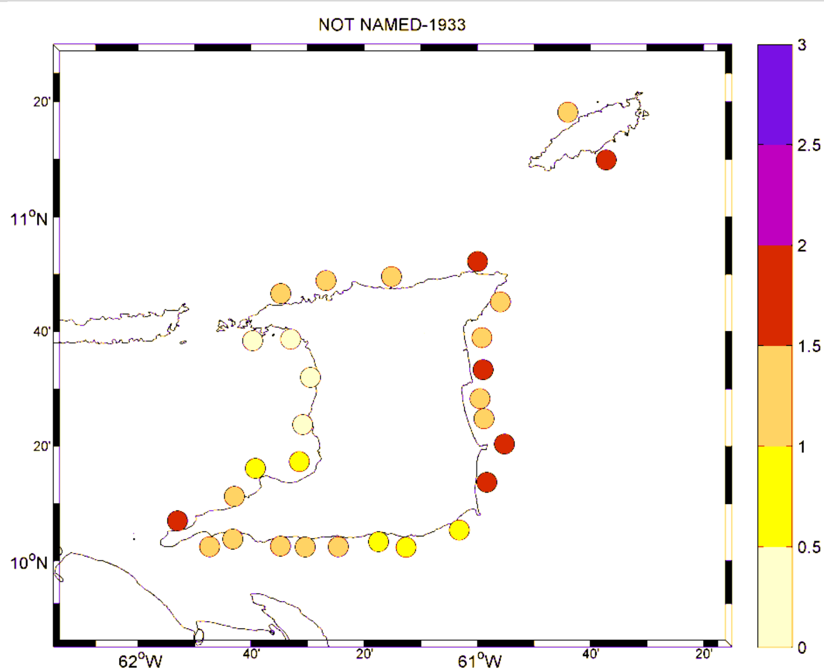


Figure 40: Maximum coastal flooding generated by the hurricane of June 1933 in TT.



In the case of Flora (1963) and Ivan (2004) hurricanes the spatial patterns of coastal flooding follow a similar distribution, with slight differences in the intensity of flooding levels in Tobago and the north coasts of Trinidad (the figures below). Hurricane Flora generated coastal flooding levels up to 2.5 m in the north coasts of Trinidad Island and up to 2 m in the west coast of Tobago, while hurricane Ivan generated higher levels in the west coast of Tobago and the north eastern tip of Trinidad (up to 2.5 m of flooding level). In the Gulf of Paria both hurricanes generated coastal flooding levels up to 2 m in important places such as San Fernando or Point Fortin. This part of the coast is the most populated and houses the main economic activities of the island, making it vulnerable, especially to coastal flooding.

Figure 41: Maximum coastal flooding generated by hurricane Flora in 1963 in TT.

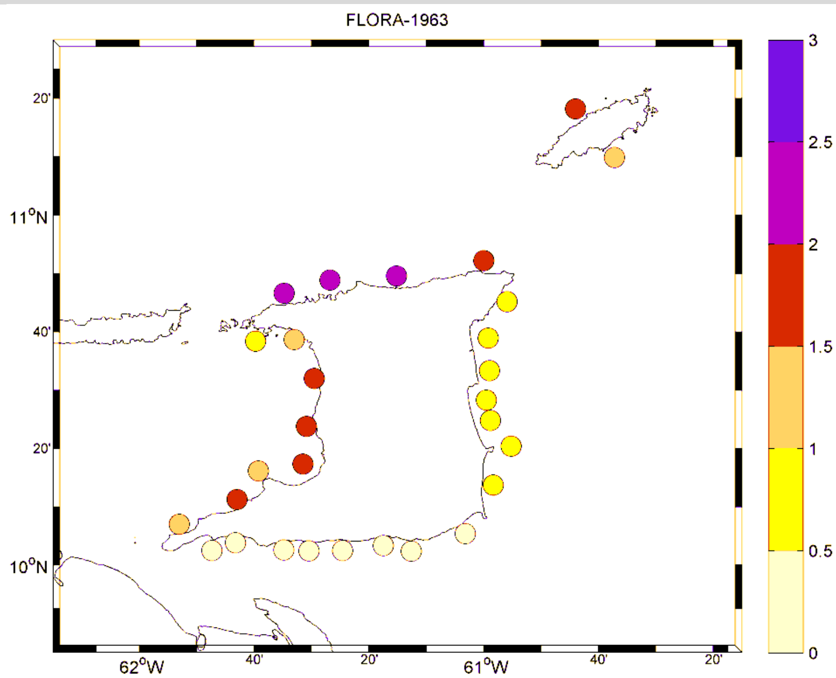
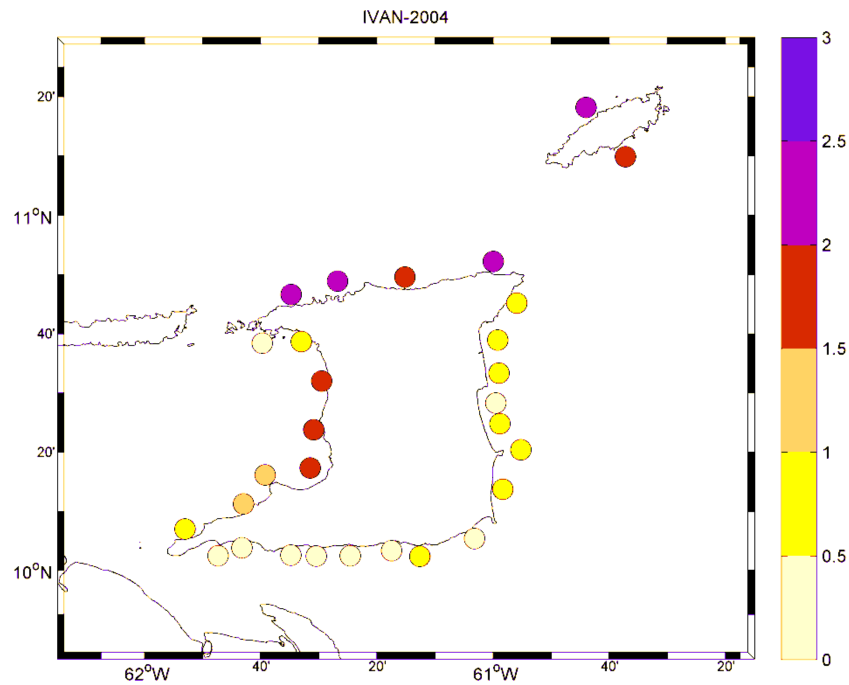
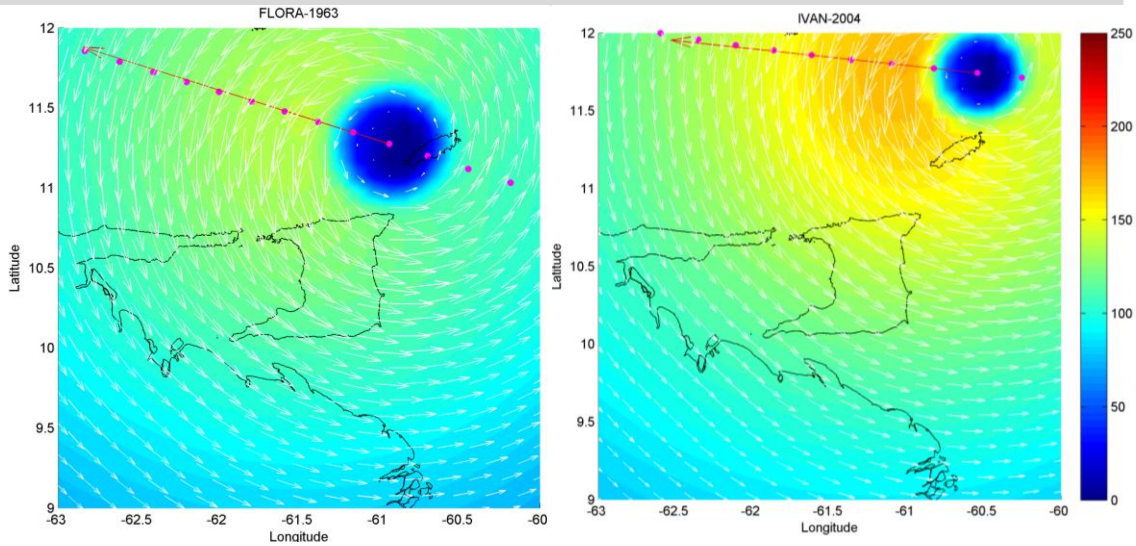


Figure 42: Maximum coastal flooding generated by hurricane Ivan in 2004 in TT



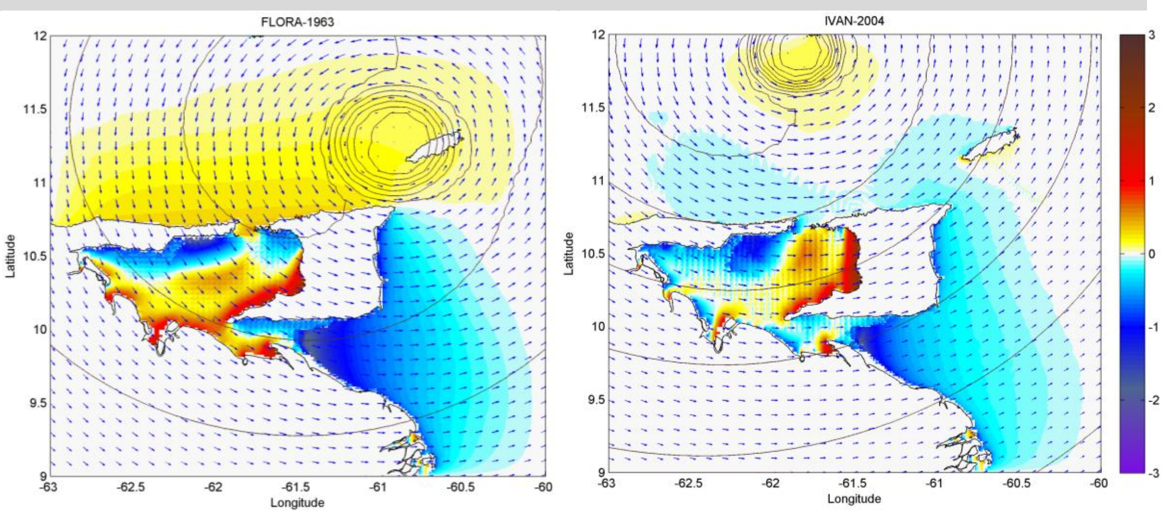
In these cases the track in their passages through the area of influence of TT where quite similar differing in the intensity and distance to Tobago Island (while Flora passed over Tobago Island, Ivan passed some kilometer northern Tobago with lower pressure level in its eye). The figure below shows the higher wind fields generated by hurricanes Flora and Ivan that affected TT. One can see that, although Ivan passed farther than Flora its intensity and configuration generated higher winds affecting the west part of Tobago Island and the eastern tip of Trinidad.

Figure 43: Wind fields generated during hurricane Flora (left panel) and hurricane Ivan (right panel) in their passage through Tobago Island.



The figure below shows the spatial distribution of two instants of the track of Flora and Ivan hurricanes. In the case of Flora the instant plotted is the same as the wind field in the figure above, which generates the highest water levels in the Gulf of Paria, especially in San Fernando and Point Fortin. In the case of Ivan, the instant plotted also generates the highest water levels in this part of the coast of Trinidad, but, as can be seen, it corresponds to a northwest displacement of the eye of the hurricane. This information provides some of the explanation for the coastal flooding obtained, but the part corresponding to the waves set up must be also taking into account.

Figure 44: Spatial distribution of storm surge generated in TT during two instants of the track of hurricanes Flora (left panel) and Ivan (right panel).



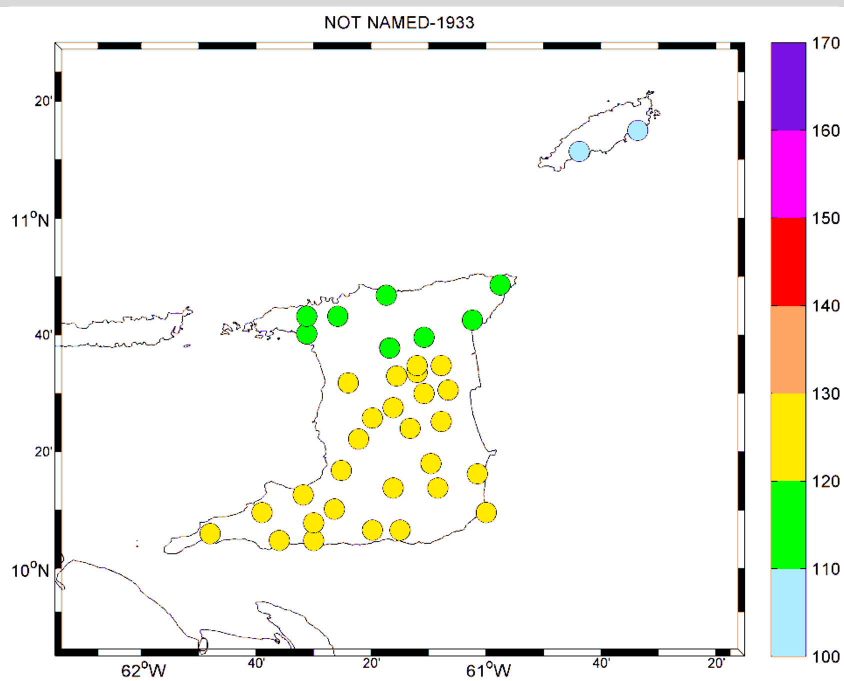
4.3.2.4.2. Wind

The wind generated by the hurricanes is considered as an impact itself. Apart from generating coastal flooding, which is already considered in the previous sub-section, the wind can generate damage in the inland system. Thus, the agricultural sector can be affected by the destruction or damage of trees or crops, the human settlements can be damage, especially roof houses or power outages, etc.

The wind impact has been obtained from the wind fields evaluated for each hurricane with the Hidromet-Rankin Vortex model. Wind intensity has been plotted in each inland point selected.

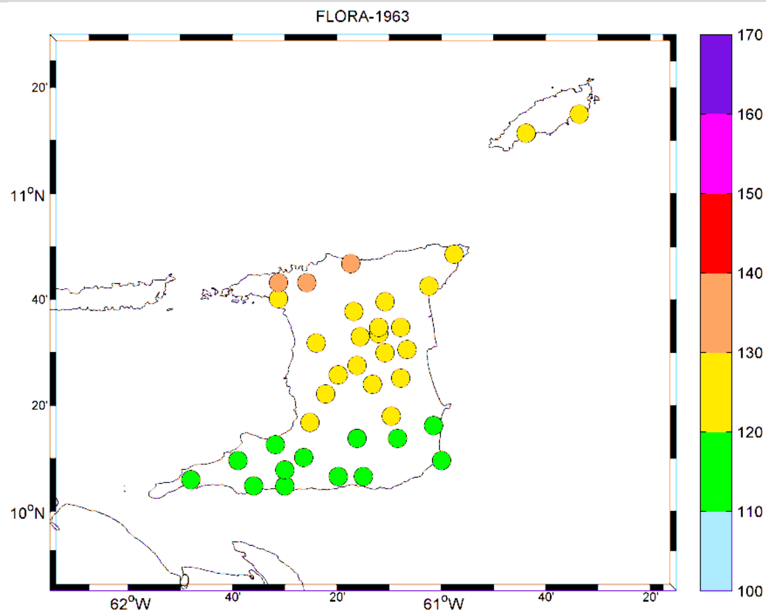
The figure below shows the maximum wind velocity generated by the hurricane of 1933 in the receptor inland points. One can see higher velocities in the south of Trinidad (up to 127 km/h) decaying to 115 km/h in the north parts of the island and 100 km/h in Tobago. This pattern of variability is accorded to the center passage of the hurricane.

Figure 45: Maximum wind velocity (km/h) in the receptor inland points for the hurricane of 1933.



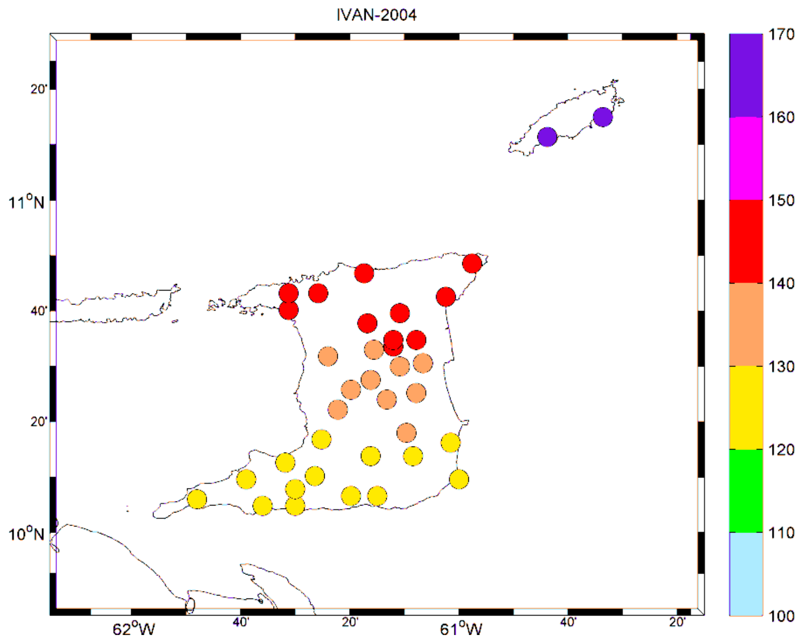
Hurricane Flora shows a different pattern of wind variability along the inland points (see the figure below). One can see the higher wind speeds (up to 130 km/h) in the North West parts of Trinidad Islands (Maracas and Diego Martin regions) and a decrease while moving to southern regions (up to 130 km/h in the center of the island and 115 km/h in the south. Tobago suffered lower wind velocities than the north of Trinidad due to the fact that the eye of the hurricane passed over Tobago, having no winds in the hurricane eye.

Figure 46: Maximum wind velocity (km/h) in the receptor inland points for the hurricane Flora in 1963.



Finally, hurricane Ivan (the figure below) shows a quite similar wind spatial distribution to Flora hurricane (the figure above) In this case, the main difference lies in the north displacement of the hurricane eye and the lower pressure that generated higher wind speed affecting mainly Tobago Island (up to 162 km/h). In this case Trinidad Island suffered a gradually decrease in the wind speed generated by hurricane Ivan when moving southwards. In the north of the island wind speed reaches 150 km/h (for example the case of Port of Spain) while in the south the wind intensity reaches 127 km/h (in the case of Point Fortin).

Figure 47: Maximum wind velocity (km/h) in the receptor inland points for the hurricane Ivan in 2004.

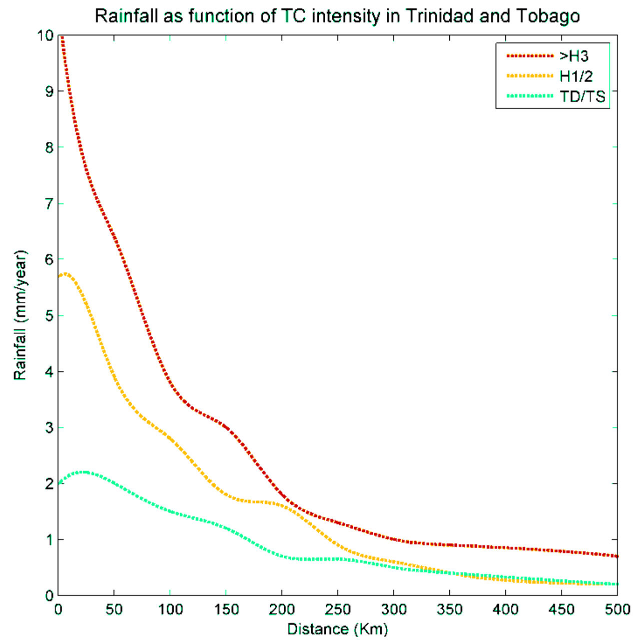


4.3.2.4.3. Rainfall

The heavy rainfalls associated to hurricane events constitute an important impact, especially for the inland system. Considering the topography and the soil conditions, the intense rainfalls can generated severe inland flooding and derived landslides.

The rainfall associated to a hurricane event has been calculated using the curves developed by Marks and Steward (2001) that relates tropical storm rainfall with eye distance and TS intensity. This study was performed using Tropical Rainfall Measuring Mission Microwave Imager and Precipitation Radar data (TRMM MI/PR) and provides good quantitative TS rain estimates. In this case, the curves have been calibrated to TT using the daily precipitation measures from Piarco and La Regalada rainfall gauges for the TS Fran in 1990, Bret in 1993, Joyce in 2000 and hurricane Ivan in 2004. The adapted rainfall curves for TT are shown in the figure below.

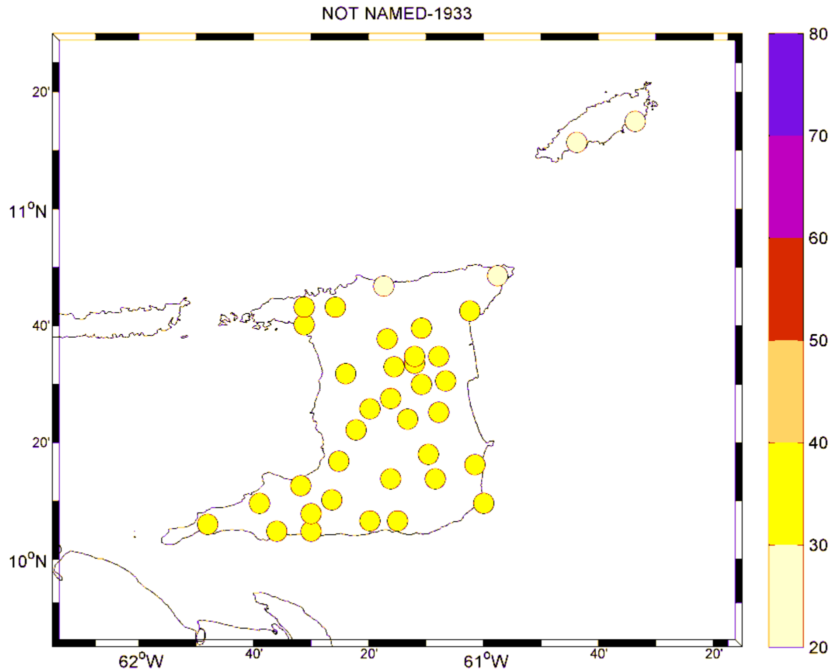
Figure 48: Rainfall as function of TS intensity. Adapted from Marks and Steward (2001) to TT.



Using the relationship between eye distance and TS category the total rainfall for each historical hurricane has been calculated in each inland point. It is considered that the active hurricane in terms of rainfall corresponds to the track passing along the area of influence of TT, which corresponds generally to two days.

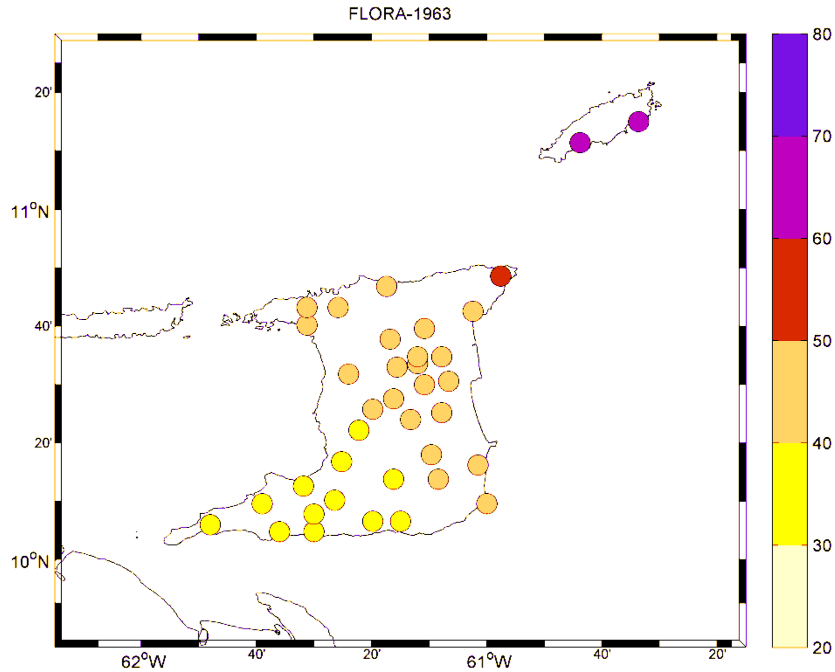
The figure below shows the maximum rainfall in each inland point generated by the passage of the hurricane in 1933. The spatial pattern shows a wide and quite homogeneous rainfall field, with maximum values in the south of Trinidad, close to the eye of the hurricane (in the range of 32-36 mm/2 days). Tobago experienced lower precipitations, up to 23 mm/2 days.

Figure 49: Maximum rainfall (mm/2 days) in the receptor inland points for hurricane of 1933 during its passage through the area of influence of TT.



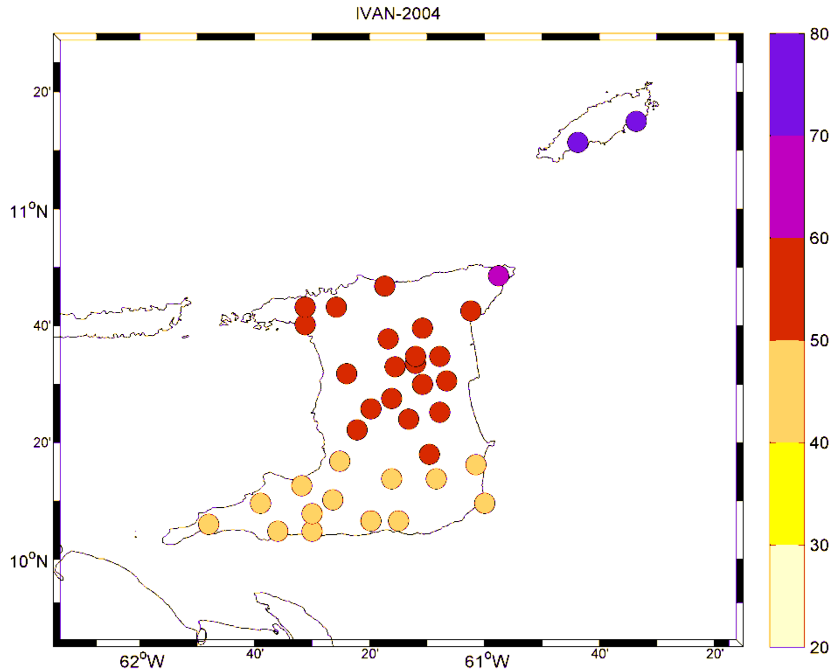
Hurricane Flora presented a more variable rainfall field (See the figure below), with maximum precipitations in Tobago (up to 65 mm/2 days) directly under the influence of the eye hurricane. The northeast tip of Trinidad presented up to 52 mm/2 days of rainfall and the quantity of rainfall decay with distance registering 33 mm/2 days in the southwestern regions.

Figure 50: Maximum rainfall (mm/2 days) in the receptor inland points for hurricane Flora in 1963 during its passage through the area of influence of TT.



Finally, hurricane Ivan shows a spatial pattern of rainfall variability in TT quite similar to Flora hurricane due to the similarity in their tracks. In this case, the southwestern track direction of the hurricane and lower translation speed or the eye leaded into a higher accumulated quantity of rainfall, as shown in the figure below. Tobago suffered the higher rainfall levels (up to 75 mm/2 days) together with the northeastern tip of Trinidad Island, where up to 61 mm/2 days were expected.

Figure 51: Maximum rainfall (mm/2 days) in the receptor inland points for hurricane Ivan in 2004 during its passage through the area of influence of TT.



4.3.3. Droughts

Droughts have been identified as another primary hazard in TT susceptible of climate change. This natural hazard can cover extensive areas and last for many years with devastating impacts on agriculture, water supply and the environment. Historically, drought has persistently affected human activity (Stine 1994; Hodell et al. 1995) and impacts on every part of the globe. Economic and social development have historically been strongly linked to the development of water resources and the breakdown of this connection might have contributed to the fall of great civilizations (Sheffield and Wood 2011). In term s of economic cost drought may be one of the most damaging natural hazards (Wilhite 2000).

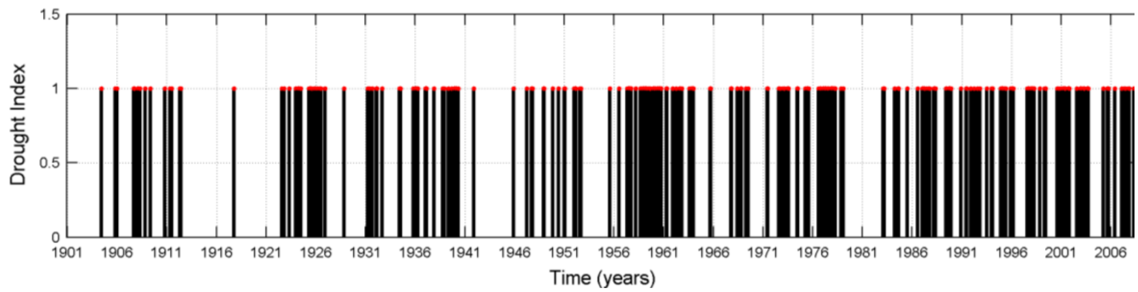
The simplest definition of drought is a deficit of water relative to normal conditions, which are governed by the hydrological cycle. The hydrological cycle describes the movement of water through the atmosphere, land and oceans and its major components are precipitation, evaporation, run off and snow, soil and groundwater. Depending on the nature of the water deficit and the objectives of its use, several definitions have been established (Palmer 1965; Rasmussen et al. 1993; Heim, 2002). Typically droughts are classified into four groups: meteorological, hydrological, agricultural and socio economic drought.

Meteorological drought only considers climate variables, being a significant negative deviation from mean precipitation. Hydrological drought includes the water supply factor, considering drought as a deficit in the supply of surface and subsurface water. In the case of agricultural drought the meteorological and hydrological drought drive a deficit in the supply of soil moisture for vegetation and finally, the socio-economic drought is considered as a combination of the other three types leading social and economic impacts.

The study of drought requires data to quantify and model its variability, cycles and possible long-term changes. There are some ways to identify and characterize drought but one of the most used are drought index. A drought index is a quantitative expression for the state of drought that allows policy makers to objectively analyze a system and make quantitative management and policy decisions. Usually a threshold is chosen below which there is drought and above which there is not. The index should capture the physical characteristics and associated impacts of a drought: the start and end of a drought, its duration, its intensity, magnitude… However, quantifying all of these characteristics is extremely difficult in only one index. Due to this fact various indices and definitions have been suggested, each with advantages and disadvantages. One of the most popular index used for agricultural drought is the Palmer Drought Severity Index (PDSI), Palmer 1965), which is used by many US agencies as a drought trigger.

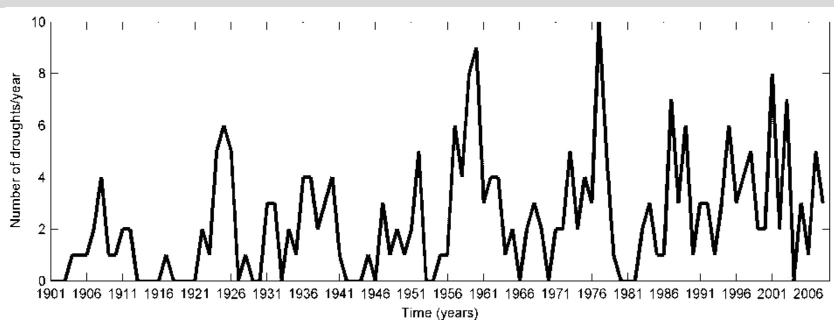
In this study a drought index kindly provided by Dr. Sheffield is used. This drought index comes from a global drought model characterizing drought in TT as a unique value of the drought index in a monthly temporal scale. The time series spans from 1901 to 2008 and consist on a boolean variable, 1 in the case of drought and 0 otherwise with monthly resolution (See the figure below).

Figure 52: Drought index monthly time series for TT.



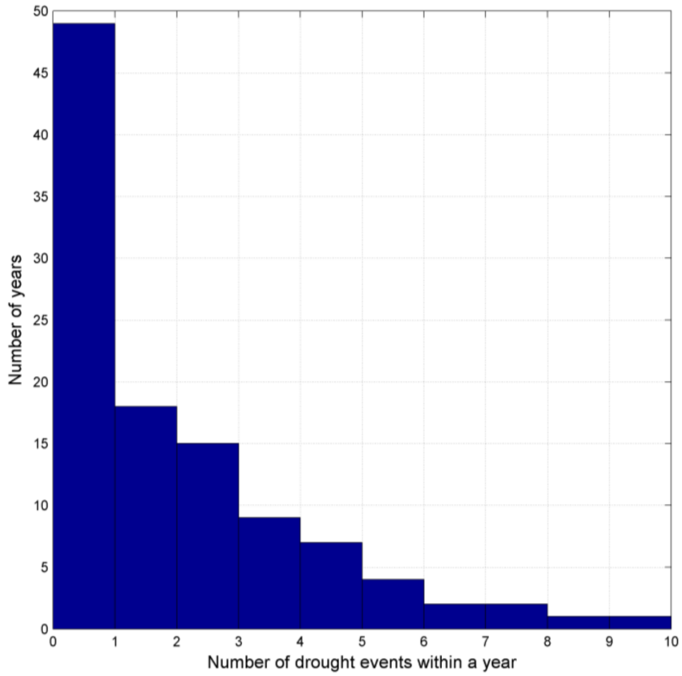
In order to understand and characterize the droughts in TT a statistical analysis is performed to the drought index. First the histogram of the number of drought events in each month of the year is plotted (See the figure below). As can be seen it does not reveal any seasonal variability or further information. Thus, the drought index has been turn into an annual scale, counting the number of drought events (drought index = 1) within a year. The time series is shown in the upper panel of the figure reveals a clear interannual variability with severe dry years such as 1960 and 1977 with 9 and 10 drought events.

Figure 53: Time series of total annual droughts per year in TT.



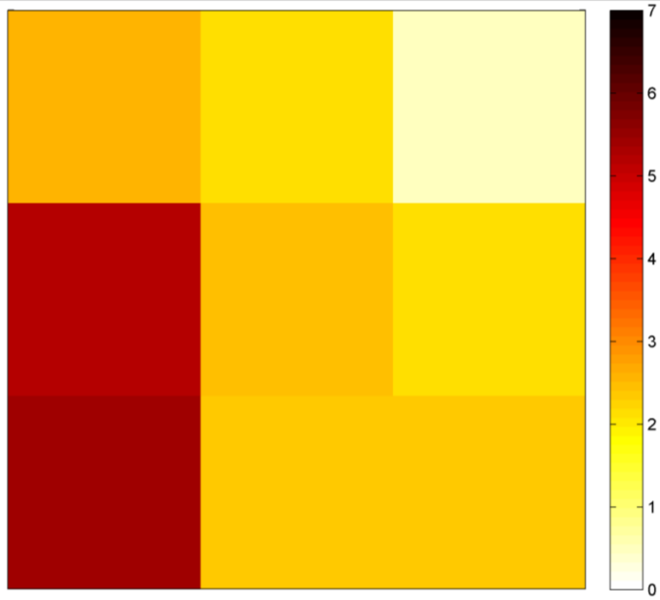
The histogram computed for the annual drought events is shown in the figure below. One can see that almost 50 years from the 107 years studied did not suffer any drought event, being the absence of drought the most probable situation. Besides, the shape of the histogram reveals a behavior of the intensity of droughts that could be modeled through the Generalized Pareto Distribution.

Figure 54: Histogram of the annual drought events in TT.



The interannual variability identified is studied through the SST patterns of variability described in section 4.3.2.1. The dependency of drought in climate variations and the relationship between SST and low frequency phenomena such as El Niño that entail high amounts of precipitation in some parts of the globe make the SST pattern a good predictor for exploring drought variability. The projection of the drought events in the SST lattice shows a clear relationship between the occurrence of drought and certain SSTs (see the figure below). The number of drought events for each SST cluster has been identified and turn into a monthly scale, showing that in the case of El Niño events (clusters 2 and 3) the annual rate of drought reaches 5.5 events/year, while in the case of La Niña it does not reach 0.5 events/year.

Figure 55: Annual rate of droughts in TT associated to SST weather types



4.4. Risk Assessment Of Natural Hazards

This section describes the methodology proposed to assess the risk associated to hurricanes and droughts, and set the bases for this risk assessment under different climate change scenarios. The methodology proposed and damage functions for hurricane hazards have been implemented and calibrated using the historical hurricane events analyzed in previous sections. In the case of drought a damage function for the agricultural sector has been developed.

4.4.1. Methodology

The aim of the methodology developed in this study is to analyzed spatial information on hazards and vulnerability to assess the damage for the identified impacts of climate change. This risk assessment will be the bases for the proposal of future adaptation measures under climate change scenarios.

The methodology is based on a system of numerical weights and scores that will provide relative hazard, vulnerability and risk maps to prioritize more vulnerable areas and targets of different climate-related impacts. According to the framework proposed by the natural hazard community (UN-ISDR, 2009), the analysis of the likely impacts or risks related to coastal hazards involves the evaluation of two main components: hazard (in this case the primary hazards identify are hurricanes and droughts) and the system vulnerability (the characteristics of a system that increase its susceptibility to the impact of climate-induced hazard). In this context, vulnerability is often expressed in a number of quantitative indexes, being a key step toward risk assessment and management (Romieu et al., 2010). Following this approach, the different hazards have also been turned into a score or index scale leading a non dimensional indicator.

Considering that climate change impacts and risk are very dependent on regional geographical features, climate and socio-economic conditions, this risk assessment has been performed at a regional scale, providing a spatial variability of the risk and hot spots identification. Besides, the total damages computed for every impact has been calculated with the aggregation of the regional scale.

The risk assessment is based on resolving a damage function for each hazard impact in the following shape:

$$D_i = \alpha_i \sum_{j=1}^{n} V_{i,j} \cdot H_{i,j} \qquad (10)$$

where i refers to the impact studied and j refers to each region or spatial division; D is the damage associated to impact i, V refers to the vulnerability of region j to impact i in a non-dimensional scored scale, and H is the hazard generating impact i in region j in a non-dimensional scored scale. a is a weight index for each impact that affects or complete the vulnerability valuation.

In the case of hurricanes the impacts considered are coastal flooding, wind and rainfall while droughts are considered an impact by itself. For example, for the case of coastal flooding where the spatial division consists of 29 points around the coasts of TT equation (15) would turn into:

$$D_{CF} = \alpha_{CF} \sum_{j=1}^{29} V_{CF,j} \cdot H_{CF,j} \qquad (11)$$

Therefore, the process of assessing the damage (risk) associated to an impact of a natural hazard is summarized as follows:

1. The impact susceptible of risk assessment should be identified, for example coastal flooding associated to hurricane events.

2. The coast should be divided in a number of receptor points where the hazard and vulnerability will be evaluated.

3. The coastal flooding hazard (as a sum of storm surge and 30% of significant wave height) should be evaluated in each coastal point.

4. The vulnerability associated to coastal flooding (taking into account exposure) should be evaluated in each coastal point.

5. Using the scored indexes for coastal flooding and vulnerability the hazard and vulnerability will be turn into a 1 to 5 non-dimensional scale.

6. Aggregating the spatial risk distribution (V·H) and using the a weight parameter the total economic damage associated to coastal flooding in TT can be obtained.

A relevant challenge of this approach is, therefore, the development of a suitable range of score indexes for hazards and vulnerability and a good calibration (the definition of a parameter) of each damage function taking into account the best available geographical information for TT, in order to highlight most critical regions. In the case of drought impact a different approach should be follow due to the lack of spatial information. In this case the risk assessment will be as follows:

$$D_D = \alpha_D \cdot H_D \tag{12}$$

A correlation between drought events/year (H_D) in a scored scale (1-5) and agricultural production damage in the island (D_D) will be established throughout the parameter a_D. A wider explanation will be given in next sections.

Note that the accuracy of the calibrated damage functions will depend on the availability of socio economic data and historical economic damage events.

A methodological issue emerges when we face the challenge to assess the risk in terms of socioeconomic indicators as the conventional Disaster Deficit Index, Local Disaster Index (LDI) Prevalent Vulnerability Index (PVI), Disaster Risk Management Index (RMI) developed by the IBD indicates(IBD, 2010) . Nevertheless this issue is more related with the circumstances of the country i.e. its socioeconomic governance level, or its financial capacity than to the increase of occurrence of extreme meteorological events. A draft estimate of the impact is included here.

DDI=0.1 This indicator evaluates the capability of the society to assume the catastrophic damages and hence compares state wealth with eventual damages. As far as eventual damages will increase and socioeconomic carrying capacity is expected to decrease in an scenario of natural resources exhausting, the index will deteriorate. Nevertheless as T&T shows one of the best performance in this index the limit of 1 that qualitatively changes the situation will hardly be reached.

LDI= presents a measure of the spatial concentration of damages due to small catastrophes. As far as we focus on high scale damages and that the spatial distribution of assets and population has been considered as static no change is expected.

PVI= 43 characterizes T& T as a vulnerable area mainly due to its lack of resiliency. Hence any increase in risk level will deteriorate the situation, but essentially will not alter the characteristics of the society measured by the index, but the expected damages.

RMI =23 is considered unsatisfactory and hence any increase in risk observed in the area will not substantially change the conclusion. T&T will still show one of the lowest value of its geographical area.

Irrespectively of the previous considerations it has to be clarified that the statistical indexes applied in the model emerge from a different risk paradigm and the only purpose of this section is to create nexus between two different approaches to risk

4.4.2. *Definition and scoring of hazards*

The definition of classes and the assignation of scores is a necessary step for the normalization and aggregation of indicators. According to various methodologies applied at the international scale (Gornitz 1990; Abuodha and Woodroffe 2006; Torresan 2012), the assignation of the scores to vulnerability classes was performed using a 1-5 scale. For each analyzed impact the classes and scores assigned are described as follows.

4.4.2.1. Hurricanes and Tropical Storms[7]

The identified impacts associated to hurricanes are coastal flooding, wind and rainfall. The categories and rankings defined for each one are based in an expert criteria and the adaptation of standard scales to TT. This adaptation has been carried out based on reported effects from historical hurricanes.

In the case of coastal flooding the categories and scores are shown in the following table. The effects reported for Flora hurricane in 1963 by the Meteorological Service of Trinidad and Tobago mention a coastal flooding between 1.5 to 2 m. These values agree with the coastal flooding modeled in section 3.3.1. in the east coasts of Trinidad Island (in the Gulf of Paria, where most population and socio-economic activity is registered) where the coastal flooding were ostensibly measured. To date, hurricane Flora was the most damaging hurricane in Trinidad, but it was Category 3 hurricane status. Therefore, the range from 1.5 m to 2 m is scored as 4 causing high damage. The very high class is let for more than 2 m of coastal flooding and lower categories have been ranging in 0.5 m steps.

[7] For the purpose of this document we summarize in this chapter both hurricanes and tropical storms although we will apply the general term Hurricanes to summarize both.

Table 35: Coastal flooding ranking categories.

COASTAL FLOODING RANGES (m)	INDEX	DAMAGE SCALE
0-0.5	1	Very low
0.5-1	2	Low
1-1.5	3	Medium
1.5-2	4	High
more than 2	5	Very High

In the case of wind impact, at a first time the Saffir-Simpson scale was considered. However, the winds suffered in TT during hurricanes Flora and Ivan where classified by this scale as winds, while they caused several string damages reported. For instance, the Meteorological Service of Trinidad and Tobago mention that "The strong winds caused severe damage to coconut, banana, and cocoa plantations with 50% of the coconut trees being destroyed and another 11% being severely damaged. 75% of forest trees fell, and most of the remaining were greatly damaged. The passage of Hurricane Flora destroyed 2.750 of Tobago's 7.500 houses and damaged 3.500 others." In the case of Ivan in 2004 the Information Bulletin from the Red Cross and Red Crescent Societies reported "…in Tobago there were power outages in parts of the island mainly as a result of downed lines. Besides, 14 villages were affected and at least 23 homes lost part or all of their roofing". Based on this information the damage scale and categories have been modified to adapt it to TT as shown in the table below.

Table 36: Wind ranking categories.

WIND (km/h)	INDEX	DAMAGE SCALE
0-40	1	Very low
40-90	2	Low
90-130	3	Medium
130-180	4	High
more than 180	5	Very High

In the case of rainfall few damages associated to this impact are reported for historical hurricanes. Only for Flora hurricane the Meteorological Service of Trinidad and Tobago reported "Heavy rainfall caused a large mudslide from Mount Dillon onto a road leading to Castara. This was considered the most well-known mudslide on the island". Based on this historical effect and an expert criterion the categories and rankings for rainfall are established.

Table 37: Rainfall ranking categories

RAINFALL (mm/hurricane)	INDEX	DAMAGE SCALE
0-30	1	Very low
30-50	2	Low
50-100	3	Medium
100-150	4	High
more than 150	5	Very High

4.4.2.2. Droughts

In the case of drought, a look into the probability distribution of drought events per year has lead into the following categories and scores:

Table 38: Drought ranking categories.

DROUGHT (events/year)	INDEX	DAMAGE SCALE
0-1	1	Very low
1-3	2	Low
3-5	3	Medium
5-9	4	High
more than 9	5	Very High

4.4.3. *Calibration of the damage functions*

Once the methodology is theoretically developed it must be calibrated for its use in TT. For that purpose, historical hurricane event damages reported and time series of agricultural production in TT have been used. Following there is a description of the calibration of damage functions for each impact considered.

The final calibration results are compatible with those included in a parallel study that has been financed by IBD and published in December 2013. The differences in the methodological appoach have already been described in this document, but specifically at the calibration step, it is important to point the observed differences in global damages. Both in this analysis and in CCRIF (2013 pp 47 and 48) the calibration parameters are consistently chosen, but the results observed in in IDB (2013) are not consistent with those provide by CCRIF. The reason for this inconsistencies relays probably on the differences on the return period associated to the events, but this discussion should be based on the availability of the statistical analysis developped in the latter document, not available at the present time.

4.4.3.1. <u>Hurricane impacts</u>

The only historical economic damage information from hurricane events available in TT comes from CCRIF (2013) where the economic losses for the most three severe hurricanes in TT are reported (See table below):

Table 39: Most significant historical hurricane events affecting TT

Source: CCRIF 2013.

Ranking	Hurricane event	Loss (USD)
Most severe	Flora 1963	299,359,310
Second most severe	Not named 1933	54,901,280
Third most severe	Ivan 2004	34,111,016

These three events will be used to calibrate the damage functions for coastal flooding, wind and rainfall.

The economic damage provided for each historical hurricane refers to the total damages in TT. However, the calibration of the damage functions requires the economic damage corresponding to each hurricane for coastal flooding, wind and rainfall. The percentages of economic damage for each impact and hurricane will be obtained using the historical damages and effects reported and the medium hazard unitless indicator.

In the case of hurricane Flora the total economic damage reported has been divided using different weights to each impact (See table below). The aggregated values of the non-dimensional index for each hazard reveal medium damage scale for wind (3 value), almost medium for coastal flooding (2.75 value) and almost low for rainfall (1.89 value). Besides, considering a total impact of hurricanes as a sum of every impact in a relative scale the wind would represent a 40 % of the total hazard, the coastal flooding a 35 % and the rainfall a 25 %. Based on this analysis and the reported damages cited above, that specially refers to wind damage, we have decided to establish the percentages shown in the table below.

Table 40: Economic damage associated to hurricane Flora in 1963

Source CCRIF 2013.

Total damage	Coastal Flooding damage	Wind damage	Rainfall damage
100 %	30 %	50 %	20 %
299,359,310 USD	89,807,793 USD	149,679,655 USD	59,871,862 USD

For the hurricane of 1933 a similar analysis has been performed to divide the total damage reported. In this case the aggregated hazard scored index for the whole TT was quite similar to that obtained for Flora. Wind is valued in a medium damage scale (3 value) while coastal flooding obtained a value of 2.5 and rainfall 2 (in both cases a low damage scale). Referring to a percentage scale wind would represent 40 % of the total hurricane hazard, coastal flooding would represent 34 % and rainfall the 26 %.

Table 41: Economic damage associated to hurricane in 1933

Source CCRIF 2013

Total damage	Coastal Flooding damage	Wind damage	Rainfall damage
100 %	35 %	40 %	25 %
54,901,280 USD	16,470,384 USD	30,195,704 USD	8,235,192 USD

Finally, in the case of hurricane Ivan in 2004 a similar process has been carried out. In this case the aggregated ranking hazard scale shows higher values in all cases: 3.6 (medium damage scale) for wind, 2.5 value for coastal flooding (low damage scale) and 2.6 value for rainfall (low damage scale). In terms of relative weight the wind 40 % of the total impacts while coastal flooding and rainfall represent 40 % each. Fue to the damages reported, especially as consequence of wind, the final weight for divided the total economic damage is set as shown in the table below.

Table 42: Economic damage associated to hurricane Ivan in 2004

Source CCRIF 2013.

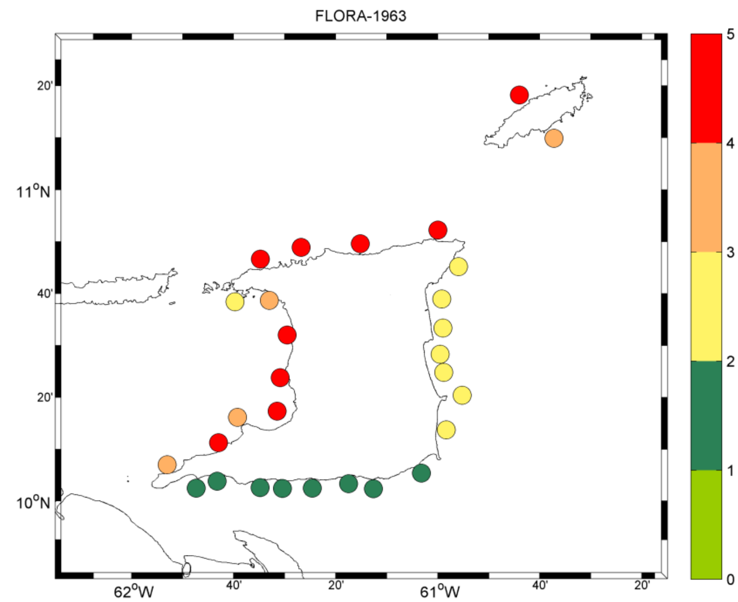
Total damage	Coastal Flooding damage	Wind damage	Rainfall damage
100 %	20 %	60 %	20 %
34,111,016 USD	6,822,203.2 USD	20,466,609.6 USD	6,822,203.2 USD

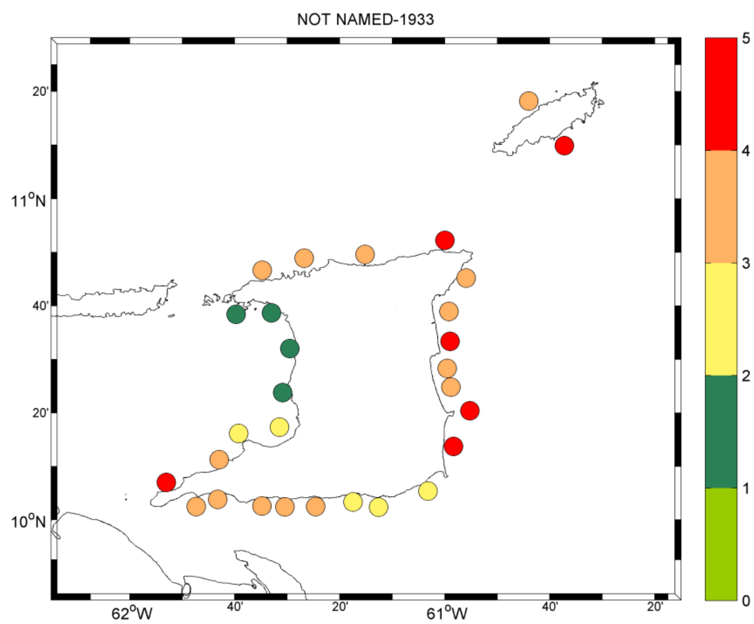
Once the economic damage for each impact and hurricane event is obtained, the impact damage functions can be calibrated.

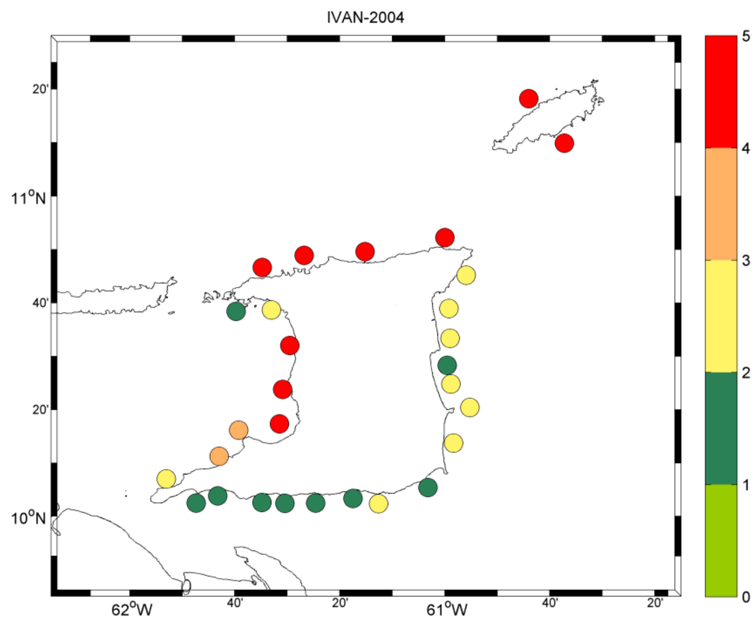
4.4.3.1.1. Coastal flooding

Following the steps of the methodology the coastal flooding evaluated in each coastal point receptor for each historical hurricane (section 4.3.3.1.) should be converted into the ranking scale. The figure below shows the spatial distribution of the coastal flooding for the three historical hurricanes studied in the relative scale defined previously. This kind of scale and visualization allows identifying quickly hot spots such as western Tobago, the north coast of Trinidad and the coasts of the Gulf of Paria in the case of Flora and Ivan hurricanes and the east coast of Trinidad in the hurricane of 1933.

Figure 56: Spatial distribution of the coastal flooding for the three historical hurricanes studied in the relative scale defined previously.







The vulnerability to coastal flooding is also rank in a relative index leading into the following map (See the figure below), where one can identify the hot spots of Scarborough, Port of Spain or San Fernando and Point Fortin.

Figure 57: Spatial variability of the vulnerability to coastal flooding in a relative ranking scale

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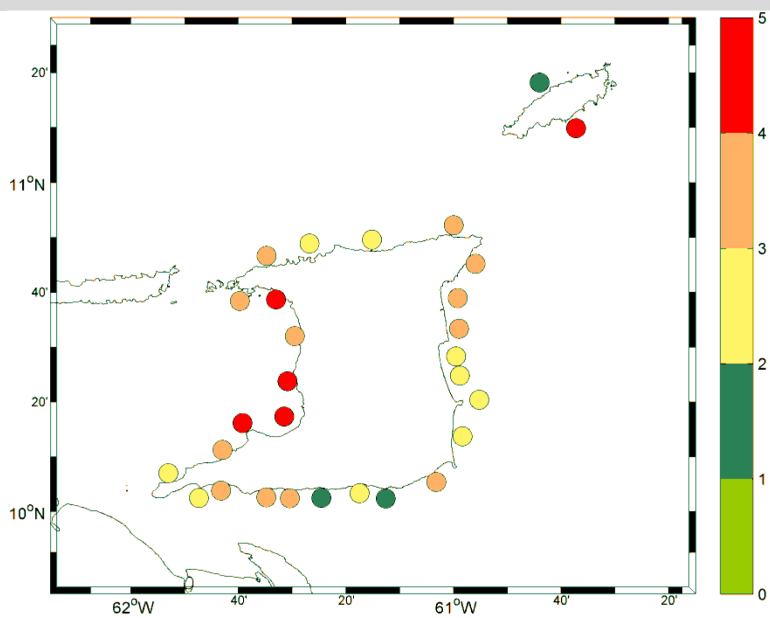

Using the data available the damage function expression will be:

$$D_{CF} = \sum_{hurricane=1}^{3} D_{hurricane} = D_{CF_{Flora}} + D_{CF_{1933}} + D_{CF_{Ivan}} = \alpha_{CF} \cdot \sum_{hurricane=1}^{3} \sum_{j=1}^{29} V_{CF_{hurricane},j} \cdot H_{CF_{hurricane},j} \qquad (13)$$

The solution of this equation leads into the value of parameter a, in this case $\alpha_{CF} = 0.213$ MUSD. Therefore, the damage function for coastal flooding is calibrated so that economic damage associated to coastal flooding can be obtained for different hurricanes using:

$$D_{CF} = 0.213 \cdot \sum_{j=1}^{29} V_{CF,j} \cdot H_{CF,j} \qquad (14)$$

Note that the parameter has economic dimension measured in million US dollars (MUSD).

4.4.3.1.2. Wind

The wind affecting TT and generated by each historical hurricane modeled in section 3.3.2. has been turned into the ranking scale define previously. The figure below shows the spatial variability of the wind in the relative scale where the most affected spots can be found in the north of Trinidad.

Figure 58: Spatial variability of the wind ranking scale for hurricanes Flora, 1933 and Ivan.

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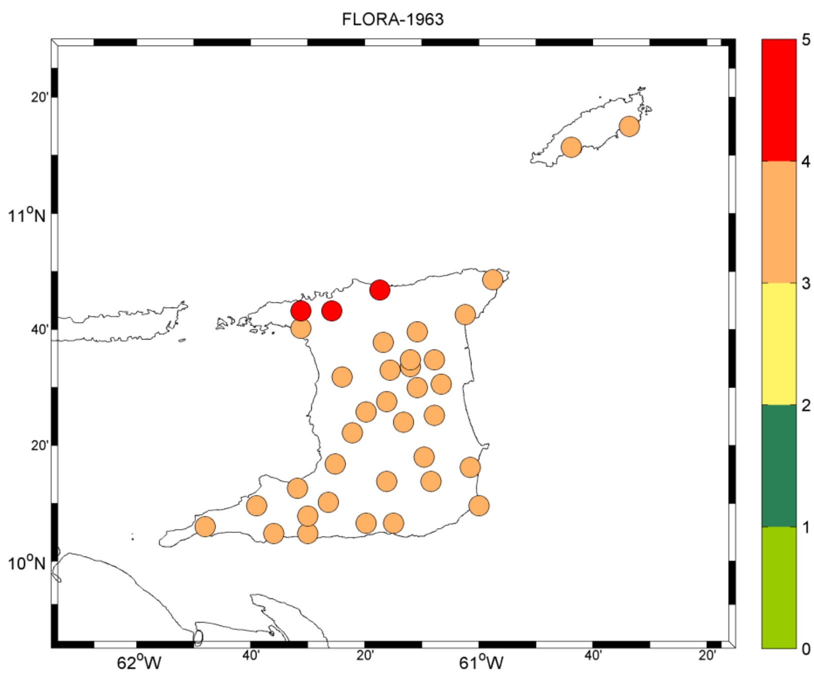

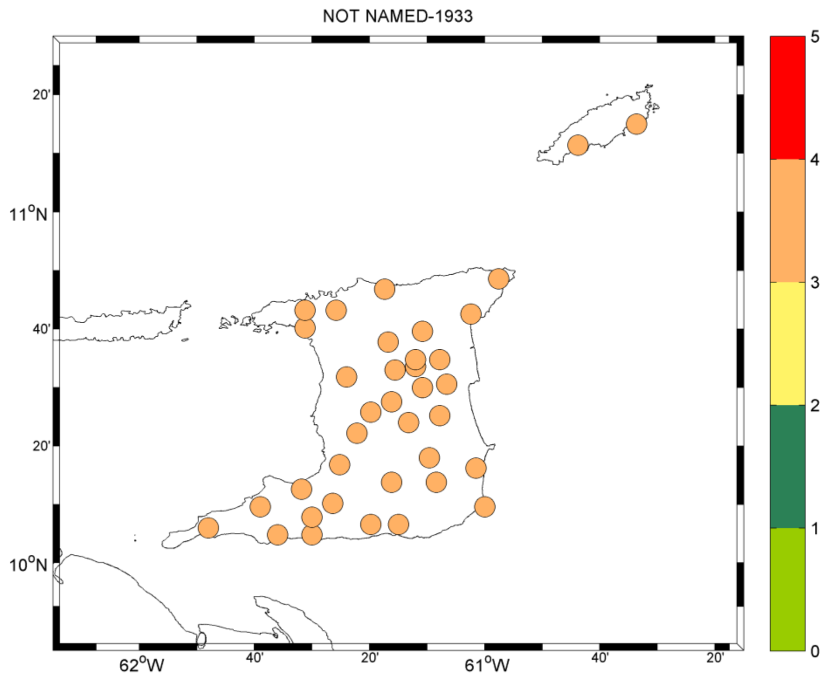

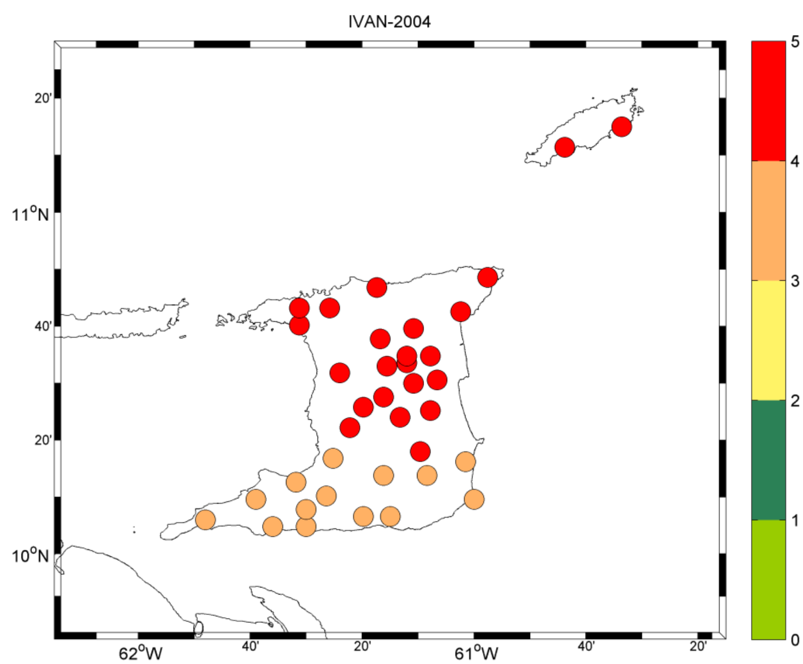

The vulnerability to wind hazard in a relative scale is shown in the figure below. Again the hot spots are found in the cities, such as Port of Spain, Chaguanas or San Fernando.

Figure 59: Spatial variability of the vulnerability to wind in a relative ranking scale.

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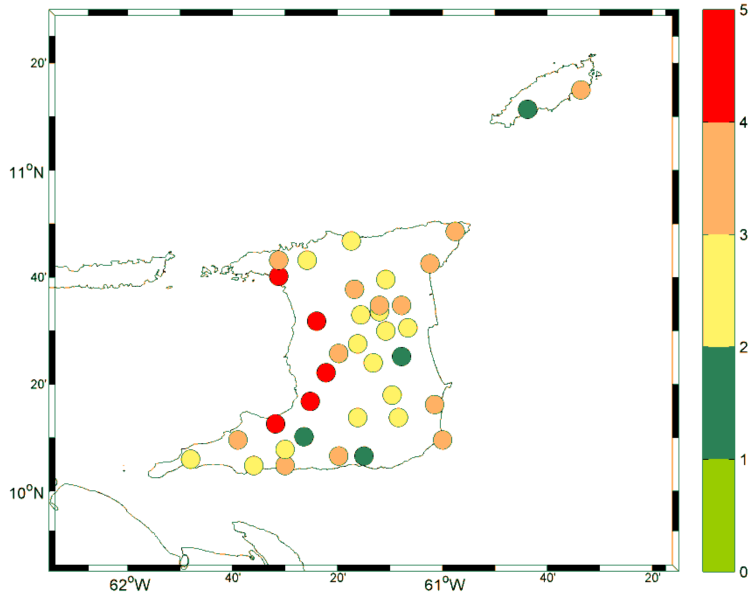

The data described above allows to solve the equation of the wind damage:

$$D_W = \sum_{hurricane=1}^{3} D_{hurricane} = D_{W_{Flora}} + D_{W_{1933}} + D_{W_{Ivan}} = \alpha_W \cdot \sum_{hurricane=1}^{3} \sum_{j=1}^{29} V_{W_{hurricane},j} \cdot H_{W_{hurricane},j} \qquad (15)$$

The parameter obtained to define the wind damage function is $\alpha_W = 0.2534$ MUDS, which allows to obtain economic damages due to wind impact for future hurricane events with the function:

$$D_W = 0.2534 \cdot \sum_{j=1}^{37} V_{W,j} \cdot H_{W,j} \qquad (16)$$

4.4.3.1.3. Rainfall

Finally, the process to calibrate the rainfall damage function follows a similar scheme. First, the rainfall affecting TT and generated by each historical hurricane modeled in section 3.3.2. has been turned into the ranking scale define previously. The figure below shows the spatial variability of rainfall impact in the relative scale.

Figure 60: Spatial variability of the rainfall ranking scale for hurricanes Flora, 1933 and Ivan

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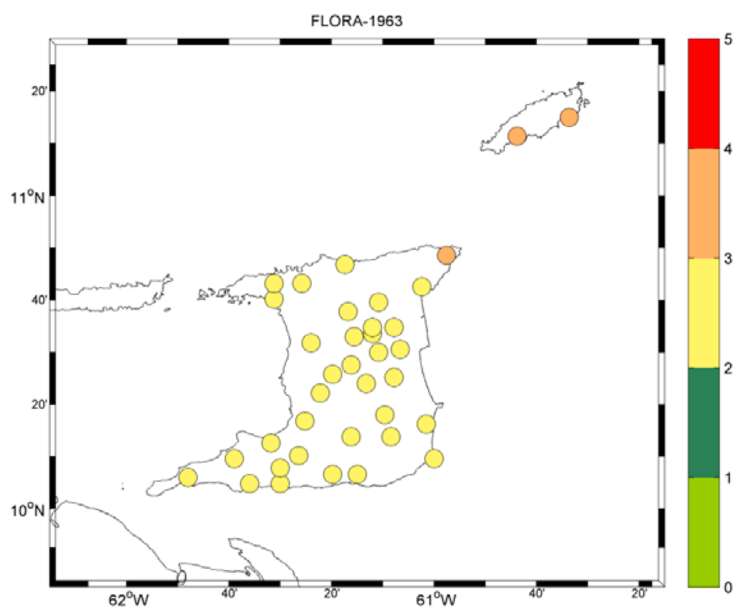
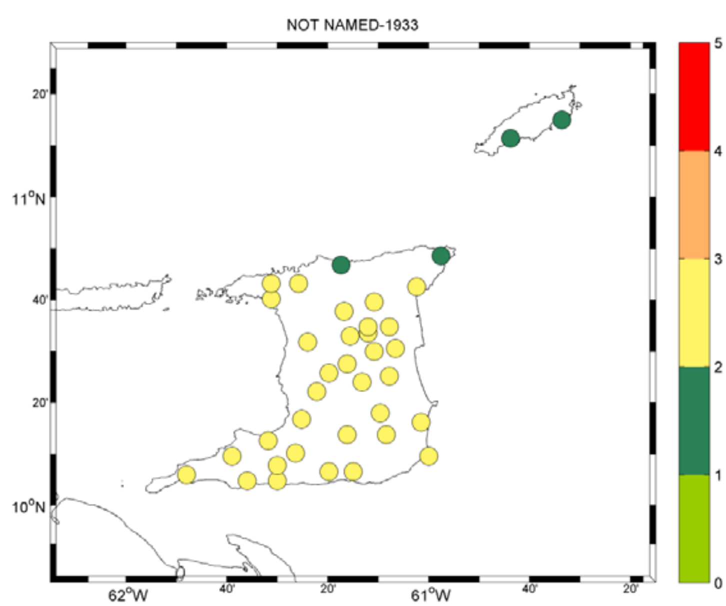
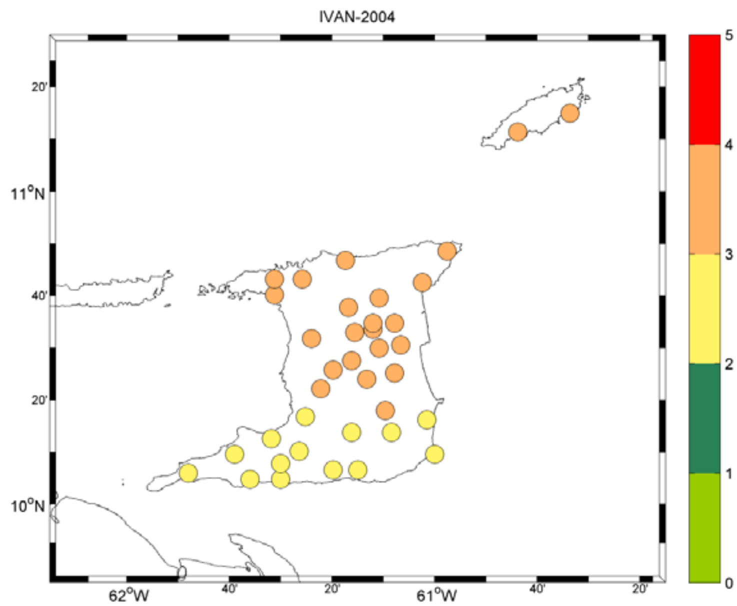
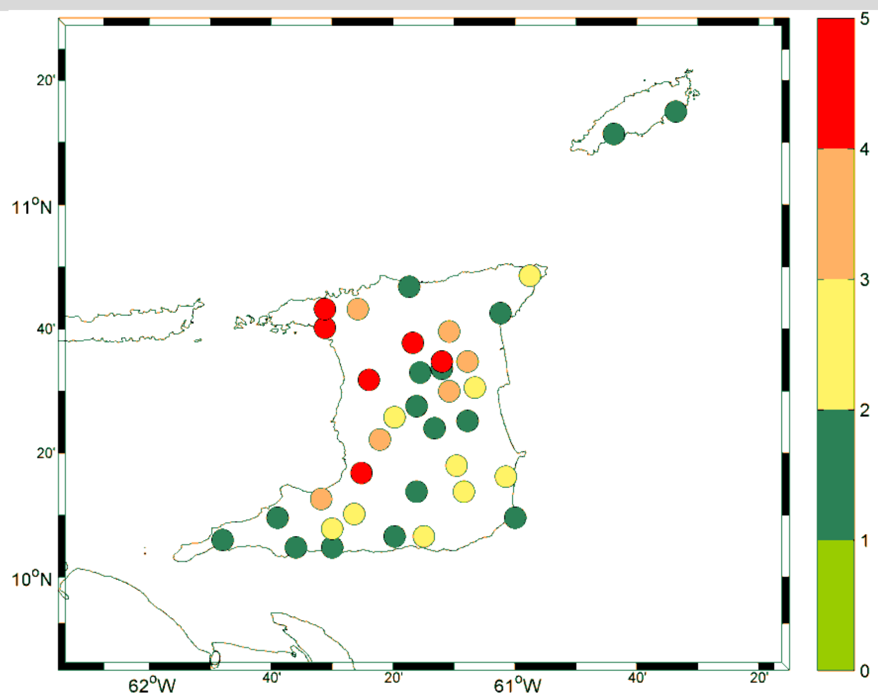






The vulnerability to rainfall hazard is also traduced into a relative scale. The spatial variability along TT is shown in the figure below. Again the hot spots are found in the cities, such as Port of Spain or San Fernando and susceptible places to landslides and inland flooding such as the area of Arima.

Figure 61: Spatial variability of the vulnerability to rainfall in a relative ranking scale.



Replacing the available information and data in the rainfall damage equation we will have:

$$D_R = \sum_{hurricane=1}^{3} D_{hurricane} = D_{R_{Flora}} + D_{R_{1933}} + D_{R_{Ivan}} = \alpha_R \cdot \sum_{hurricane=1}^{3} \sum_{j=1}^{29} V_{R_{hurricane},j} \cdot H_{R_{hurricane},j} \qquad (17)$$

The solution of the equation leads into the aR parameter value of 0.15 MUSD. Replacing this value in the rainfall damage function it is defined as:

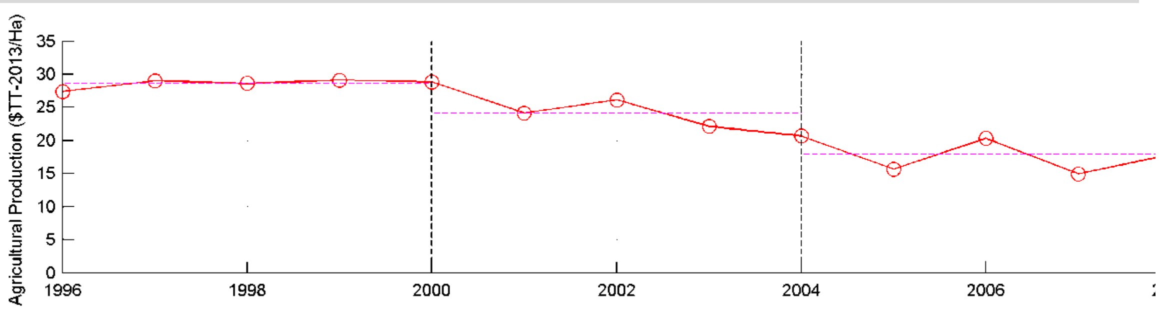
$$D_R = 0.15 \cdot \sum_{j=1}^{37} V_{R,j} \cdot H_{R,j} \qquad (18)$$

4.4.4. *Droughts*

In the case of drought the lack of spatial and detailed information leaded into a different approach for obtaining a damage function.

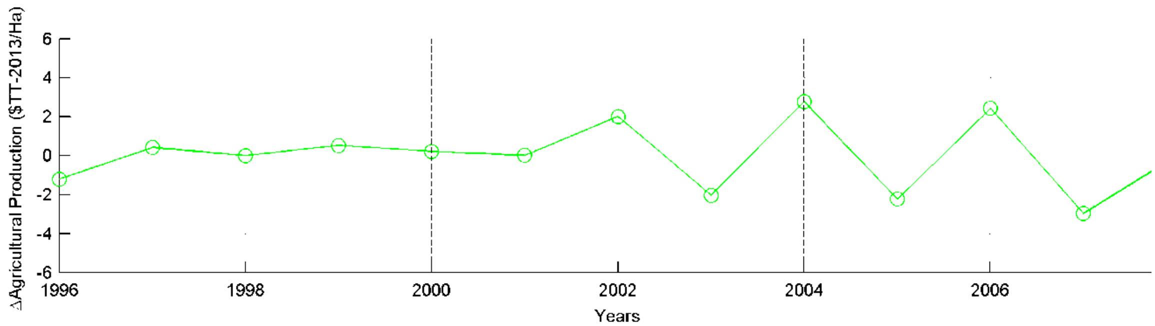
In this case the hazard is defined as a monthly scale time series of a drought index which indicates if there is drought or not. The main economic activity susceptible of drought events is agriculture, so the study of a damage function for drought will be focus on this sector. The total annual agricultural production in TT from 1996 to 2012 provided by CSO T&T is available, just like the total cultivated area. Looking at both series (production and cultivated area) one can see a decrease in the cultivated area especially in the last 5 years. Therefore, this fact has taken into account obtaining the agricultural production per Ha cultivated. Despite this correction, the annual production shows a decreasing tendency since 2000, as shown in the figure below.

Figure 62: Time series of the annual agricultural production per Ha cultivated ($TT).



Three different sections can be identify, first a constant production from 1996 to 2000, then a decreasing stretch and finally another more or less constant production section with higher variability than that in 1996-2000. This behavior corresponds with cyclic changes in the structure of the agriculture and represents a sample of the different strategies that can be adopted in the future as far as the economy is expected to suffer different pressures within the time horizon of the project. Thus, the time series susceptible of study remains as shown in the figure below

Figure 63: Standardized signal of annual agricultural production in TT per cultivated Ha ...



The proposed drought damage function follows the shape:

$$D_D = \alpha_D \cdot H_D \quad (19)$$

In this case the hazard corresponds to the drought index that is aggregated into a annual scale. Using the relative scored scale defined in section 4.2.2. the number of droughts per year will be traduced into a damage scale that ranks the severity of the drought in the year. The time series of the relative scale can be seen in the figure below.

Figure 64: Time series of the droughts per year in a relative scored scale in TT.

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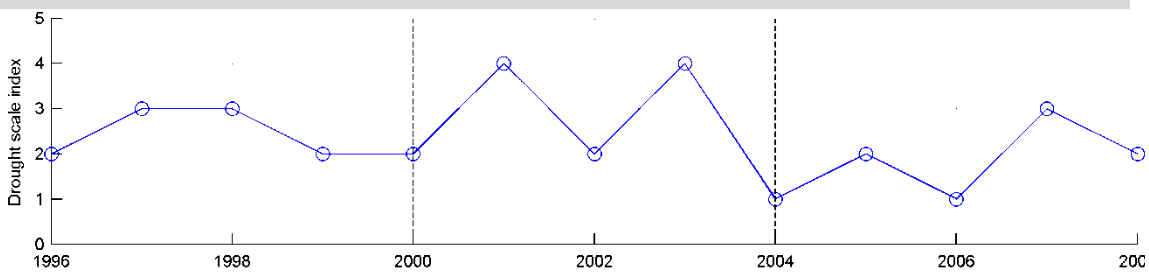
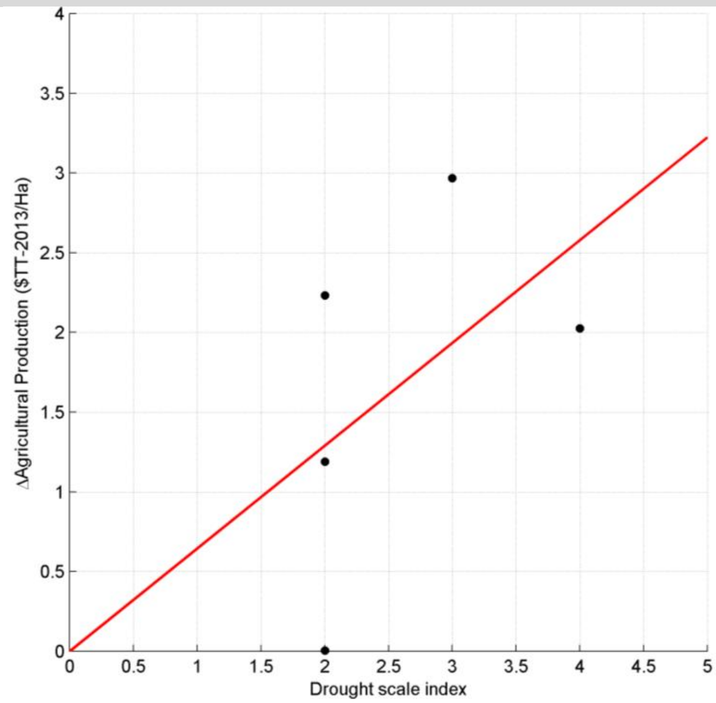


Comparing the twi figures above, at a first look, one can see a decrease in the production when severe drought years, such as 2003 or 2007. Relating the drought indicator time series and the annual production per cultivated Ha with a linear regression the a parameter has been calibrated obtaining $\alpha_D = 0.6448$ $TT.

Figure 65: Linear regression of the aD parameter.



The economic damage function associated to drought is, therefore, equation

$$D_D = 0.6448 \cdot H_D \quad ()$$

that provides the decrease in the agricultural production with respect to the mean production of 1996-2000:

$$D_D = 0.6448 \cdot H_D \quad (25)$$

Note that the scarcity of data in terms of spatial variability of drought conditions, temporal length of agricultural production and different crop production lead into a limited analysis and poor quality of the result obtained. Better information will allow defining a more rigorous drought damage function.

4.5. Conclusions

Methodological considerations: The procedure followed in this work presents the following steps,

- At the first step, we build a vulnerability function where both the assets and human beings and exposure degree at the present situation are considered
- At a second step the damage function is calibrated so that the effect of past occurrence of extreme events in the vulnerability qualified areas is accurately measured in the damage function
- At the third step these calibrated functions that represents, as accurately as possible, the situation in the area, are applied to measure the consequences of different changes that presumably happen in the future due to climate change.

The distribution of these tasks among the interim reports is as follows, the first two steps are integrally present in this second interim report, and the third is globally presented in the third interim report. Nevertheless as we use the baseline case (no change scenario) to calibrate damage functions, this first approach to damage estimates has been included in this second interim report as it was available at the time of completion of the document.

The purpose of this deliverable was hence to serve to the following objectives

"Identify the most relevant socio-economic areas in terms GDP (Gross Domestic Product) generation, employment and population concentration in Trinidad and Tobago". To cover this demand a socio-economic spatial survey has been developed and specific hotspots have been identified and introduced into the model in sub sections 4.3 and 4.4. The internal consistency between different results has been checked in order to validate the results. The downscaling process has allowed us to obtain spatially distributed vulnerability indexes to test the actual impact that can be expected from the different environmental scenarios included in the study.

For this purpose in order carry on the Second and Third Interim reports according with the Work Plan, we present in this document the baseline of the situation according to the present available information. Hence what we present here is the assessment of expected losses <u>before</u> climate change effects are considered. In the third interim report hazard assessment of the expected damage under different climate scenarios hypothesis, the identification of assets at risk and the vulnerability and economic assessment due to Sea Level Rise, increase in extreme winds and rains and droughts due to climate change will be included. According to this task schedule, this document presents the probabilistic vulnerability assessment of critical socioeconomic areas in Trinidad and Tobago and hence the Third interim report presents both the estimation of expected economic losses under various climate change scenarios and the identification of potential adaptation and DRR measures and their feasibility.

The reason for this procedure is strictly methodological, at the first step, we build a vulnerability function according with present exposure, at a second step the damage function

“Development of easily understandable hazard maps along the country to help decision makers to evaluate impacts.”

For this purpose the spatial distributions of affected areas have been established across the country as a distribution of receptors points that have been indexed and qualified according with the exposure to extreme events eventually present in each one. Again the methodology is developed and presented here, and the analysis presented in this document focuses strictly on the no change scenario. Additional results are presented in the third interim report.

“Assessment and estimation of expected economic loss under various climate change scenarios (no change, moderate and high climate change scenarios)”. This objective is shared between second and third interim report. As has been described previously damage functions are provided in this second interim report and applied results for the two additional scenarios capturing the combined effect of additional vulnerability and increasing hazards are presented in the third interim report.

5. Assessment of Expected Losses

5.1. Damage characterization of natural hazards

In the following sections, the approach and methodology for the assessment of economic damage in Trinidad and Tobago due to tropical storms and hurricanes and droughts is explained. A statistical analysis is used to characterize the damage distribution associated to tropical storm events, obtaining the mean and the variance of the distribution. However, note that the lack of data concerning agricultural damage and drought will limit the analysis for drought damage.

The methodology, tools and methods used have been coded in Matlab environment which is a flexible software and easily adaptable to any other study case.

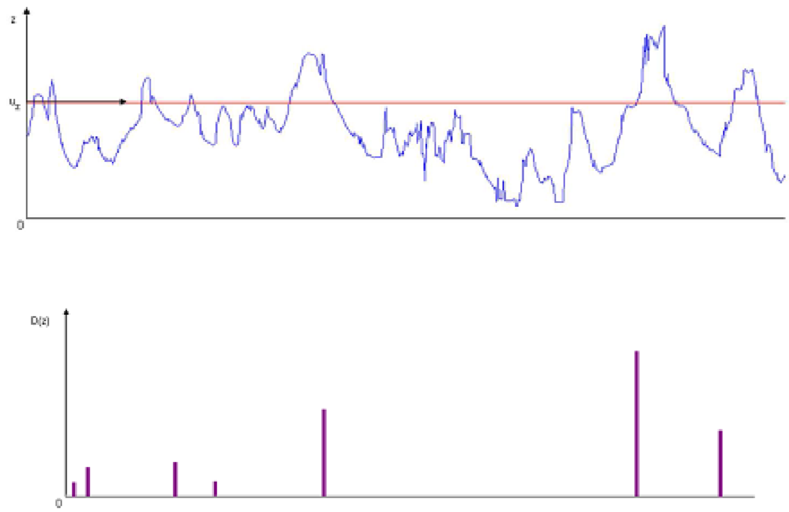
5.1.1. Tropical storm damage distribution

5.1.1.1. Theoretical approach

The total damage associated with tropical storm events is performed by addition of damage due to coastal flooding, wind and rainfall. The following theoretical approximation presented in Losada et al. (2012) and used in the European project of climate change, THESEUS, (http://www.theseusproject.eu/) to characterize flooding damage distribution is adopted.

The damage distribution associated to the extreme events of a geophysical variable can be obtained using the temporal information shown in the figure below.

Figure 66: Temporal distribution of z variable and its associated damage D(z).
Source: Prepared by the authors.



If a extreme value model based on the method Peak Over Threshold (POT) is assumed for variable z, the temporal distribution of the damage associated to z, D(z), will be the addition of every damage event associated with each event that occurs in a time step Δt.

$$S = D_1 + D_2 + \ldots + D_{N_{\Delta t}} \tag{26}$$

where $N_{\Delta t}$ is a random variable that defines the number of events in the time step Δt.

The mean and the variance define the damage distribution, S, and depend on the number of events exceeding a threshold and the damage distribution for each event:

$$\begin{aligned} \mu_S &= mean(S_{\Delta t}) = E[N_{\Delta t}] \cdot E[D] \\ \sigma_S^2 &= \mathrm{var}(S_{\Delta t}) = E[N_{\Delta t}] \cdot \mathrm{var}[D] + \mathrm{var}[N_{\Delta t}] \cdot E^2[D] \end{aligned} \tag{27}$$

The number of events exceeding the threshold can be considered a Poisson process and modelled using the Poisson distribution characterized with parameter λ. In this case, the mean and the variance of $N_{\Delta t}$ are λ_{uz}. Replacing in equation (2):

$$\begin{aligned} \mu_S &= mean(S_{\Delta t}) = E[N_{\Delta t}] \cdot E[D] = \lambda_{u_z} \cdot E[D] \\ \sigma_S^2 &= \mathrm{var}(S_{\Delta t}) = E[N_{\Delta t}] \cdot \mathrm{var}[D] + \mathrm{var}[N_{\Delta t}] \cdot E^2[D] = \lambda_{u_z} \cdot \left(\mathrm{var}[D] + E^2[D]\right) \end{aligned} \tag{28}$$

Concerning to the distribution of the damage of each event, the following damage function is considered:

$$D(z) = a \cdot z^b \tag{29}$$

With mean and variance defined as:

$$\begin{aligned} E[D] &= \int_{u_z}^{\infty} f_z(z) \cdot D(z) \cdot dz \\ \operatorname{var}[D] &= \int_{u_z}^{\infty} f_z(z) \cdot D^2(z) \cdot dz \end{aligned} \tag{30}$$

The intensity of variable z can be modelled using the generalized Pareto distribution defined with parameters σ and ξ. The probability density function (pdf) is defined in eq. (6).

$$f_z(z) = \frac{1}{\sigma}\left(1 + \xi \frac{z}{\sigma}\right)^{-\frac{1}{\xi}-1} \tag{31}$$

Taking into account the pdf and the damage function, the mean and the variance can be defined as:

$$\begin{aligned} E[D] &= \int_{u_z}^{\infty} f_z(z) \cdot D(z) \cdot dz = a\left(\frac{\xi}{\sigma}\right)^{-b} \frac{\Gamma(1+b) \cdot \Gamma\left(-b + 1/\xi\right)}{\Gamma\left(1/\xi\right)} \\ \operatorname{var}[D] &= \int_{u_z}^{\infty} f_z(z) \cdot D^2(z) \cdot dz = a^2\left(\frac{\xi}{\sigma}\right)^{-2b} \frac{\Gamma(1+2b) \cdot \Gamma\left(-2b + 1/\xi\right)}{\Gamma\left(1/\xi\right)} \end{aligned} \tag{32}$$

Finally, assuming the Pareto-Poisson distribution for the definition of damage distribution and replacing (7) in equation (3) the mean and the variance of variable S is obtained:

$$\begin{aligned} \mu_S &= \lambda_{u_z} \cdot a\left(\frac{\xi}{\sigma}\right)^{-b} \frac{\Gamma(1+b) \cdot \Gamma\left(-b + 1/\xi\right)}{\Gamma\left(1/\xi\right)} \\ \sigma_S^2 &= \lambda_{u_z} \cdot a^2\left(\frac{\xi}{\sigma}\right)^{-2b} \left[\frac{\Gamma(1+2b) \cdot \Gamma\left(-2b + 1/\xi\right)}{\Gamma\left(1/\xi\right)} + \frac{\left[\Gamma(1+b) \cdot \Gamma\left(-b + 1/\xi\right)\right]^2}{\left[\Gamma\left(1/\xi\right)\right]^2}\right] \end{aligned} \tag{33}$$

5.1.1.2. Methodology

The methodology proposed, and described below in detail, is a pragmatic approach relating the historical catastrophic events with reported damages. A critical point at the calibration stage (described in the Second Interim Report) is that nowadays the database of reported economic losses due to tropical storm events is very scarce. However, the rescaled approach done to disaggregate the total damage into the receptor points is a suitable approach.

The characterization of the historical damage associated to tropical storm events is performed using the above theoretical approach (Losada et al. 2012). The definition of the damage distribution requires a sample of tropical storm data so first, the historical tropical storms and hurricane events passing across the area of influence of TT defined in the Second Interim Report have been selected.

Using this criteria, the number of TS and hurricanes affecting TT in the last century reaches 77 events, which is a limited sample to statistically characterize the damage.

Due to this fact a stochastic simulation process is computed to obtain a representative sample of TS events which is based on the statistical analysis of damage. For each historical tropical storm event the trajectory will be altered obtaining 10000 synthetic simulations that lead to a significant sample of data. This number of representative sample of data is selected based on previous studies in the area (CCRIF 2010) and on the experience of IH Cantabria studying the Caribbean area.

The total damage associated with each tropical storm event requires the assessment of damage related to coastal flooding, wind and rainfall using the damage functions obtained and calibrated in the Second Interim Report. However, the high number of simulations makes it a very computational costly process. In order to avoid computational limitations hybrid (statistical and dynamical) downscaling is used. The main advantage of this approach is that using statistical methods of selection only a representative subset of tropical storm data need to be numerically modelled. A number of representative tropical storm events are selected using data mining methods (a maximum dissimilarity selection algorithm). The reduced number of selected cases spans the tropical storm variability guaranteeing that all possible tropical storm events are represented and capturing even the extreme events (Camus et al. 2011). The representative tropical storm events are modelled and used to obtain the coastal flooding, wind and rainfall impacts and their associated damage. The next step consists of translating the impacts into a scored scale index from 0 to 4 so that a dimensionless value for the impacts in each point of the domain is obtained. At the same time, the vulnerability is characterized in a dimensionless scored index. This kind of approach has been successfully applied at the international level (Torresan et al. 2012, Abuodha and Woodroffe 2006, Gornitz 1990). For each analysed impact, this scoring method allowed the definition of relative ranking for hazard and vulnerability.

Later on, using advanced statistical techniques the damage associated with each simulation event will be reconstructed from the representative tropical storm events. Finally, the statistical characterization of the damage will be carried out.

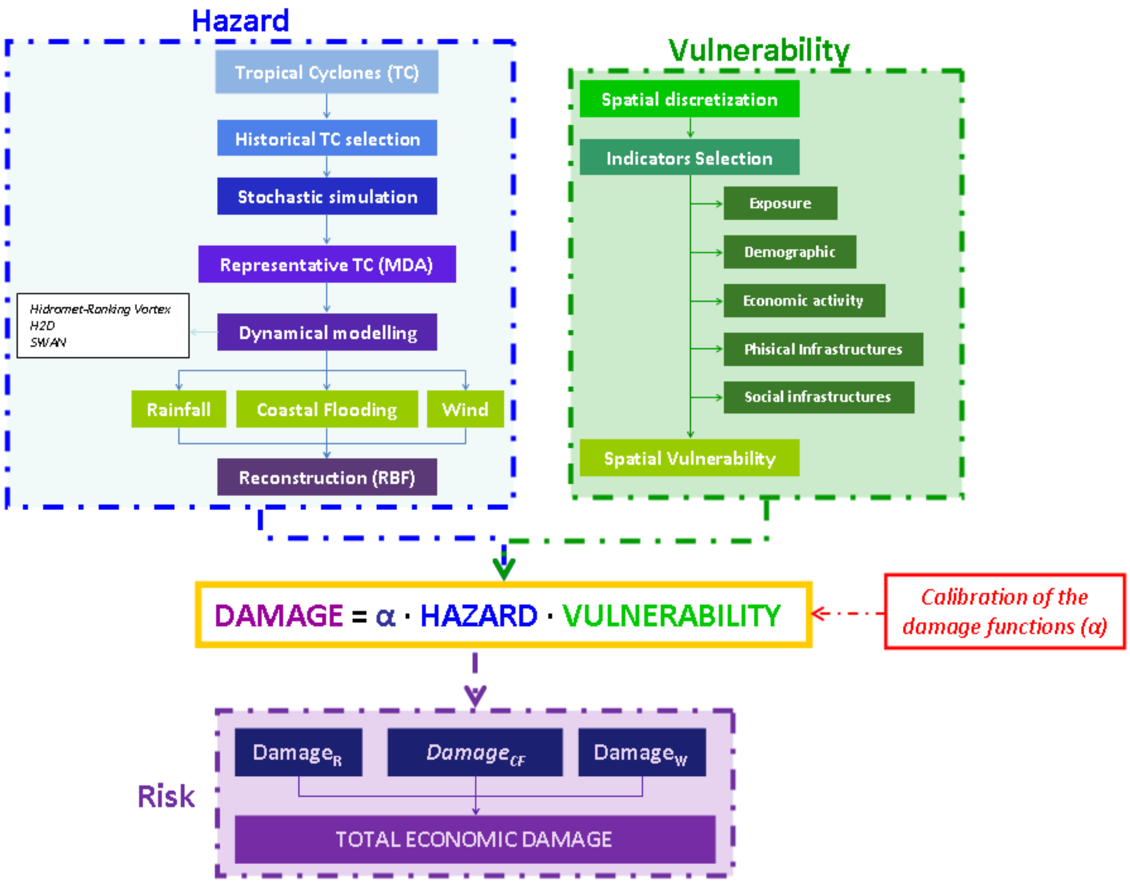
The methodology is summarized as follows:

1. Selection of historical tropical storm and hurricane events in the area of influence of TT.
2. Stochastic simulation of TS and hurricane events (10,000 simulations for each selected TS).
3. Selection of representative number of TS or hurricane events using data mining methods.
4. Dynamical modelling (wind, waves and storm surge) of the representative events using the models describe in The Second Interim Report.
5. Reconstruction of the coastal flooding, wind and rainfall impacts
6. Hazard translation into a scored dimensionless index.
7. Assessment of the vulnerability using a scored dimensionless index for each analyzed impact in each point of the domain.
8. Assessment of the impact associated and total damage for the total simulated events.

The methodology is applied to a national scale, which does not allow a better characterization of the hazard and the vulnerability. However, a good balanced between the complexity of the hazards/dynamics, the definition of the vulnerability and the damage estimation in a disaggregated (regional scale) and aggregated at the national level is achieved.

To illustrate it, the figure below shows a scheme of the methodology proposed:

Figure 67: Methodology proposed.
Source: Prepared by the authors.



5.1.2. *Drought damage characterization*

The drought damage is obtained using the calibrated damage function defined in The Second Interim Report (section 6.3.2):

$$D_D = 0.6448 \cdot H_D \qquad (34)$$

where H_D is the drought hazard in terms of scored dimensionless index. The characterization of the average historical damage will be carry on using the average value of scored index in a certain period of the last century while the drought damage associated to climate change scenarios will be assessed using projected values of the hazard index.

5.2. Historical damage distribution of natural hazards

The main natural hazards affecting Trinidad and Tobago (tropical storms and droughts) already represent a significant risk to inhabitants and economies. CCRIF 2010 reports that the annual expected losses from wind, storm surge and inland flooding amount to up to 6% of GDP in some countries of the Caribbean. In this section, the historical economic damage associated to tropical storms and droughts is obtained in order to set a baseline to compare future damage of different climate change scenarios.

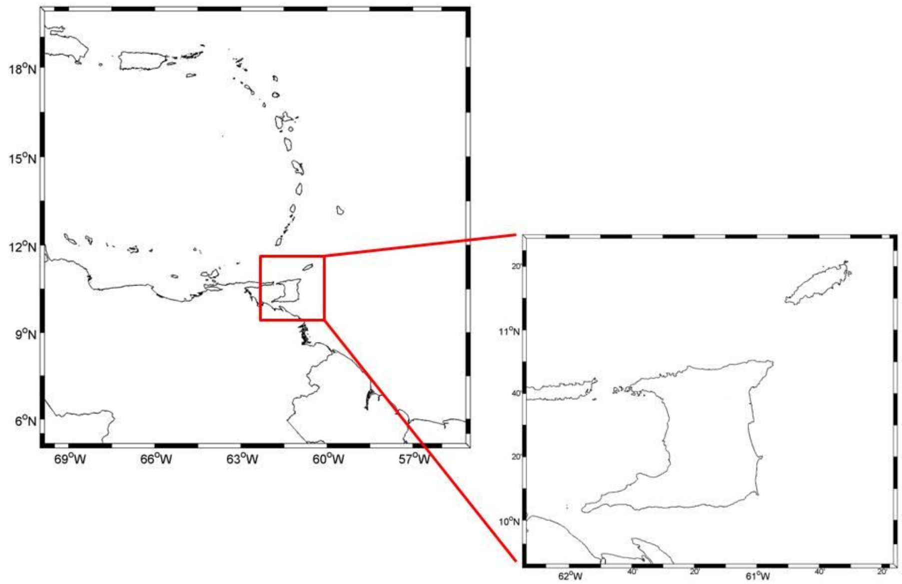
5.2.1. Historical damage associated with tropical storm events

The damage associated with tropical storm events in TT in the present climate (Today's climate from now on) is assessed using the methodology described in section 5.1.2.

5.2.1.1.1. Selection of historical events

Due to the destructive potential of hurricanes and their high economic and societal impacts, the analysis of Trinidad and Tobago's tropical cyclones is of paramount importance. The main problem for this type of analysis is that tropical cyclones are quite rare over the area of influence of Trinidad and Tobago located between coordinates 63°W, -59°W and 9°N, 13°N.

Figure 68: Area of influence of TT (-63ºW,-59ºW and 9ºN, 13ºN).
Source: Prepared by the authors.



Following this criterion, and the North Atlantic hurricane database, HURDAT, (Jarvinen et al 2004, Landsea et al 2004 and 2008) the total number of tropical storms passing through the influence area was 77. Note that HURDAT contains the 6-hourly center locations and intensities (maximum wind speed and minimum pressure) for all tropical storms (TS) and hurricanes (H) from 1851 through 2012 in the Atlantic Ocean, Gulf of Mexico and Caribbean Sea.

The following table shows the 77 historical TS represented by their name, identification, year, and month in which they were produced.

Table 43: Selected historical tropical storm events in the area of influence of TT.
Source: North Atlantic hurricane database, HURDAT, NOAA.
http://www.nhc.noaa.gov/data/#annual.

NAME	ID	YEAR	MONTH
"NOT_NAMED"	3	1851	7
"NOT_NAMED"	2	1853	8
"NOT_NAMED"	4	1855	8
"NOT_NAMED"	2	1856	8
"NOT_NAMED"	4	1862	10
"NOT_NAMED"	3	1872	9
"NOT_NAMED"	4	1877	9
"NOT_NAMED"	5	1878	9
"NOT_NAMED"	5	1886	8
"NOT_NAMED"	6	1886	8
"NOT_NAMED"	4	1887	7
"NOT_NAMED"	5	1887	8
"NOT_NAMED"	19	1887	12
"NOT_NAMED"	8	1888	11
"NOT_NAMED"	9	1891	10
"NOT_NAMED"	7	1892	10
"NOT_NAMED"	6	1894	10
"NOT_NAMED"	5	1895	10
"NOT_NAMED"	7	1896	11
"NOT_NAMED"	5	1897	10
"NOT_NAMED"	4	1898	9
"NOT_NAMED"	9	1898	10
"NOT_NAMED"	2	1901	7
"NOT_NAMED"	5	1901	8
"NOT_NAMED"	1	1905	9
"NOT_NAMED"	4	1909	7
"NOT_NAMED"	4	1911	9
"NOT_NAMED"	6	1915	9
"NOT_NAMED"	3	1916	7
"NOT_NAMED"	13	1916	10
"NOT_NAMED"	1	1917	7
"NOT_NAMED"	1	1918	8
"NOT_NAMED"	2	1918	8
"NOT_NAMED"	3	1921	9
"NOT_NAMED"	3	1924	8
"NOT_NAMED"	1	1928	8
"NOT_NAMED"	2	1928	8
"NOT_NAMED"	5	1931	9
"NOT_NAMED"	2	1933	6
"NOT_NAMED"	6	1933	8
"NOT_NAMED"	7	1933	8
"NOT_NAMED"	15	1933	9
"NOT_NAMED"	2	1938	8
"NOT_NAMED"	2	1944	7
"NOT_NAMED"	4	1944	8
"NOT_NAMED"	3	1949	8

"HAZEL"	9	1954	10
"JAET"	10	1955	9
"AA"	1	1961	7
"FLORA"	7	1963	9
"FRACELIA"	6	1969	8
"EDITH"	6	1971	9
"IREE"	10	1971	9
"ALMA"	4	1974	8
"GERTRUDE"	10	1974	10
"CORA"	4	1978	8
"GRETA"	8	1978	9
"DAIELLE"	4	1986	9
"EMILY"	6	1987	9
"ISAAC"	10	1988	10
"JOA"	11	1988	10
"ARTHUR"	1	1990	7
"FRA"	6	1990	8
"BRET"	2	1993	8
"CESAR"	3	1996	7
"JOYCE"	10	2000	10
"IRIS"	9	2001	10
"JERRY"	10	2001	10
"ISIDORE"	9	2002	9
"LILI"	12	2002	9
"CHARLEY"	3	2004	8
"EARL"	5	2004	8
"IVA"	9	2004	9
"DEIS"	4	2005	7
"EMILY"	5	2005	7
"ERESTO"	6	2006	8
"FELIX"	6	2007	9

The study of damage based on this historical record (a sample of 77 extreme events) would be inappropriate due to the lack of very long time series records. As an alternative stochastic methods are required to capture the real threat produce by these events. Note that the effects in terms of rainfall, winds, storm surge and waves associated with tropical cyclones are relatively local (100 km from the storm eye) and strongly dependent on the track. A small deviation on the historical tracks might have changed considerably the hit areas and thus the consequences, which depend on the vulnerability of the new exposure areas.

5.2.1.1.2. Stochastic simulation for TT tropical storms

Thus, using a stochastic simulation process a sample of synthetic tropical storm data is going to be performed. The proposed method consists of the specific parameter estimation associated with all historical tracks, and posterior simulation to construct synthetic or alternative tracks for past tropical cyclones. This alternative tracks are consistent with environmental atmospheric conditions and allows simulation of physically plausible events hitting different parts of Trinidad and Tobago. This information would be very valuable for appropriate risk analysis.

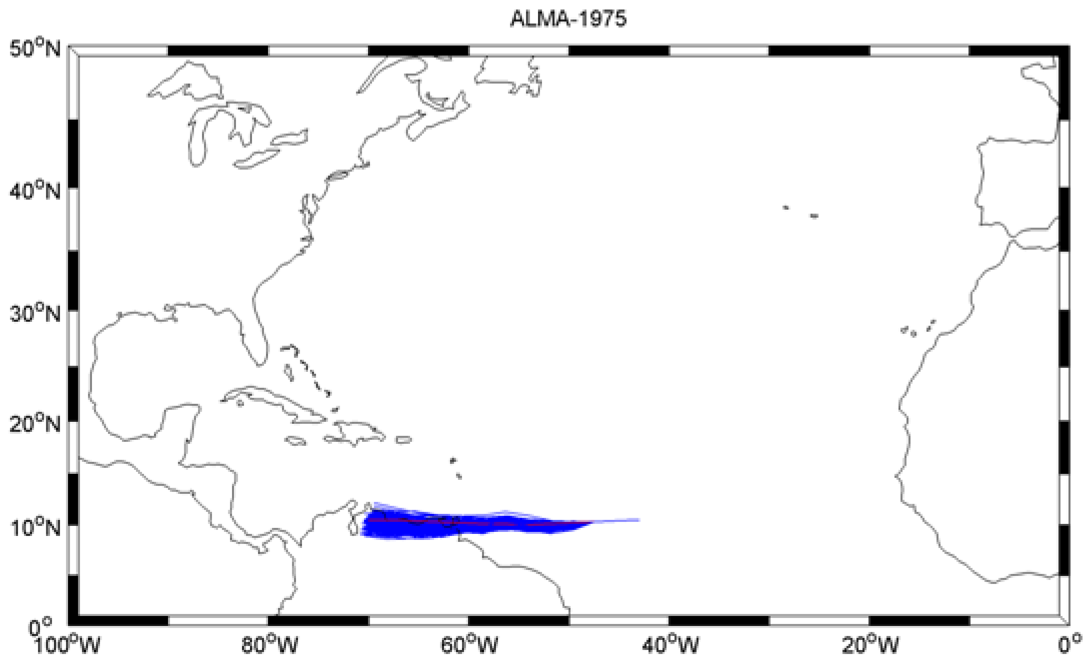
From the 77 historical tropical storms selected affecting TT only 32 have been chosen for the stochastic modelling. This is due to the fact that the NCEP-NCAR atmospheric conditions were only available since 1949.

Using the stochastic process 10,000 artificial trajectories for each historical tropical storm have been performed, leading into a final number of 320,000 simulations. As an example, figure 5 shows the trajectory of ALMA-1974 hurricane (red line) and the 10,000 artificial trajectories simulated. One can see good agreement between trajectories.

The prediction of TS trajectories in the ocean is a complex problem plagued with uncertainties. This problem is usually solved simulating the possible trajectories based on weighted vertical mean of the environmental flow in which they are embedded plus a drift effect due to Coriolis drag force (beta and advection model Marks (1992)), which are incorporated into Lagrangian trajectory models. However, both data and Lagrangian models are approximations of reality and when comparing trajectory data collected from existing track databases with respect to Lagrangian models results, they differ considerably. This work introduces a stochastic Lagrangian trajectory model that allows quantifying the uncertainties related to: i) weighted vertical mean of the environmental flow, and ii) the Lagrangian trajectory model. These uncertainties are accounted for within the model through random model parameters.

The quantification of these uncertainties consists on an estimation problem, where the parameters of the probability distribution functions of the random variables are estimated based on real historical tracks. Particularly, it is assumed that estimated parameters maximize the likelihood of this model to reproduce the trajectories from the tropical cyclone. Once the probability distribution parameters are estimated, they can be used to simulate different trajectories, obtaining location probability density functions at different times. The advantage of this method is that it allows: i) site and tropical cyclone specific calibration, and ii) comparing uncertainties related to different atmospheric reanalysis databases. For further details of the stochastic model, a extensive description can be found in Annex 1.

Figure 69: Trajectories from ALMA-1974 hurricane (red line) and from stochastic simulations (blue lines).
Source: Prepared by the authors.



5.2.1.1.3. Selection of representative tropical storms

Using the stochastic simulation, the data sample of tropical storms reaches 320,000. This high amount of data allows making a good statistical analysis of the damage but requires high computational resources when modelling wind, storm surge or waves. In order to limit the computational cost, hybrid downscaling is carried out. The hybrid downscaling consists of a combination of statistical and numerical modeling. Using data mining techniques a number of representative tropical storms events are selected, then modelled and used to reconstruct the impact and damage series of the whole hurricane event. This methodology has been successfully implemented in Camus et al. (2011) and Camus et al. (2013) for transferring wave climate into shallow waters. The selection process is one of the key stages of the methodology since the subset of tropical storms should be representative of available storm conditions. The maximum-dissimilarity algorithm (MDA) has been proved to identify a subset of tropical storms comprising the most dissimilar storm conditions in a database (Camus et al., 2011), even the extreme conditions. The number of representative cases will depend on the size and variability of the population and will be one of the main assumptions of the process.

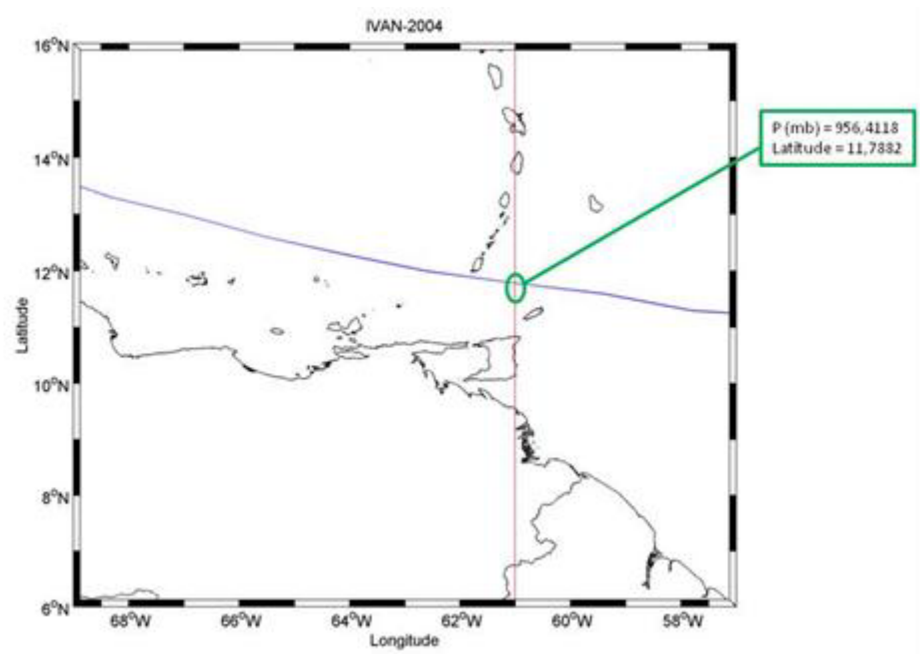
<u>Representative parameters</u>

The characterization of each tropical storm affecting TT is performed using two representative parameters. They have been calculated using the following criteria:

- Latitude when the trajectory intersects the meridian -61°W.
- Minimum pressure at the same instant.

The figure below illustrates the procedure of obtaining the representative parameters, in this case for hurricane IVAN-2004.

Figure 70: Trajectory of hurricane IVAN-2004, minimum pressure and latitude when passing through the meridian -61ºW.
Source: Prepared by the authors.

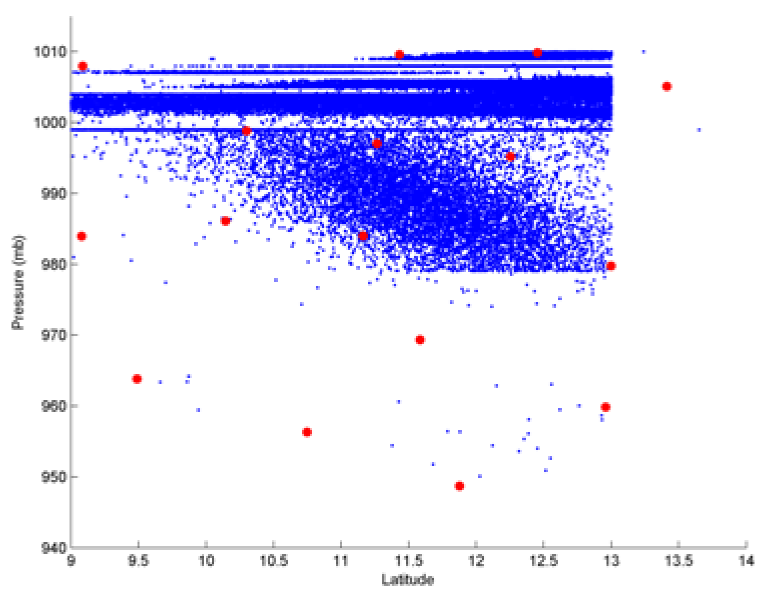


Selection of events

The aim of the selection process is to extract a subset of tropical storm events representative of available extreme event conditions from the simulated database. The selection technique used is the maximum-dissimilarity algorithm (MDA), one subclass of data mining techniques. The subset of representative hurricanes selected by this algorithm is distributed fairly evenly across the space with some points selected in the outline of the data space.

The aim of MDA is to select a representative subset of size M from a database of size N. Therefore, given a data sample X={x1,x2,…,xN} consisting of N n-dimensional vectors, a subset of M vectors {v1,…,vM} representing the diversity of the data is obtained by applying this algorithm. The selection starts initializing the subset by transferring one vector from the data sample {v1}. The rest of the M-1 elements are selected iteratively, calculating the dissimilarity between each remaining data in the database and the elements of the subset and transferring the most dissimilar one to the subset. The process finishes when the algorithm reaches M iterations (Camus et al. 2011). Based on previous studies and the experience of IH Cantabria in the characterization of hurricane events in the Caribbean we have selected a size of 16 as an agreement between the number of representative hurricane events and the computational cost-effectiveness. The whole sample of 320,000 hurricanes simulated can be represented by 16 events, as shown in the figure below, where each hurricane event is represented by its latitude and minimum pressure when passing through the meridian -61°.

Figure 71: Maximum dissimilarity selection (red points) and hurricane events population.
Source: Prepared by the authors.



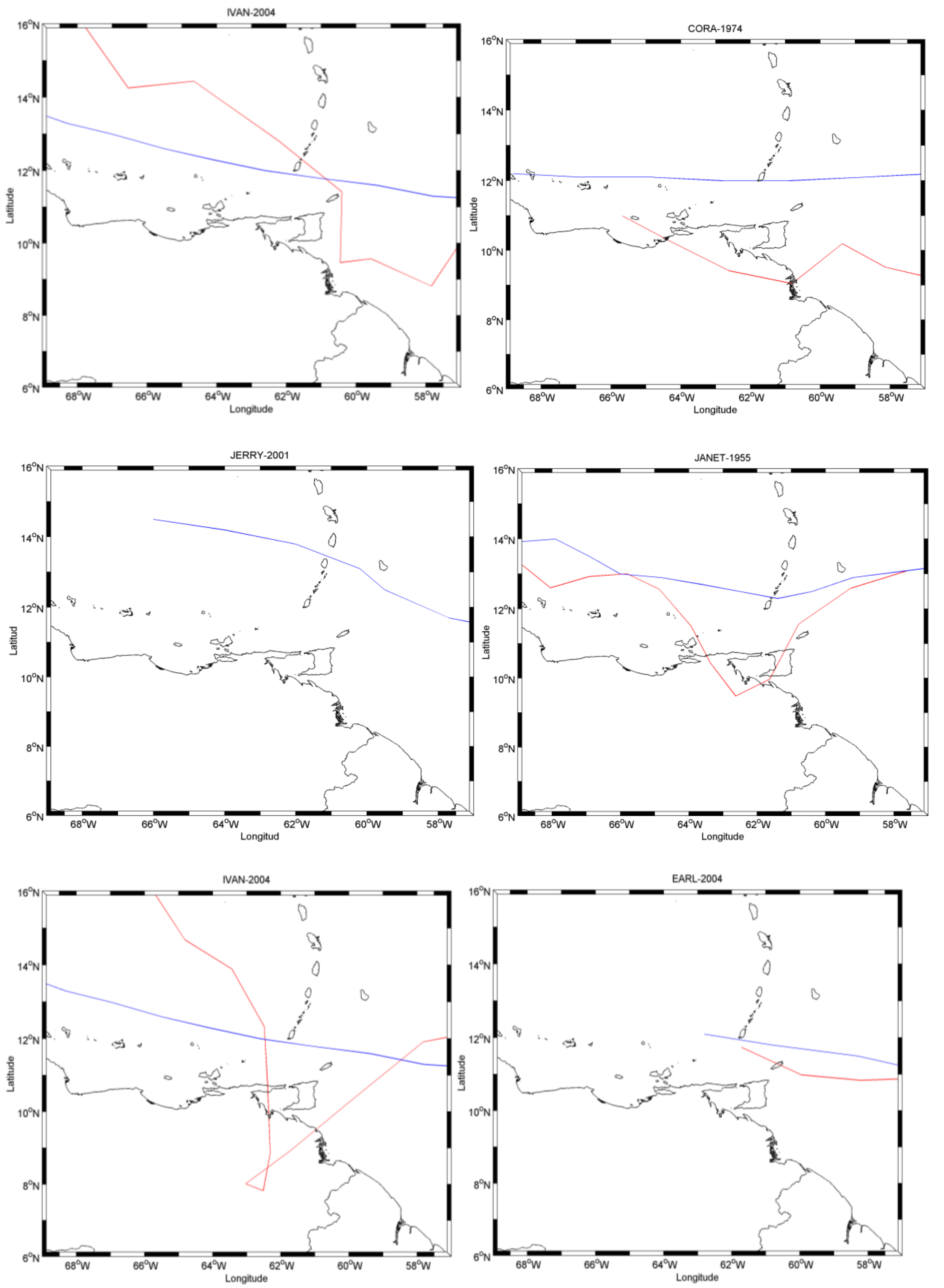
The table below shows the characteristics (representative parameters) of the 16 selected tropical storms, the number of simulated events and real hurricanes. As can be seen, only one real tropical storm (JERRY-2001) is selected with the MDA technique as representative from the whole sample of data.

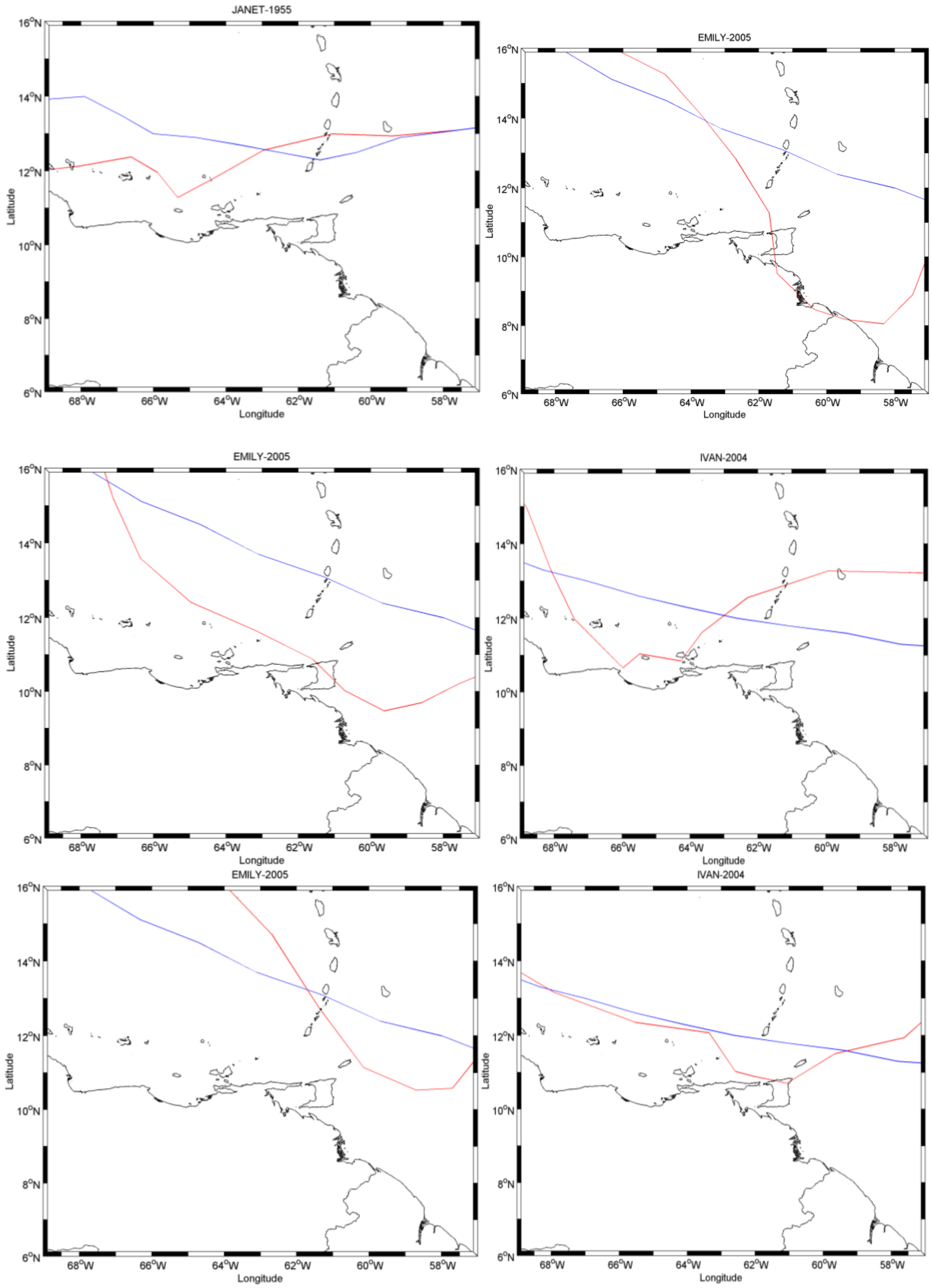
Table 44: Characteristics of the 16 representative tropical storm events.
Source: Prepared by the authors.

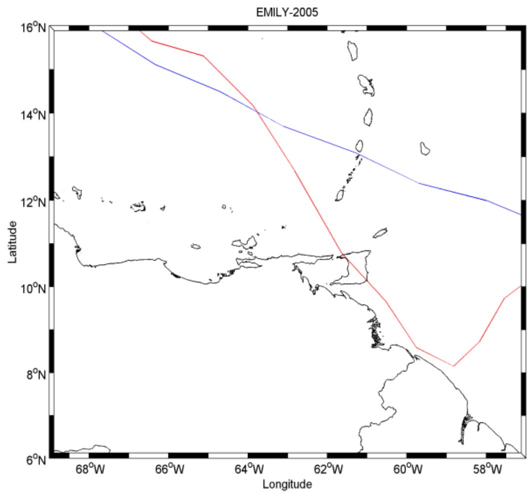
NAME	YEAR	SIMULATION	PRESSURE (mb)	LATITUDE
IVAN	2004	5259	948.6909	11.877186
CORA	1978	155	1008	9.0865889
JERRY	2001	REAL HURRICANE	1005.1111	13.411111
JANET	1955	7234	984.01099	11.163778
IVAN	2004	998	963.84821	9.4891758
EARL	2004	7048	1009.5926	11.432673
JANET	1955	5907	979.76087	12.996039
EMILY	1987	1949	983.94174	9.0784476
EMILY	1987	9721	998.83336	10.298044
IVAN	2004	8278	959.86751	12.955882
EMILY	1987	3560	995.22461	12.25681
IVAN	2004	3495	956.33271	10.746758
EMLY	1987	1419	969.35931	11.584755
EARL	2004	9952	1009.8839	12.454795
EMILY	1987	9182	986.11086	10.142354
JANET	1955	3693	997.03582	11.264422

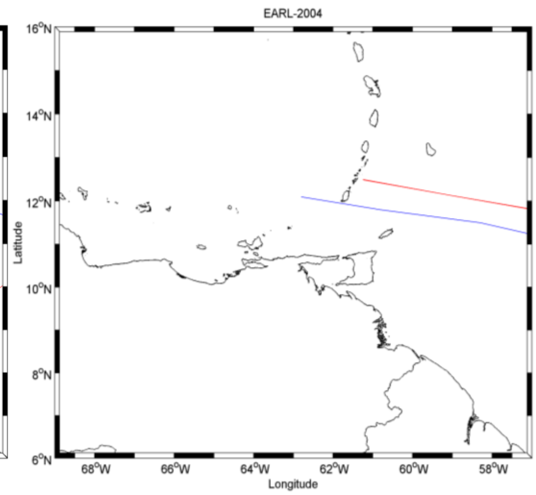
In order to illustrate the characteristics of the selected tropical storms the figure below shows, 16 panels with the trajectory of the simulated tropical storms and the trajectory of the original real hurricane.

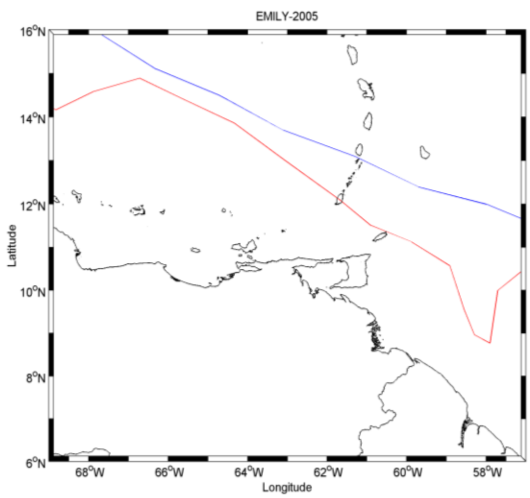
Figure 72: Trajectories of the 16 representative tropical storms (red line=simulated events, blue line=real trajectory).
Source: Prepared by the authors.

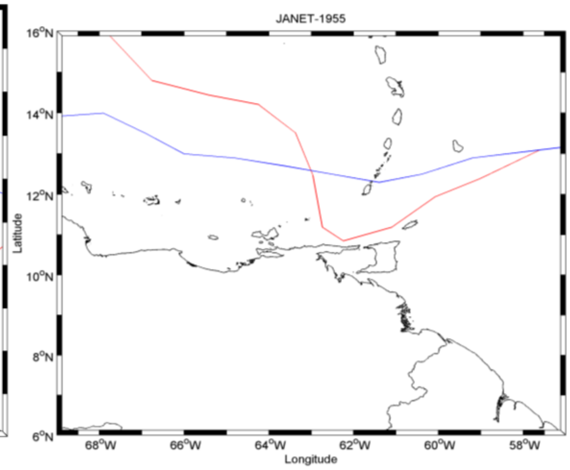



JANET-1955
EMILY-2005
EMILY-2005
IVAN-2004
EMILY-2005
IVAN-2004
16°N
14°N
12°N
10°N
8°N
6°N
68°W
66°W
64°W
62°W
60°W
58°W
Latitude
Longitude









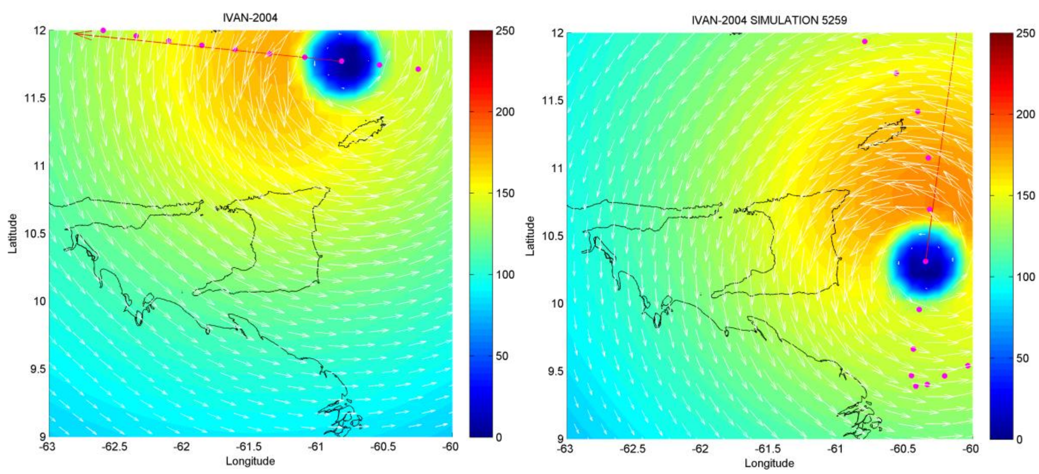
5.2.1.1.4. Dynamical modelling of wind, waves and storm surge

The benefit of using a hybrid downscaling analysis to characterize the impacts and damage associated with hurricane events falls on the computational cost. The modelling of wind, waves and storm surge for each hurricane using the dynamical models (VORTEX, SWAN and H2D) described in The Second Interim Report will demand unviable computational resources. On the contrary, the dynamical modelling of the 16 representative tropical storms and the subsequent reconstruction of the coastal flooding, wind and rainfall impacts and its associated damage using statistical techniques allows us to carry on a perfect analysis with limited resources.

The dynamical modelling follows a similar scheme to that described in The Second Interim Report. In this case, as an example, the dynamical modelling of wind, waves and storm surge for a representative simulated tropical storm and its original real one is presented. The chosen hurricane is simulation 5259 from hurricane IVAN-2004.

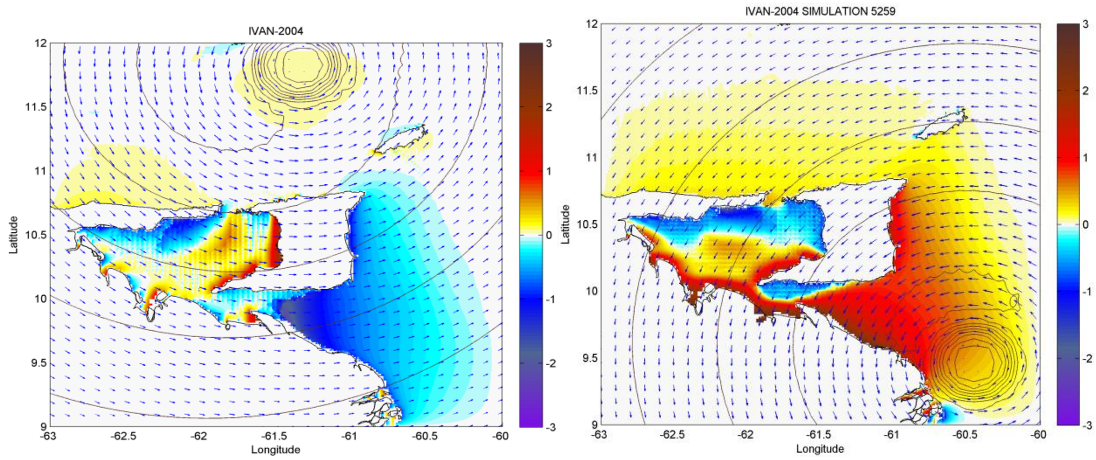
Using the Hidromet-Ranking VORTEX model we have simulated the wind fields for each position of the track of the hurricane. The figure below shows the wind fields for two instants of the trajectories of hurricane IVAN-2004 and its simulated number 5259, selected as a representative one. As can be seen, the trajectory followed by hurricane IVAN generated strong winds hitting Tobago (reaching 180 km/h) and the north of Trinidad. In the simulated event, the modified trajectory described a northward passage till Tobago Island, when it generated strong winds impacting the east coasts of Trinidad and Tobago Islands. When arriving near Tobago it turned in a western direction generating winds that hit the western coast of Tobago and north of Trinidad.

Figure 73: Wind fields of two positions of the trajectories of IVAN-2004 (at 17:00 pm, left panel) and the simulation number 5259 (at 21:00 pm, right panel).
Source: Prepared by the authors.



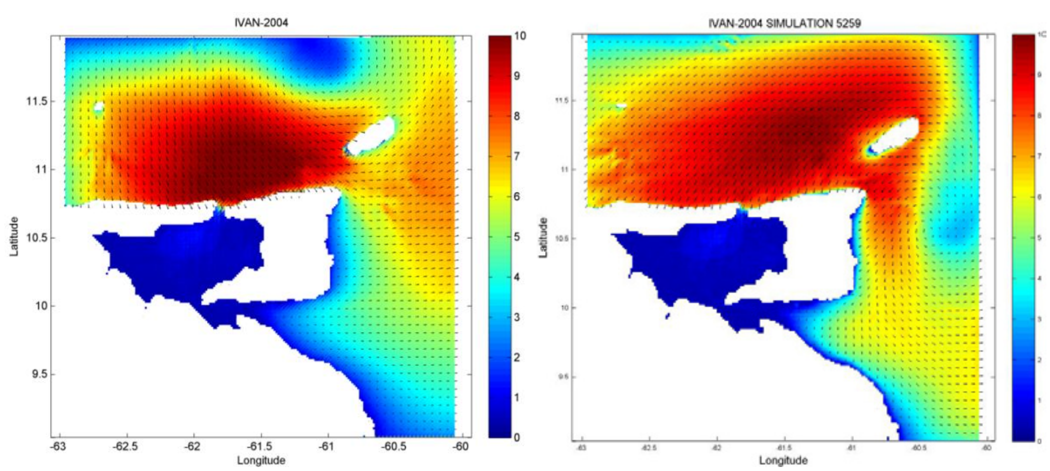
Using the modeled wind fields and the atmospheric NCEP-NCAR data, the H2D model is used to obtain the storm surge across TT. The figure below shows the storm surge generated by hurricane IVAN-2004 and simulation (5259) at concordant positions is shown in Figure 10. The difference in the trajectory (especially the northward passage of the simulation is opposite to the westward direction of the real hurricane)leads to different spatial variability of the storm surge with different impacted zones: in the case of hurricane IVAN-2004 higher levels of storm surge (up to 3 m) are recorded in the Gulf of Paria, where most population is concentrated and, in consequence, higher vulnerability; in the case of simulation 5259 the higher levels of storm surge hit the southeast and east coast of Trinidad Island, where the a calculated index of vulnerability is lower.

Figure 74: Storm surge generated at two positions of the trajectories of IVAN-2004 (at 21:00 pm, left panel) and the simulation number 5259 (at 18:00 pm, right panel).
Source: Prepared by the authors.



Finally, the wave fields are modelled using the SWAN model (described in The Second Interim Report). One can see a quite similar spatial distribution of waves in Trinidad Island in terms of the significant wave height: the north coast of Trinidad received the higher waves, up to 9 m in the case of hurricane IVAN and up to 8 m in simulation 5259. However, the wave direction differs in both cases: while hurricane IVAN generates waves coming from the northwest, the waves generated by the trajectory of the simulation 5259 come from the northeast, as seen in the figure below.

Figure 75: Significant wave height (m) generated by hurricane IVAN-2004 (at 19:00, left panel) and simulation number 5259 (at 23:00, right panel) in the instant.
Source: Prepared by the authors.



5.2.1.1.5. Impact characterization

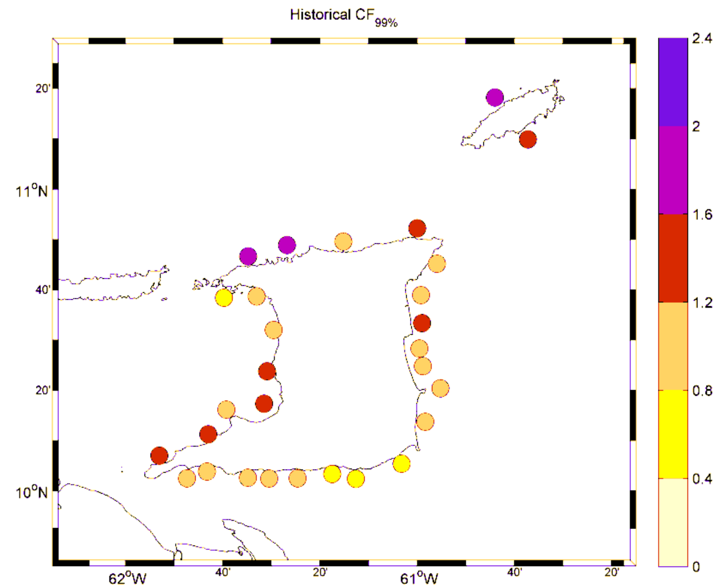
Using the numerical modelling, the coastal flooding, wind and rainfall impacts are calculated for each representative event in the receptor points specified in The Second Interim Report.

The coastal flooding is calculated as the addition of storm surge and wave set up in the 29 coastal points defined. The maximum wind is assessed using the VORTEX model in the inland receptor points and the rainfall generated by each representative tropical storm is obtained using the curves of rainfall adapted for TT from Marks and Steward (2001). Once the impacts from the 16 tropical storms are obtained at the receptor points, the objective is to reconstruct the coastal flooding, wind and rainfall for each tropical storm for the population data. For that purpose an interpolation technique based on radial basis functions (RBF) is used because it is a scheme which is very convenient for scattered and multivariate data. The RBF approximation has been applied successfully in many fields, usually with better results than other interpolation methods (Hardy, 1990). A brief explanation of this reconstruction technique is given in Camus et al. (2011).

The reconstruction of the 320,000 coastal flooding, wind and rainfall impacts for each receptor point leads into a sample of data that allows statistically characterizing the historical conditions of each impact.

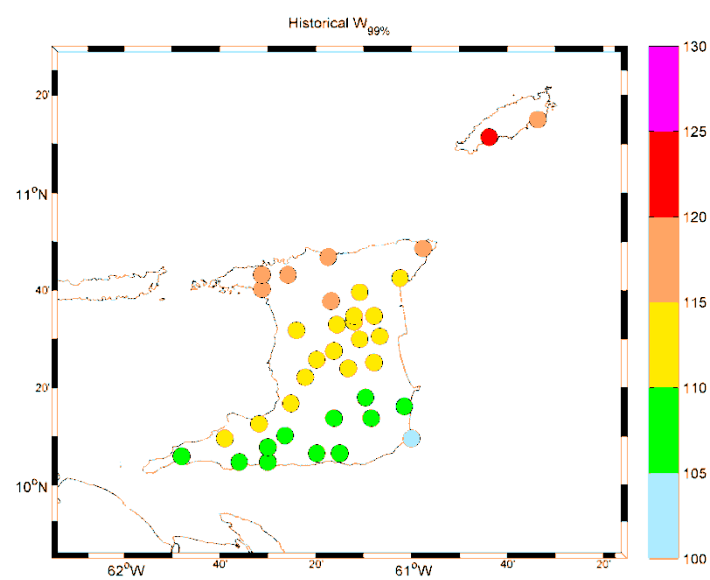
The figure below shows the coastal flooding corresponding to the 99th percentile of the distribution. This map shows the most exposed places but also the spatial variability of the intensity of a high event from the statistical distribution of coastal flooding. Western Tobago and the northwest coast of Trinidad experience the higher levels of coastal flooding (up to 2.4 m) while eastern Tobago and the south of the Gulf of Paria also registers high levels of flooding (up to 1.6 m).

Figure 76: Coastal flooding (m) corresponding to the 99 percentile.
Source: Prepared by the authors.



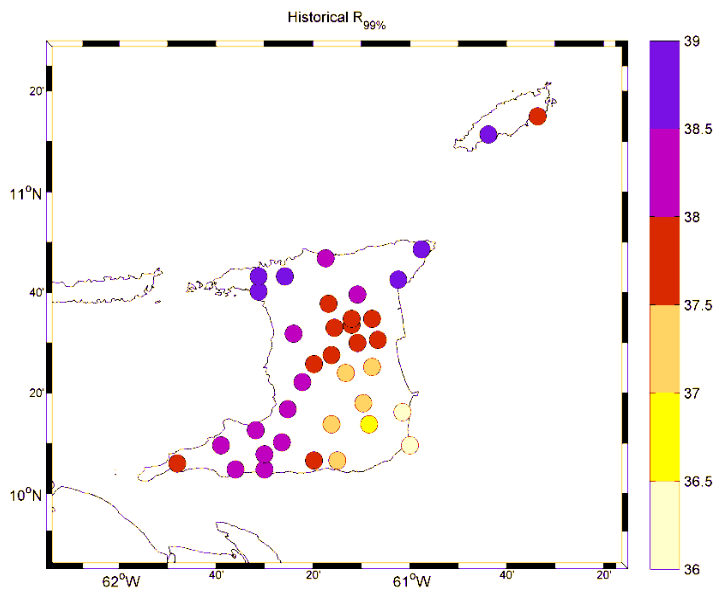
The wind intensity corresponding to the 99th percentile of wind distribution is shown in the figure below. The spatial variability shows Scarborough as the most exposed place of TT (up to 125 km/h) and higher wind speeds also occur along the north coast of Trinidad.

Figure 77: Wind intensity (km/h) corresponding to the 99 percentile.
Source: Prepared by the authors.



Finally, the rainfall statistics corresponding to the 99th percentile in the figure below, shows that the most exposed areas are the south of Tobago and the east of Trinidad, with up to 40 mm of rainfall per tropical storm event.

Figure 78: Rainfall (mm/TS) corresponding to the 99 percentile.
Source: Prepared by the authors.



5.2.1.1.6. Historical damage assessment

Once the coastal flooding, maximum wind and rainfall for each tropical storm data are calculated, the next step is to assess the damage associated to each impact for each tropical storm event using the damage functions obtained in The Second Interim Report.

At this point a cautionary warning should be stated. After working with the damage functions calibrated in The Second Interim Report, too high economic losses were obtained for TS or low category hurricanes which, at first, were not expected to generate very high damage. The table below provides the damage associated to some of the representative tropical storms obtained with the damage functions calibrated in the Second Interim Report. As can be seen the economic loss expected for the simulations of hurricane Ivan are too much higher than that reported. In the case of simulation 5259 the minimum pressure is lower when passing at the same longitude and latitude, but losses are almost eight-times higher which seem to be excessive. Simulation 8278 has higher minimum pressure and cross at higher latitude than hurricane Ivan but the model provides loss of 160.49 MUSD which is almost five-times more than the real losses reported. Another example is the real tropical storm Jerry which had 1005 mb of minimum pressure when passed over Trinidad and Tobago (at high latitude) and the model reported 75 MUSD of economical loss, twice than those reported for hurricane Ivan.

Table 45: Coastal flooding ranking categories.
Source: Prepared by the authors.

Name	Year	Simulation	Pressure (mb)	Latitude	Total Damage(MUDS)
IVAN	2004	5259	948,6909	11,877186	266,7104
JERRY	2001	REAL HURRICANE	1005,1111	13,411111	75,67600
IVAN	2004	8278	959,86751	12,955882	160,4968
EARL	2004	9952	1009,8839	12,454795	75,67600

Due to this concern, the scored index for each impact was rescaled using the following new rankings from 0 to 4 shown in the following three tables:

Table 46: Coastal flooding ranking categories.
Source: Prepared by the authors.

COASTAL FLOODING RANGES (m)	INDEX	DAMAGE SCALE
0-0.5	0	Very low
0.5-1	1	Low
1-1.5	2	Medium
1.5-2	3	High
more than 2	4	Very High

Table 47: Wind ranking categories.
Source: Prepared by the authors.

WIND (km/h)	INDEX	DAMAGE SCALE
0-40	0	Very low
40-90	1	Low
90-130	2	Medium
130-180	3	High
more than 180	4	Very High

Table 48: Rainfall ranking categories.
Source: Prepared by the authors.

RAINFALL (mm/TS)	INDEX	DAMAGE SCALE
0-30	0	Very low
30-50	1	Low
50-100	2	Medium
100-150	3	High
more than 150	4	Very High

Using these new scored categories, the damage functions for each impact were recalibrated obtaining the new values for a parameters: $\alpha_{CF} = 0.3024$ MUDS, $\alpha_W = 0.318$ MUDS and $\alpha_R = 0.254$ MUDS. Therefore, the damage functions used to obtain the associated damage for each tropical storm event were:

$$D_{CF} = 0.3024 \cdot \sum_{j=1}^{29} V_{CF,j} \cdot H_{CF,j} \tag{35}$$

$$D_W = 0.318 \cdot \sum_{j=1}^{37} V_{W,j} \cdot H_{W,j} \tag{36}$$

$$D_R = 0.254 \cdot \sum_{j=1}^{37} V_{R,j} \cdot H_{R,j} \tag{37}$$

where V refers to vulnerability in each receptor point and H refers to the hazard in each receptor point.

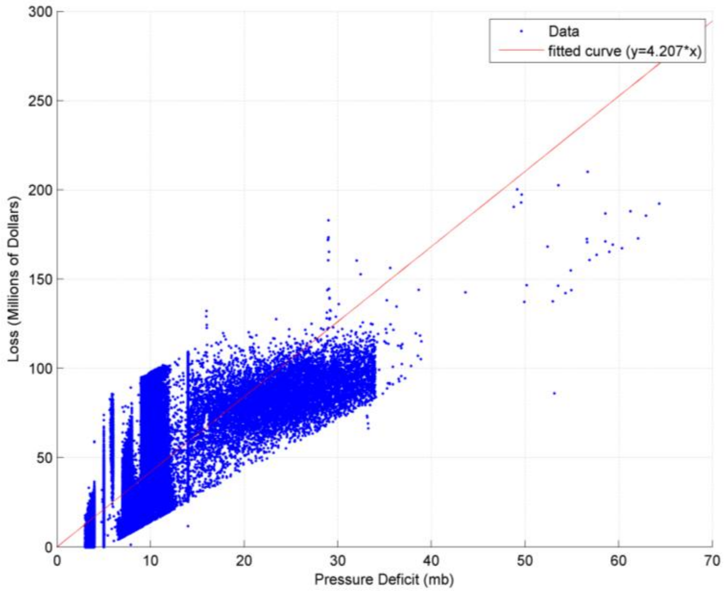
The total damage associated with each tropical storm event is computed as the addition of the economic damage due to coastal flooding, wind and rainfall. As an example, the table below shows the damage associated to coastal flooding, wind and rainfall for the 16 representative selected tropical storms.

Table 49: Economic damage associated with coastal flooding, wind and rainfall for the 16 representative hurricanes.
Source: Prepared by the authors.

Name	Year	Simulation	Pressure (mb)	Latitude	$Damage_{CF}$ (MUDS)	$Damage_{W}$ (MUDS)	$Damage_{R}$ (MUDS)	Total Damage (MUDS)
IVAN	2004	5259	948.6909	11.877186	60.7824	90.63000	40.89400	192.306400
CORA	1978	155	1008	9.0865889	0	29.89200	0	29.8920000
JERRY	2001	Real Hurricane	1005.1111	13.411111	0	1.272000	0	1.27200000
JANET	1955	7234	984.01099	11.163778	52.6176	89.67600	40.64000	182.933600
IVAN	2004	998	963.84821	9.4891758	70.7616	89.67600	39.87800	200.315600
EARL	2004	7048	1009.5926	11.432673	3.32640	29.89200	0	33.2184000
JANET	1955	5907	979.76087	12.996039	22.9824	42.93000	0.508000	66.4204000
EMILY	1987	1949	983.94174	9.0784476	42.0336	88.72200	34.54400	165.299600
EMILY	1987	9721	998.83336	10.298044	22.3776	34.66200	0.7620000	57.8016000
IVAN	2004	8278	959.86751	12.955882	26.3088	59.78400	0	86.0928000
EMILY	1987	3560	995.22461	12.25681	15.1200	29.89200	0	45.0120000
IVAN	2004	3495	956.33271	10.746758	69.5520	89.67600	50.80000	210.028000
EMLY	1987	1419	969.35931	11.584755	49.8960	69.32400	23.36800	142.588000
EARL	2004	9952	1009.8839	12.454795	0	1.272000	0	1.27200000
EMILY	1987	9182	986.11086	10.142354	35.6832	59.78400	0	95.4672000
JANET	1955	3693	997.03582	11.264422	51.1056	60.73800	20.32000	132.163600

Using the damage data and the minimum pressure in the eye of the hurricane a damage function has been defined, based on parameters *a* and *b* (eq. 4). The figure below shows the damage data (blue points) and the damage function fitted (a=4.207 and b=1).

Figure 79: Damage function associated to tropical storms events in TT.
Source: Prepared by the authors.



The damage function defined, the annual rate of tropical storms events and the theoretical approach described in section 1.1.1, allows characterization of the damage distribution. A Gaussian distribution is used to statistically characterize the damage, with Expected Annual Damage (EAD) of 19.6 MUDS and variance of 45.63 MUDS.

5.2.2. Historical drought damage

The characterization of the average annual damage due to drought events is obtained using the damage function calibrated in The Second Interim Report:

$$D_D = 0.6448 \cdot H_D \qquad (38)$$

First, the average annual drought events and its corresponding index in the scored scale for the period 1978-2008 is computed. A period of 30 years is considered in the scientific community as a representative climatic period in terms of mean and variance for a statistical characterization of the climate (Rosenzweig and Hillel 2008). The mean score index of annual drought events in the studied period comes to 2.1, which leads into an average damage of 1.354 $TT.

5.3. Climate change scenarios

In the previous section the current climate risk to tropical storms and droughts has been evaluated in terms of economic damage. This can be interpreted also as the lack of adaptation to current climate conditions or a start scenario known as Today's climate.

The uncertainty of forecasting future climate conditions (specially) and future socioeconomic systems makes into the use of scenario analysis the main tool to help decision makers. In this section three potential climate risk scenarios (apart from the Today's climate) are proposed based on the combination of different climate and socioeconomic conditions. The horizon year for each climate change scenario is 2040 which corresponds to a short-medium term horizon. The inclusion of a short-term scenario to year 2030 has been considered, but finally rejected since projections for the year 2040 represent a short-medium-term horizon an the mean conditions for a climatic period of 30 years.

5.3.1. Changes in the hazard

Two different risk scenarios for defining changes in the hazard are considered: moderate climate change and high climate change. The moderate change is built on the average forecast of climate change from all available studies while the high climate change is built on the outer range of the climate change considered possible to 2040 by existing studies and expert consulted. The "high change" scenario gives decision makers a science-based indication of the probable maximum extent of the risk posed by the hazard(s) in question over the period of the scenario. The "high change" scenario was developed using the upper end of conditions described in the majority of IPCC reports and global circulation models published and accepted as likely by the scientific community. Recently, the scientific publications suggest even the highest IPCC predictions may be much too conservative (for example, sea level rise) so that the "high change" scenario should not be considered as an extreme or unlikely forecast (ECA, 2009). The effects of these changes are expressed in terms of sea level rise (SLR) and changes in the frequency of hurricane events (changes in the annual rate of hurricanes), and changes in the frequency of drought events. Changes for the moderate scenario are linked to the results of the IPCC for the emission scenario A1B, while values for the high scenario are linked to that of the A2 emission scenario.

Sea level rise is one of the main effects of climate change, especially important in island states. Mean sea level is a slowly changing variable, combining absolute (or eustatic) sea level with any regional movement of the land surface. Relative mean sea-level rise can lead to the permanent inundation of low-lying areas. Besides, increasing sea levels also contribute to an increasing hazard associated with extreme events, such as hurricanes. Two main factors contribute to global average sea level rise: the thermal expansion due to ocean warming and the contribution of land-based ice due to increased melting. Increasing atmospheric temperatures are leading to warmer ocean waters, while the addition of new water from glaciers and icecaps and from the ice sheets of Greenland and Antarctica are making the ocean less saline. Global mean sea level has risen 210 mm from 1880 to 2009 (Church and White 2011). However, considerable variability in the rate of increase in the last century has been observed. Since 1993, high-quality satellite observations of sea level have enabled more accurate modeling of global and regional sea level change. From 1993 to 2003 global sea level rose by about 3.1 mm per year, compared to 1.8 mm/year from 1961 to 2003. These rates of increase are an order of magnitude greater than the average rate of sea-level rise over the previous several thousand years.

To arrive at the two scenarios the observed trends described below and results from global and regional circulation models based on the A1B and A2 IPCC 4th AR emission scenario. Considering sea level rise a rate of of 3 mm/year regionalized with subsidence rate for the moderate change scenario and 15 mm/year regionalized with subsidence rate for the high change scenario have been chosen (CCRIF 2010). The subsidence rate obtained for TT is -0.29 mm/year (DIVA project).

Changes in the frequency of hurricane events is based on a deep review of scientific literature. Holland G.J and P.J Webster (2007) reported a considerably increased in the hurricane frequency in the North Atlantic since the mid-thirties due to the increase in the sea surface temperatures, over 0.7°C in the last century. However, Landsea (2007) attribute this hurricane rate increase to the improvement in the satellite systems of measure. On the other hand, Knutson et al. (2013) compares ten individual models from the A1B scenario assessing hurricane activity and obtaining a significant increase in the frequency of 87% in the late 21st century. Based on the state of the art and to be consistent with the emission scenario used for determining SLR, the annual rate of hurricane events is considered to be an increase of 30 % for both, moderate and high, scenarios (the increase obtained in Knutson et al. 2013 for the end of the century brought to the horizon year 2040).

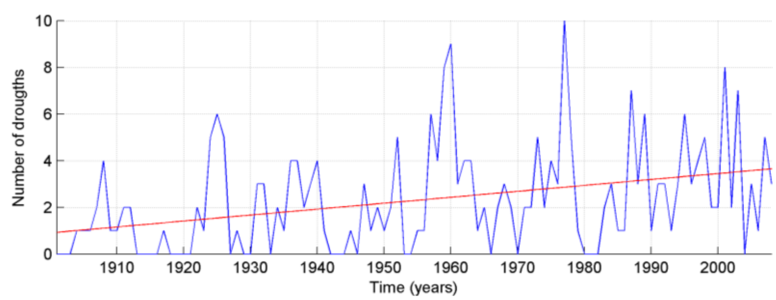
The effects of the two climate change scenarios considered in terms of SLR and annual rate of hurricanes when assessing damage associated with hurricane events is summarized in the table below.

Table 50: Summary of the effects of climate change scenarios proposed.
Source: Sea level rise proposed by ECA.

Scenarios	Sea Level Rise (SLR)	Frequency of hurricanes
Moderate Change (C1)	+3 mm/year plus local uplift/subsidence	+30%
High Change (C2)	+15 mm/year plus local uplift/subsidence	+30%

Finally, the changes proposed for drought events are based in the extrapolation of long term trends in the drought signal. The annual time series of drought events based on the drought index described in the Second Interim Report is shown in the figure below. A positive long-term trend of 0.025 droughts/year is detected and considered as the change in the rate of droughts for both moderate and high scenarios.

Figure 80: Time series of annual drought events (blue line) and long-term trend (red line).
Source: Prepared by the authors.



In the case of drought only one climate change scenario is considered based on the extrapolation of the long-term trend of annual rate of droughts (+0.025 droughts/year) to the horizon year (2040).

5.3.2. *Changes in the vulnerability*

Changes in vulnerability have been developed according to the previously defined scenarios (see 2nd Interim Report). The main restrictions that have been introduced in the model are summarized below.

Demographic Scenario:

According with the information collected in previous documents, the demographic situation in Trinidad by 2040 will be substantially different compared to the present.

1st Local population will decrease from about 1,328,000 at present to 1,243,000 in the horizon year

2nd Spatial distribution will be homogeneous with present values. Hence the population distribution will be proportional to present values

3rd Population Vulnerability will increase as the dependent population ratio will double

In accord with these stated premises, the indicators specified will be corrected by increasing demographic vulnerability index.

Economic Scenario:

According with the information collected in previous documents. The future proposed economic scenario will show the following trends.

1st Maintenance of agricultural industry performance. The uncertainty about the direction of the effects of climate change in T&T supports this hypothesis

2nd Increase in vulnerability in oil based industry on the level of available resource. This is so even though the estimated resource depletion horizons can be subject to debate due to technological advances and new discoveries, and in any event will be subject to increasing difficulties. (Any increase on average temperature will modify the chemical processes involved in the activity).

3rd Homogeneous spatial distribution is concordant with available observed data. This distribution has showed high correlation with the distribution of road density per spatial unit

With these assumptions the estimates for damages have been developed.

5.3.3. Summary of the potential climate risk scenarios

For the analysis of tropical storm events three different climate conditions have been described previously, while two socioeconomic scenarios are set. The combination of the different climate and vulnerability conditions lead to the final potential climate risk scenarios used in the assessment of future economic damage.

Concerning to the climate conditions three different scenarios are considered. The Today's climate scenario (C0) where no SLR is considered. A moderate change (C1) and a high change (C2) scenario, where regional sea level rise and future frequency of tropical storm events are defined (table below):

C0 = Today's climate

C1 = Moderate Change

C2 = High Change

When talking about socioeconomic conditions only two scenarios are considered. The Today's vulnerability scenario (V0) with the current socioeconomic conditions and a future vulnerability scenario (V1) based on the extrapolation of observed long-term trends:

V0 = Today's vulnerability scenario

V1 = Future vulnerability scenario

The combination of both hazard and vulnerability scenarios lead to four potential climate risk scenarios (table below).

Table 51: Summary of the final potential climate risk scenarios used in the damage assessment.
Source: Prepared by the authors.

Potential Climate Risk Scenarios	**Climate Scenario**	**Vulnerability Scenario**
S0 (Today's Climate)	C0	V0
S1	C1	V0
S2	C1	V1
S3	C2	V1

The Today's Climate (S0) scenario (with current conditions on the hazard, C0, and the vulnerability, V0) has been used only to characterize the historical damage due to tropical storms.

The first future scenario considered (S1) combines the moderate change scenario in the climatic conditions (C1) with the current socioeconomic conditions that is no changes in the vulnerability (V0). The second future scenario considered (S2) combines the moderate change scenario in climatic conditions (C1) with future changes in the vulnerability (V1). Finally, the third future scenario (S3) considers the combination of a high change in the climatic conditions (C2) and future changes in the vulnerability (V1).

In the case of drought, the lack of data has led to a limited analysis of the damage associated to climate change scenarios. Only one scenario is considered based on the extrapolation of the observed long-term trend of the rate of droughts per year to the horizon year (2040).

5.4. Expected damage of natural hazards under climate change scenarios

The conclusions introduced in this sub-section are expected to describe the overall trend of the situation in T&T in terms of stochastic variables. Hence they shouldn't be read as accurate predictions for certain damage but as ex-ante predictors of the future impacts of climate change. The monetization process included serves the purpose of making results clearly visible and understandable for decision makers, and not as a representation of a monetary magnitude.

The economic damage associated to tropical storms is obtained in terms of total damages, with no sector distinction. This is due to the fact that the historical information of economic loss used to calibrate the damage function provided total economic losses at a national scale. Therefore, the results obtained cannot distinguish between economic sectors. On the other hand, the economic damage associated to droughts is focus on the agricultural sector.

5.4.1. Damage associated to tropical storm events

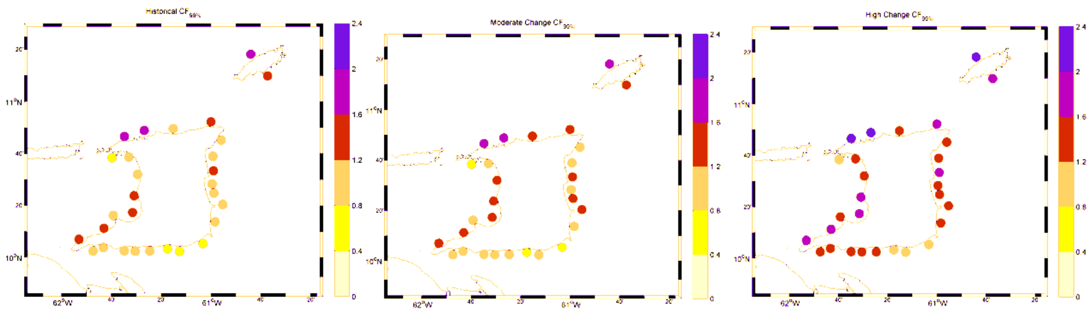
The total damage associated with tropical storm events for each potential risk scenario is assessed following the methodology described in section 5.1.2. The aim is to obtain the statistical distribution of damage characterized by its mean (expected annual damage) and its variance and compare it to the historical damages (Today's climate). Both statistics depend on the rate of hurricane events, λ (Poisson parameter), the Pareto parameters (σ and ξ) and parameters *a* and *b* that define the damage function.

The relative SLR described for each scenario will modify the coastal flooding impact. Therefore, the coastal flooding associated with each tropical storm event will be assessed following the next equation:

$$CF=SS+0.3H_s+RSL_{2040} \quad (40)$$

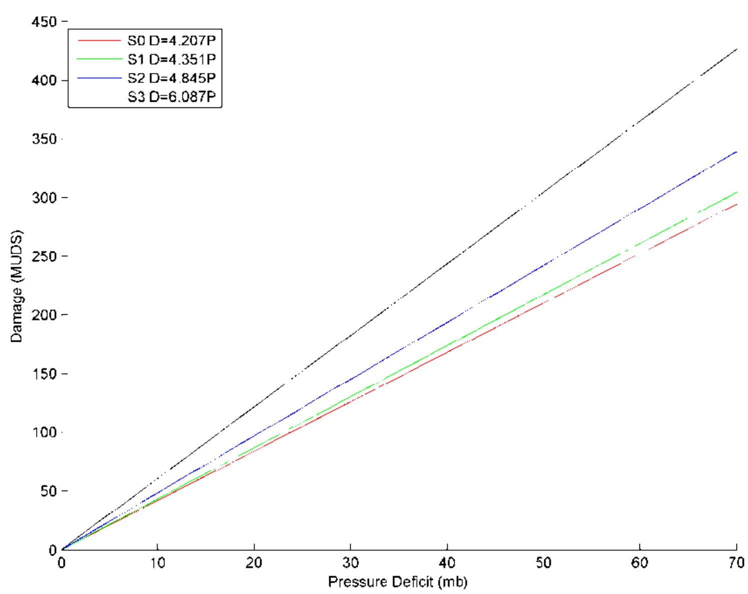
where SS is the storm surge, H_s is the significant wave height and RSL_{2040} is the relative sea level at the horizon year 2040. The regional SLR for the moderate change scenario reaches +0.073 m while for the high change scenario reaches +0.40 m. Figure 17 shows the new statistics corresponding to the coastal flooding associated to the 99th percentile for Today's climate (C0) and the moderate and high climate scenarios (C1 and C2).

Figure 81: Coastal flooding (m) corresponding to the 99 percentile for Today's climate (left panel), moderate change scenario (central panel) and high change scenario (right panel).
Source: Prepared by the authors.



Changes in the vulnerability (vulnerability scenario V1) together with changes in the coastal flooding will lead to changes in the damage associated with coastal flooding, but also changes in the damage associated with wind and rainfall. After obtaining the new economic damage for the 16 representative tropical storms and the three potential climate risk scenarios the reconstruction of the total damage data for each scenario is carried out. The characterization of the mean and variance of the damage distribution for each climate change scenarios requires the definition of the new damage function, based on parameters *a* and *b* in the figure below.

Figure 82: Damage function associated to tropical storm events for the proposed climate change scenarios in TT.
Source: Prepared by the authors.



Finally, the new rate of hurricane events λ=0.66 hurricanes/year for the horizon year (2040) is introduced in eq. 8. The mean and the variance that characterizes a Gaussian distribution of the damage associated with tropical storm events for each potential climate risk scenarios are shown in the table below. One can see an increase in the mean values of damage depending on the severity of each scenario but also changes in the variance, which provides a complete characterization of the future damage. An increase of 6.75 MUSD in the mean damage relating to historical damage is detected with moderate climate change and today's vulnerability (S1), while in the case of moderate climate change and changes in the vulnerability only represent 3 MUSD more. A heavy increase is detected in the case of high climate change and changes in the vulnerability (17.2 MUSD). One can see that, in the case of S3 scenario the EAD corresponds to an event more dangerous than hurricane IVAN in 2004 (which caused a loss of 34.111 MUSD, CCRIF 2010).

Table 52: Mean variance and 95% confidence interval of damage distribution for each potential climate risk scenario. Today's climate (scenario S0) is shown in grey color.
Source: Prepared by the authors.

	Mean Damage (MUSD/year)	Variance (MUSD/year)	95% confidence interval
S0	19.5953	45.6387	± 0.2507
S1	26.3465	53.818	± 0.2956
S2	29.3377	59.9283	± 0.3291
S3	36.8614	75.2967	± 0.4135

The statistical characterization of the damage for different scenarios allows the derivation of the damage associated with different return periods. The return period is related to the probability as follows:

$$R = \frac{1}{1 - F(x)} \qquad (41)$$

where F(x) refers to the cumulative distribution function (CDF) of damage.

The damage associated with the return period corresponding to 50 and 200 years (probability of occurrence of 0.02 and 0.005) is obtained for each scenario as shown in the table below. Although changes in the mean are not very significant for S1 and S2 scenarios relating to S0, in terms of damage with low probability of occurrence the changes are more noticeable: 17% of change in the D50 for S1 scenario and 30.2% of change (almost double) for S2. In the case of S3 scenario the relative change in the D50 and D200 is up to 63%.

Table 53: Damage associated to 50 and 200 years of return period for each climate change scenario and relative change from S0.
Source: Prepared by the authors.

Scenarios	D_{50} (MUSD)	D_{50}-D_{50S0} (%)	D_{200} (MUSD)	D_{200}-$D_{50\ -S0}$ (%)
S0	170,115	0	205,883	0
S1	199,012	16,986	239,864	16,505
S2	221,607	30,268	267,098	29,732
S3	278,437	63,675	335,594	63,002

5.4.2. *Damage associated to drought events*

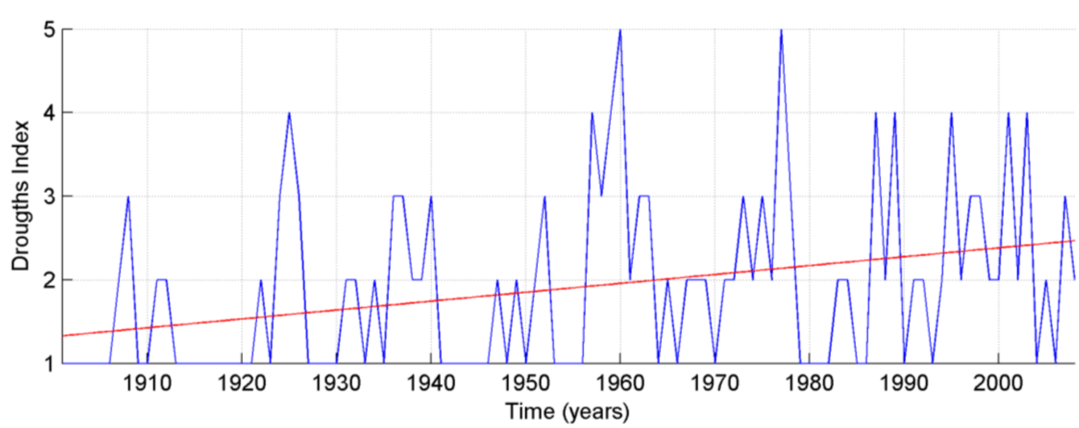
In this case the damage associated with drought events was obtained for one scenario where changes in the rate of annual droughts is defined. The definition of the damage function for drought events does not take into account vulnerability, due to the lack of available data.

$$D_D = 0.6448 \cdot H_D \quad (42)$$

were H_D is introduced in terms of scored index. (Sheffield, 2011)

The number of droughts per year for the horizon year (2040) has been obtained by extrapolating the long-term trend defined previously, obtaining 4.458 months of drought in 2040. In order to avoid the lack of information in this step of introducing the intensity of the hazard into the ranking scale, the long term trend in terms of the scored dimensionless index and its extrapolation to 2040 has been obtained as shown in the figure below.

Figure 83: Time series of scored drought index (blue line) and its long-term trend (red line).
Source: Prepared by the authors.



Using this information the scored index projected to 2040 reaches 2.8 which leads to a drought damage of 1.815 M$TT in the agricultural sector. In terms of relative change, the damage associated with this climate change scenario represents an increase of 34% relating to historical damage due to drought events. This is consistent with previous analysis (Trotman et alt., 2009)

6. Identification of responses

6.1. Prioritization of actions.

In order to reduce the effects of climate change in Trinidad and Tobago, as required in the 3rd stage of the ECA methodology, an analysis of the possible actions which could be developed in the country was carried out. To do so, a tailor-made prioritization methodology was designed, with which different possible adaptation actions were assessed and selected for the country level.

As a first step, for the sectors included in the scope of the project - agriculture, industry, human health, human settlements and water resources - the direct and indirect consequences of the hazards that Trinidad and Tobago will face due to climate change were analysed. In the tables below, the results of the analysis are shown:

Table 54: Consequences of the climate change hazards in the agriculture sector of Trinidad and Tobago.
Source: Prepared by the authors.

Event	Direct consequence	Indirect consequence
Torrential rains	Flooding	Harm to agricultural and livestock sites
	Erosion and land loss caused by water runoff	
Storm surge	Erosion and land loss in low lying zones of the coastal area	
Hurricanes and tropical storms	Losses in crops	
	Damage in farms and livestock deaths	
Sea level rise	Erosion and land loss in low lying zones of the coastal area	
Droughts	Longer dry season	Reduction of crops Higher incidence of pests and diseases Increase in exploitation and pollution of groundwater

Table 55: Consequences of the climate change hazards in the industry sector of Trinidad and Tobago.
Source: Prepared by the authors.

Event	Direct consequence	Indirect consequence
Torrential rains, storm surge and hurricanes	Demolition of poles, infrastructure and overall material damage	Cuts in electricity and water supply, harming the industrial activity

Event	Direct consequence	Indirect consequence
and tropical storms	Higher sinister risk	Higher insurance costs
	Flooding in coastal areas	Economic losses caused by the damages in the industrial installations
Sea level rise	Land loss in coastal areas, affecting particularly some industrial areas located near the coast to facilitate the delivery of goods by sea (Point Lisas, Point Fortin)	
Droughts	Lower freshwater reserves	Higher costs in the water supply infrastructure
		Reduction of the availability of refrigeration water in power generation plants
		Higher demand of desalinated water
	Worse water quality	Need for more complex water treatment processes before it can be used in refrigeration processes

Table 56: Consequences of the climate change hazards in the human health sector of Trinidad and Tobago.
Source: Prepared by the authors.

Event	Direct consequence	Indirect consequence
Torrential rains, storm surge and hurricanes and tropical storms	Demolition of poles, infrastructure and overall material damage	Cuts in electricity and water supply, harming the industrial activity
	Higher sinister risk	Higher insurance costs
	Flooding in coastal areas	Economic losses caused by the damages to industrial installations
Sea level rise	Land loss in coastal areas, affecting particularly some industrial areas located near the coast to facilitate the delivery of goods by sea (Point Lisas, Point Fortin)	
Droughts	Lower freshwater reserves	Higher costs in the water supply infrastructure
		Reduction of the availability of refrigerated water in power generation plants
		Higher demand of desalinated water
	Worse water quality	Need for more complex water treatment processes before it can be used in refrigeration processes

Table 57: Consequences of the climate change hazards in the human settlements sector of Trinidad and Tobago.
Source: Prepared by the authors.

Event	Direct consequence	Indirect consequence
Torrential rains, storm surge and hurricanes and tropical storms	Damage in coastal areas caused by erosion and the modification of wave patterns	
	Damages in infrastructure	Economic losses, particularly in the most vulnerable areas, due to increased costs per family due to the need for restoration
	Increased presence of pathogens in food and water	Higher incidence of stomach diseases caused by the bad state of water and food
	Possibility of transmission of infectious diseases	
Sea level rise	Reduction of beach surface and higher risk of flooding in coastal areas	Higher risks of flooding for households located in those areas Oxidation processes of infrastructure accelerated
Droughts	Change in precipitation trends, reducing the water reservoirs	Lower availability of water for human consumption Higher dependency from desalinated water
	Climate change can affect precipitation trends, causing anomalous rain distribution, which can lengthen the rain season or reduce it, as well as the annual mean values	
	Higher water demand in industry and agricultural sectors	Lower availability of water for human consumption

Table 58: Consequences of the climate change hazards in the water resources sector of Trinidad and Tobago.
Source: Prepared by the authors.

Event	Direct consequence	Indirect consequence
Torrential rains, storm surge and hurricanes and tropical storms	Higher demand of drinking water in emergency situations	
	Higher number and frequency of floods	Pollution of groundwater reservoirs in urban areas
	Increased presence of pathogens in food and water	Higher incidence of stomach diseases caused by the bad state of water and food
	Possibility of transmission of infectious diseases	
Sea level rise	Flooding in coastal areas	Damage in water supply infrastructure in those areas
Droughts	Lower recharge of water reservoirs and, therefore, in the freshwater volume	Lower availability of water for human consumption Higher dependency from desalinated water Higher competition between sector caused by the lower availability and the

Event	Direct consequence	Indirect consequence
		higher demand Increase in the concentration of bacteria in wastewater, causing groundwater pollution
	Climate change can affect precipitation trends, causing anomalous rain distribution, which can lengthen the rain season or reduce it, as well as the annual mean values	

After analyzing the direct and indirect consequences, the identification of the priorities of the country in adaptation terms was carried out. Therefore, from those direct and indirect consequences, the priorities in terms of climate change adaptation for Trinidad and Tobago can be defined as:

5) Prevent flooding in:
    a. Human settlements
    b. Industry
    c. Agricultural land
6) Prevent the erosion of
    a. Coastal land
    b. Agricultural land
7) Reduce the damage caused by extreme events (tropical storms, hurricanes, droughts, heat waves), in the:
    a. Human settlements
    b. Industry
    c. Agriculture
8) Guarantee the water supply to the
    a. Human settlements
    b. Agriculture
    c. Industry

The next step in the prioritization methodology was the analysis of the actions, which was carried out considering different approaches. On the one hand, the results of the country priorities were considered by determining which priorities every action would respond to. Additionally, for every action, an evaluation of specific parameters which would likely act as barriers to implementation was carried out. These parameters included: economic requirements, legal capacity, institutional capacity, technological capacity and social capacity.

Since not all the parameters have the same relevance for the implementation of the actions, they were classified depending on their importance as shown in the table below.

Table 59: Analysis of priorization parameters for the actions.
Source: Prepared by the authors.

Parameter	**Economic evaluation**	**Capacities**					
		Legal	**Institutional**		**Technological**	**Social**	
Importance	Absolutely essential	Essential	Essential		Essential	Very important – insurmountable barrier	
Possible values	**High CB**	**Non-existing framework**	**Not considered in governmental plans**	**Undefined institutional mandate**	**Innovative technology with few trials**	**Not supported by the general population**	**High investment and participation of the private sector required**
	Medium CB	**Partially developed framework**	**Considered in governmental plans without concrete actions**	**Partially defined institutional mandate**	**Technology implemented abroad**	**Controversial issue**	**Low or no investment and participation of the private sector required**
	Low CB	**Fully developed framework**	**Considered in governmental plans with concrete actions**	**Well defined institutional mandate**	**Technology already implemented in T&T**	**Supported by the general population**	**No participation of the private sector required**

Once several climate change adaptation options were identified, an analysis of each measure based on the parameters shown in the table above, the priorities they respond to and previous success cases was executed. For the parameters, a weighted mark was given based on the economic evaluation and the different capacities. In the table below, the full analysis carried out is displayed.

Table 60: Prioritization of actions.
Source: Prepared by the authors.

Action	Attended priorities	Economic evaluation	Capacities: Legal	Capacities: Institutional		Capacities: Technological	Capacities: Social		Previous experiences and success cases	Weighted score
National Building Code	1. Prevent flooding in human settlements and industry. 2. Reduce the damage caused by extreme events in the human settlements and industry.	Medium CB	Non-existing framework	Considered in governmental plans with concrete actions	Well defined institutional mandate	Technology already implemented in T&T	Controversial issue	High investment and participation of the private sector required	USA(United States Environmental Protection Agency), Florida (University of Florida), Japan (World Bank), Grand Isle (UNISDR)	**29**
		Implies hiring personnel and carrying out studies prior to the development of the code.	There is not a legal framework regarding building codes.	TA code is being developed at the moment, being promoted by the government. In fact, there is a National Building Code Committee. The agency in charge of this issue is the Ministry of the Environment and Water Resources.		The Small Building Code has already been developed in Trinidad and Tobago.	In some countries, building codes have faced difficulties in its implementation because, from the perspective of the private sector and inhabitants, they increase construction costs without providing benefits that would balance the costs.			
		2	1	3	3	3	2	1		
Dike Construction in Trinidad	1. Prevent flooding in human settlements, industry and agricultural land. 2. Prevent the erosion of coastal land. 3. Reduce the damage caused by extreme events in the human settlements, industry and agriculture.	High CB	Partially developed framework	Considered in governmental plans without concrete actions	Undefined institutional mandate	Technology already implemented in T&T	Controversial issue	Low or no investment and participation of the private sector required	Canada (British Columbia Ministry of Environment), Europe (European Commission), The Netherlands (Jonkman S.N. et al.) Vietnam (The World Bank), New Orleans, Bulgaria (A. H. Pickaver), The Netherlands (Jan Oosthoek	**23**
		This action requires constructing infrastructure.	There is not a specific legal framework for the protection of coastal areas in Trinidad and Tobago. The Town and Country Planning Act and the National Integrated Water	The National Spatial Development Strategy includes remarks on the protection of coastal areas, including the need to develop an Integrated Coastal Zone Management Plan, but no concrete actions to protect the Coastal Areas are included. The Ministry of Planning and Sustainable Development is responsible for the National Spatial Development Strategy, however, it is unclear who will be responsible for the development of the Integrated Coastal Zone Management Plan,		Dikes have already been constructed in Trinidad and Tobago's coastal areas.	Even in countries where dikes are widely implemented, their construction may pose some controversy due to their aesthetic impacts in the environment and their high cost. This action would only require investments from the private sector in cases where the land is privately owned. In this case, depending on the terms of the Integrated Coastal Management Plan, it will be decided whether the investment needs to be carried out by the owner or the government.			

Action	Attended priorities	Economic evaluation	Capacities: Legal	Capacities: Institutional		Capacities: Technological	Capacities: Social		Previous experiences and success cases	Weighted score
			Resources Management Policy 2005 include some references, but there is not a well defined framework.	considering that it needs to account for environmental issues that may fall under the responsibilities held by the Ministry of the Environment and Water Resources.						
Meteorological Alert System connected to the Monitoring System	3. Reduce the damage caused by extreme events in the human settlements, industry and agriculture.	1	2	2	1	3	2	2	France (David Rogers and Vladimir Tsirkunov), Europe (Stéphane Hallegatte).	**30**
		Low CB	Partially developed framework	Not consistent with governmental plans	Partially defined institutional mandate	Technology already implemented in T&T	Supported by the general population	Low or no investment and participation of the private sector required		
		It would only imply designing and maintaining a website and developing some TV and radio ads.	Trinidad and Tobago has a Disasters Measures Act Chapter 16:50 (Act 47 of 1978), but it needs to be revised and adapted to reflect the current situation	Even if Trinidad and Tobago has an Office of Disaster Preparedness and Management, it does not have a policy developed for this matter. The Office of Disaster Preparedness and Management depend on the Ministry of National Security. A Policy including a better definition of who holds the responsibility regarding this issue would be needed.		This action would imply creating a website and developing TV and radio ads.	The experiences with alert systems in other countries show that they are usually supported by the general population, who make good use of them, therefore enhancing the results obtained by their implementation.			
Emergency Protocols	3. Reduce the damage caused by extreme events in the human settlements and agriculture.	3	2	1	2	3	3	2	El Salvador (UNISDR), France (David Rogers and Vladimir Tirkunov	**29**
		Medium CB	Partially developed framework	Considered in governmental plans without concrete actions	Partially defined institutional mandate	Technology already implemented in T&T	Supported by the general population	Low or no investment and participation of the private sector required		
		It would imply the creation of the protocols, brochures	Trinidad and Tobago has a Disasters Measures Act Chapter 16:50 (Act 47 of	There are currently national and local plans for emergency situations, as well as drafts which are being developed, however, it is necessary to create a well developed framework that clearly defines the		This action would imply developing new emergency protocols for the general	As shown in the experiences of other countries, local communities are usually the first to act when emergencies take place, therefore, the support of the local communities and private sector is expected in this			

Action	Attended priorities	Economic evaluation	Capacities						Previous experiences and success cases	Weighted score
			Legal	Institutional		Technological	Social			
		and the development and emission of some TV and radio ads.	1978), but it needs to be revised and adapted to the current situation.	areas covered by each plan and ensures that there are no contradictions and that all the institutional responsibilities are well defined in the broad image.		population, which has been already done in the country, designing brochures and developing and emitting TV and radio ads.	action. However, to obtain the best results from that support, it is necessary to provide them with detailed and specific information.			
		2	2	2	2	3	3	2		
Social Awareness Program	2. Prevent the erosion of agricultural land. 3. Reduce the damage caused by extreme events in the human settlements and agriculture. 4. Guarantee the water supply to the human settlements and agriculture.	Low CB	Non-existing framework	Considered in governmental plans without concrete actions	Well defined institutional mandate	Technology already implemented in T&T	Supported by the general population	No participation of the private sector required	Philippines (Linda M. Peñalba et al.), Mexico City (4th World Water Forum).	**33**
		It would imply creating a program, developing brochures and holding workshops.	There is an Environmental Management Act, but it does not focus on climate change aspects.	The Climate Change Policy of Trinidad and Tobago considers awareness raising as an action which needs to be developed in the Country. In terms of mandate, due to the fact that climate change depends of the environment, the Ministry of the Environment and Water Resources would be responsible for this action.		The action implies developing a program, brochures and workshops, which do not pose any difficulty in technological terms.	In social terms, the action should not face too many difficulties if the program is well implemented and an effort is made to choose the right people to lead the measure. It is not a controversial issue and no participation from the private sector is required.			
		3	1	2	3	3	3	3		
Institutional Training Program	1. Prevent flooding in human settlements, industry and agricultural land.	Low CB	Partially developed framework	Considered in governmental plans without concrete actions	Partially defined institutional mandate	Technology already implemented in T&T	Supported by the general population	No participation of the private sector required	Colombia (Michael Comstock et al.), Honduras (The World Bank).	**33**

Action	Attended priorities	Economic evaluation	Capacities: Legal	Capacities: Institutional		Capacities: Technological	Capacities: Social		Previous experiences and success cases	Weighted score
	2. Prevent the erosion of coastal land and agricultural land. 3. Reduce the damage caused by extreme events in the human settlements, industry and agriculture. 4. Guarantee the water supply to the: human settlements, agriculture and industry.	The cost of the action is low; it only requires the organization and conduction of workshops.	Trinidad and Tobago has a Disasters Measures Act Chapter 16:50 (Act 47 of 1978), but it needs to be revised and adapted to the current situation. Additionally, there is an Environmental Management Act, but it does not focus on climate change aspects.	The Climate Change Policy of Trinidad and Tobago considers capacity building as an action which needs to be developed in the Country. In terms of mandate, due to the fact that climate change depends of the environment, the Ministry of the Environment and Water Resources would be responsible for this action. On the other hand, the Office of Disaster Preparedness and Management, which depends on the Ministry of National Security, may have some responsibility in the sections related to disaster management.		The development and organization of workshops is a well developed path of action in Trinidad and Tobago.	This action would affect the general population in a beneficial way because they would gain support in terms of climate change and disaster management from the "facilitators" who will be taught how to assist them in these workshops. Additionally, there is no need of the private sector to support financially the action.			
		3	2	2	2	3	3	3		
Rainwater harvesting	4. Guarantee the water supply to the human settlements and agriculture.	Medium CB	Partially developed framework	Considered in governmental plans without concrete actions	Partially defined institutional mandate	Technology already implemented in T&T	Controversial issue	High investment and participation of the private sector required	Rainwater harvesting from rooftop catchments (Eduardo Torres et al.), Brazil (C. Peixe), St. Thomas, US Virgin Islands (Kalyan Ray et al.)	**27**
		It involves the installation of several water harvest systems, but it is not very demanding in terms of infrastructure requirements.	There are several acts regarding water management in Trinidad and Tobago, but an integration of all of them is needed.	The National Integrated Water Resources Management Policy of Trinidad and Tobago focuses on the importance of guaranteeing water supplies but does not include concrete actions to do so. The responsibilities related to water management are of the Ministry of the Environment and Water Resources, while those of the installation of the harvest system would depend on the agency that is responsible for the implementation		There are companies in Trinidad and Tobago which include the implementation of those systems in their brochures.	Awareness among the population needs to be raised on water scarcity for a better implementation of the action, mainly because the investment would be afforded by the property owners.			

Action	Attended priorities	Economic evaluation	Capacities: Legal	Capacities: Institutional		Capacities: Technological	Capacities: Social		Previous experiences and success cases	Weighted score
				of the National Building Code.						
		2	2	2	2	3	2	1		
Infrastructure and Building Reinforcement	1. Prevent flooding in human settlements. 3. Reduce the damage caused by extreme events in the human settlements.	High CB	Partially developed framework	Not consistent with governmental plans	Partially defined institutional mandate	Technology already implemented in T&T	Controversial issue	High investment and participation of the private sector required	Scotland (South West Scotland Energy Agency).	**22**
		It involves the improvement of the infrastructure of the households of Trinidad and Tobago	The Small Building Code exists, but a broader base is needed for the implementation of the action.	There are no policies or plans in Trinidad and Tobago regarding building reinforcement. Responsibility would need to be defined between the Ministries of Housing and the Environment and Works and Infrastructure.		The insulation and concrete reinforcement are well known technologies in Trinidad and Tobago-	The action can be controversial because it requires a high investment and the benefits are only observed after extreme events take place.			
		1	2	1	2	3	2	1		
Retention ponds	1. Prevent flooding in human settlements, industry and agricultural land. 2. Prevent the erosion of agricultural land. 4. Guarantee the water supply to the human settlements, agriculture and industry.	Low CB	Partially developed framework	Considered in governmental plans without concrete actions	Well defined institutional mandate	Technology implemented abroad	Supported by the general population	No participation of the private sector required	Paraguay (José Barbosa dos Anjos, et al.), Latin America and The Caribbean (Gonzalo Zorrilla et al.)	**33**
		The costs of constructing the ponds are low.	There are several acts regarding water management in Trinidad and Tobago, but an integration of all of them is needed.	The National Integrated Water Resources Management Policy of Trinidad and Tobago focuses on the importance of guaranteeing water supplies but does not include concrete actions to do so. The responsibility water management is held by the Ministry of the Environment and Water Resources.		Even if retention ponds have never been built in Trinidad and Tobago, they have been implemented with positive results in other countries.	The action has been implemented in other countries with successful results and it is beneficial for the general population, particularly those who will make use of the harvested water. Furthermore its implementation does not require any investment from the private sector.			
		3	2	2	3	2	3	3		

Action	Attended priorities	Economic evaluation	Capacities						Previous experiences and success cases	Weighted score
			Legal	Institutional		Technological	Social			
Filter Strips	1. Prevent flooding in agricultural land. 2. Prevent the erosion of agricultural land.	Low CB	Non-existing framework	Considered in governmental plans without concrete actions	Well defined institutional mandate	Technology already implemented in T&T	Supported by the general population	Low or no investment and participation of the private sector required	Filter Strips (C.H. Green and R. Haney), Iowa (Charles Gipp et al.)	**32**
		It does not imply any infrastructure or tools; it can be carried out by the land owners without external help.	There is not a legal framework in terms of land conservation or climate change adaptation for the agricultural sector.	The Ministry of the Environment and Water Resources would be responsible for the implementation of any land degradation related actions. This problem is considered in the National Action Programme to Combat Land Degradation in Trinidad and Tobago 2006-2020, but there are not concrete actions regarding how to prevent land degradation in the agricultural sector.		Even if there are no filter strips in Trinidad and Tobago, the technology needed to construct them is readily available for all the farmers in the country.	No socially controversial issues have been observed in the success cases of the implementation of this action; however, it requires the participation of the private sector, which would be responsible for constructing or assuming the costs of the construction of the filter strips.			
		3	1	2	3	3	3	2		
Permeable pavements	1. Prevent flooding in human settlements. 3. Reduce the damage caused by extreme events in the human settlements.	High CB	Non-existing framework	Considered in governmental plans without concrete actions	Partially defined institutional mandate	Technology implemented abroad	Supported by the general population	No participation of the private sector required	Italy (Gianluca Dell'Acquaa), Cambridge (Sass Pledger et al.), Texas (Texas Asphalt Pavement Association).	**23**
		The cost of the installation of the system is very high. However, it reduces the number of car accidents.	There is not a legal framework regarding the road safety in Trinidad and Tobago.	The National Spatial Development Strategy includes as a policy the sustainable transport in the country, but without concrete actions. The responsibilities need to be defined between the Ministry of Works and Infrastructure and the Trinidad and Tobago National Road Safety Council.		It has been successfully used in other countries. It is a well developed technology.	It is beneficial in social terms because it reduces the rate of deaths and casualties caused by car accidents without creating controversy and does not require participation from the private sector.			
		1	1	2	2	2	3	3		
Beach Nourishment in Tobago	2. Prevent the erosion of coastal land. 3. Reduce the damage	High CB	Partially developed framework	Considered in governmental plans without concrete actions	Partially defined institutional mandate	Technology already implemented in T&T	Controversial issue	No participation of the private sector required	United States (ERDC), United Stated (EPA).	**26**

Action	Attended priorities	Economic evaluation	Capacities: Legal	Capacities: Institutional	Capacities: Technological	Capacities: Social	Previous experiences and success cases	Weighted score
	caused by extreme events in human settlements.	Beach nourishment is costly, because it implies obtaining the sand and the use of the equipment needed for the action.	There is not a specific legal framework for the protection of coastal areas in Trinidad and Tobago, the Town and Country Planning Act and the National Integrated Water Resources Management Policy 2005 include some references but there is not a well defined framework.	The National Spatial Development Strategy includes remarks on the protection of coastal areas, including the need to develop an Integrated Coastal Zone Management Plan, but no concrete actions to protect the Coastal Areas are included. The Ministry of Planning and Sustainable Development is responsible for the National Spatial Development Strategy, however, it is unclear who will be responsible for the development of the Integrated Coastal Zone Management Plan, considering that it needs to account for environmental issues that may fall under the mandate of the Ministry of the Environment and Water Resources. The Division of Infrastructure and Public Utilities is responsible for the physical planning and development control framework of Tobago, but the Comprehensive Economic Development Plan does not focus particularly on coastal area protection.	This technology is not unknown for any coastal country, it is widely used worldwide.	Even if the direct participation of the inhabitants of Tobago is not required for this action, their involvement is required to reduce the illegal sand mining in the beaches of Tobago, which could reduce the effectiveness of this action.		
		1	2	2 2	3	2 3		
Mangrove Restoration in Trinidad	1. Prevent flooding in human settlements, industry and agricultural land. 2. Prevent the erosion of coastal land. 3. Reduce the	Medium CB	Partially developed framework	Considered in governmental plans without concrete actions Partially defined institutional mandate	Technology already implemented in T&T	Supported by the general population No participation of the private sector required	Importance of Mangrove Ecosystem (K. Kathiresan).	**30**
		Mangrove restoration actions have medium costs. With this	There is not a specific legal framework for the protection of coastal areas in	The National Spatial Development Strategy includes remarks on the protection of coastal areas, including the need to develop an Integrated Coastal Zone Management Plan, but no concrete	At the moment, in Trinidad and Tobago mangrove restoration actions are	It is beneficial in social terms, because it can provide financial sources for the inhabitants of the surrounding areas such as timber or fisheries. At the same time, it enhances the biodiversity and offers protection		

Action	Attended priorities	Economic evaluation	Capacities						Previous experiences and success cases	Weighted score
			Legal	Institutional		Technological	Social			
	damage caused by extreme events in the human settlements, industry and agriculture.	approach, the need to plant mangroves is avoided, but there are certain costs related to the restoration of the coastal tides.	Trinidad and Tobago. The Town and Country Planning Act and the National Integrated Water Resources Management Policy 2005 include some references, but there is not a well defined framework.	actions to protect the Coastal Areas are included. The Ministry of Planning and Sustainable Development is responsible for the National Spatial Development Strategy, however, it is unclear who will be responsible for the development of the Integrated Coastal Zone Management Plan, considering that it needs to account for environmental issues that may fall under the mandate of the Ministry of the Environment and Water Resources.		being carried out.	against extreme events such as tropical storms.			
		2	2	2	2	3	3	3		
Parametric Insurance Scheme	3. Reduce the damage caused by extreme event in the agriculture.	Low CB	Non-existing framework	Considered in governmental plans without concrete actions	Well defined institutional mandate	Technology already implemented in T&T	Controversial issue	High investment and participation of the private sector required	The Caribbean (MCII), Spain (Agroseguro), Jamaica (JIIC), Weather Index-based Insurance in Agricultural Development (IFAD).	**30**
		This action has a low cost because it does not require any infrastructure, or particular equipment, but just the development of the insurance program.	There are some acts in Trinidad and Tobago regarding the agricultural sector, but none of them approach the insurance policies, the development of a legal framework would be necessary.	The institutional responsibilities in this case are held by the Ministry of Food Production. Regarding the policies, there is a Strategic Plan 2011-2015 of the Ministry of Food Production, but it does not include any concrete actions on insurance policies.		Insurance programs are widely used in other sectors in Trinidad and Tobago.	This action can be complicated in social terms. Even if it would be beneficial for the farmers, it can be regarded as an additional cost instead of as a way or cutting losses when extreme events take place.			
		3	1	2	3	3	2	1		

Action	Attended priorities	Economic evaluation	Capacities						Previous experiences and success cases	Weighted score
			Legal	Institutional		Technological	Social			
Agriculture & Climate Change Research Unit	1. Prevent flooding in agricultural land. 2. Prevent the erosion of agricultural land. 3. Reduce the damage caused by extreme events in the agriculture. Guarantee the water supply to the agriculture.	Medium CB	Partially developed framework	Considered in governmental plans without concrete actions	Well defined institutional mandate	Technology already implemented in T&T	Supported by the general population	Low or no investment and participation of the private sector required	Tasmania (Tasmanian Climate Change Office), Tasmania (Tasmanian Institute of Agriculture), Technologies for Climate Change Adaptation (Rebecca Clements).	**31**
		It would require hiring a team of scientists and purchasing the required materials.	There are acts regarding the environment and the agricultural sector, but none of them particularly approach the effects of climate change on the agricultural sector.	The institutional responsibilities in this case are held by the Ministry of Food Production. Regarding the policies, there is a Strategic Plan 2011-2015 of the Ministry of Food Production, but it does not include any concrete actions on reducing the vulnerability of the agricultural sector. The same applies to the National climate change policy, which does not particularly address any actions.		There is a Faculty of Science and Agriculture in the University of the West Indies, as well as Caribbean Agriculture Research & Development Institute which focus their work on agricultural research.	The experiences from other countries show that agricultural workers usually get involved in these practices and obtain benefits from them. The results of this action, however, depend highly on the participation of the farmers, otherwise it would be useless.			
		2	2	2	3	3	3	2		
Green Roofs	1. Prevent flooding un human settlements. 3. Reduce the damage caused by extreme events in the human settlements.	Medium CB	Non-existing framework	Not consistent with governmental plans	Well defined institutional mandate	Technology already implemented in T&T	Supported by the general population	High investment and participation of the private sector required	New York Metropolitan Region (Cynthia Rosenzweig et al.), Ottawa (The National Research Council of Canada)	**26**
		There is certain investment required to develop the roofs, however, it is not a big infrastructure construction.	There is not a legal framework in terms of building code or climate change actions.	Governmental actions do not include green roofs. Responsibility would be held by the Ministry of Environment and Housing.		Green roofs are already present in some buildings in Trinidad and Tobago.	Green roofs are usually supported by the general population. However, the action would require investment from the private sector, which can make implementation more difficult.			
		2	1	1	3	3	3	1		
Coral Reef Protection and Restoration	1. Prevent flooding in human settlements.	Low CB	Partially developed framework	Considered in governmental plans without concrete	Partially defined institutional mandate	Technology already implemented in T&T	Supported by the general population	No participation of the private sector required	Philippines (Linda M. Peñalba et al.), Jamaica (United Nations).	**33**

Action	Attended priorities	Economic evaluation	Capacities: Legal	Capacities: Institutional	Capacities: Technological	Capacities: Social	Previous experiences and success cases	Weighted score
	2. Prevent the erosion of coastal land. 3. Reduce the damage caused by extreme events in the human settlements.	This action has low costs because it focuses on the protection of the coral reefs instead, it can be regarded as an awareness raising action. 3	There is not a specific legal framework for the protection of coastal areas in Trinidad and Tobago, the Town and Country Planning Act and the National Integrated Water Resources Management Policy 2005 include some references but there is not a well defined framework. 2	actions The National Spatial Development Strategy includes remarks on the protection of coastal areas, including the need to develop an Integrated Coastal Zone Management Plan, but no concrete actions to protect the Coastal Areas are included. The Ministry of Planning and Sustainable Development is responsible for the National Spatial Development Strategy, however, it is unclear who will be responsible for the development of the Integrated Coastal Zone Management Plan, considering that it needs to account for environmental issues that may fall under the competences of the Ministry of the Environment and Water Resources. 2 / 2	At the moment, in Tobago some coral reef projects have been carried out; however, efforts have been relatively unsuccessful. 3	It is beneficial in social terms, because it can provide financial sources for the inhabitants of the surrounding areas and, at the same time, enhances the biodiversity and offers protection against extreme events such as tropical storms. 3 / 3		
Climate Change Adaptation Tool	1. Prevent flooding in industry. 3. Reduce the damage caused by extreme events in the industry. 4. Guarantee the water supply to the industry.	Low CB The development of the tool does not require a high investment.	Non-existing framework There is not a legal framework regarding vulnerability assessment in climate change.	Not consistent with governmental plans / Well defined institutional mandate The responsibilities of any policy in this field would be held by the Ministry of the Environment and Water Resources. However, there are not plans or policies that consider the option of assessing climate change vulnerability in the private sector.	Innovative technology with few trials It is a cutting-edge and innovative technology. It has been successfully used in some private companies to	Supported by the general population / Low or no investment and participation of the private sector required It would be beneficial in social terms. However, it would imply the private sector's participation in both for the financing and the development of the tool.	Adapting to Climate Change: A Guide for the Energy and Utility Industry (Tiffany Finley et al.). A Systematic Review of the Literature on Business Adaptation to Climate Change (David Nitkin et	**26**

Action	Attended priorities	Economic evaluation	Capacities						Previous experiences and success cases	Weighted score
			Legal	Institutional		Technological	Social			
						assess vulnerability.			al.)	
		3	1	1	3	1	3	2		
Sustainable Drainage Systems	1. Prevent flooding in human settlements and industry. 2. Reduce the damage caused by extreme events in the human settlements and industry. 3. Guarantee the water supply to the human settlements and industry.	Medium CB	Partially developed framework	Considered in governmental plans without concrete actions	Well defined institutional mandate	Technology implemented abroad	Supported by the general population	Low or no investment and participation of the private sector required	Cambridge (Sass Pledger et al.), United Kingdom (Royal Haskoning).	**29**
		They require investment in terms of infrastructure, but it is not very high.	There are several acts regarding water management in Trinidad and Tobago, but an integration of all of them is needed.	The National Integrated Water Resources Management Policy of Trinidad and Tobago focuses on the importance of developing a flood management programme but further definition is needed. The mandate for water management is held by the Ministry of the Environment and Water Resources.		The technology has been widely used in other countries.	It is positive in social terms because it reduces the risk of surface flooding. Depending on its location, the investment may need to be assumed by the private sector.			
		2	2	2	3	2	3	2		
Resettlement of population	3. Reduce the damage caused by extreme events in the human settlements.	High CB	Non-existing framework	Considered in governmental plans without concrete actions	Undefined institutional mandate	Innovative technology with few trials	Not supported by the general population	High investment and participation of the private sector required	Climate Change Adaptation and Mitigation: Implications for land acquisition and population relocation (McDowell, C.A.), Pacific Island Countries (Asia-Pacific Network for Global Change Research), Alaska (The University of	**15**
		They require a very high infrastructure investment.	There is not a specific legal framework for the protection of coastal areas in Trinidad and Tobago. Furthermore,	The National Spatial Development Strategy includes remarks on the protection of coastal areas, including the need to develop an Integrated Coastal Zone Management Plan, but no concrete actions to protect the Coastal Areas are included. The Ministry of Planning and		It has never been done in Trinidad and Tobago or worldwide.	Resettlement of population is usually not supported by the general population. In fact, it is a solution that is usually only carried out if no other options are available. Depending on the terms of the Integrated Coastal Management Plan, the investment will be carried out by the private or public sector.			

Action	Attended priorities	Economic evaluation	Capacities: Legal	Capacities: Institutional		Capacities: Technological	Capacities: Social		Previous experiences and success cases	Weighted score
			there is not a building code in the country or any legislation considering resettlement.	Sustainable Development is responsible for the National Spatial Development Strategy, however, it is unclear who will be responsible for the development of the Integrated Coastal Zone Management Plan, considering that it needs to account for environmental issues that may fall under the mandate of the Ministry of the Environment and Water Resources.			However, it will definitely imply a high participation of the private sector.		Oregon and the USDA Forest Service Pacific Northwest Research Station).	
		1	1	2	1	1	1	1		
Elevation of infrastructure	1. Prevent flooding in human settlements and industry. 3. Reduce the damage caused by extreme events in the human settlements and industry.	High CB	Non-existing framework	Considered in governmental plans without concrete actions	Undefined institutional mandate	Technology implemented abroad	Controversial issue	High investment and participation of the private sector required	Maldives (James G. Titus), Boston (Linnean Solutions, The Built Environment Coalition, The Resilient Design Institute), Homeowner's Guide to Retrofitting (U.S. Department of Homeland Security), New York (Wouter Botzen et al.)	**18**
		They require a very high infrastructure investment.	There is not a specific legal framework for the protection of coastal areas in Trinidad and Tobago. Furthermore, there is not a building code in the country or any legislation considering elevation of infrastructure.	The National Spatial Development Strategy includes remarks on the protection of coastal areas, including the need to develop an Integrated Coastal Zone Management Plan, but no concrete actions to protect the Coastal Areas are included. The Ministry of Planning and Sustainable Development is responsible for the National Spatial Development Strategy, however, it is unclear who will be responsible for the development of the Integrated Coastal Zone Management Plan, considering that it needs to account for environmental issues that may fall under the mandate of the Ministry of the Environment and Water Resources.		It has not been implemented in Trinidad and Tobago, but it has been widely used abroad.	In social terms, this action has been implemented in several countries and it is usually well accepted; however, its high costs for the private sector need to be considered. Depending on the terms of the Integrated Coastal Management Plan, the investment will be carried out by the private or public sector. However, it will definitely imply a high participation of the private sector.			
		1	1	2	1	2	2	1		

Action	Attended priorities	Economic evaluation	Capacities						Previous experiences and success cases	Weighted score
			Legal	Institutional		Technological	Social			
Pumping systems	1. Prevent flooding in human settlements and industry. 3. Reduce the damage caused by extreme events in the human settlements and industry.	High CB	Non-existing framework	Not consistent with governmental plans	Well defined institutional mandate	Technology implemented abroad	Controversial issue	High investment and participation of the private sector required	Homeowner's Guide to Retrofitting (U.S. Department of Homeland Security), Prepare your property for flooding (UK Environment Agency).	**20**
		They require a high infrastructure investment.	There are several acts regarding water management in Trinidad and Tobago, but an integration of all of them is needed. Additionally, there is not a building code regulating the use of pumping systems.	The National Integrated Water Resources Management Policy of Trinidad and Tobago focuses on the importance of developing a flood management programme, but further definition is needed. There are no other actions regarding the use of pumping systems. The responsibilities of water management are held by the Ministry of the Environment and Water Resources.		The technology has been widely used in other countries.	It is positive in social terms because it helps to mitigate the effects of flooding; however, its purpose is more focusing on the effects of the flooding than in prevention. Furthermore, it has high energy consumption. The private sector would be responsible for its cost and installation.			
		1	1	1	3	2	2	1		
Cover crops	2. Prevent the erosion of agricultural land. 3. Reduce the damage caused by extreme events in agriculture.	Medium CB	Non-existing framework	Not consistent with governmental plans	Well defined institutional mandate	Innovative technology with few trials	Controversial issue	High investment and participation of the private sector required	Cover Crops for Conservation Tillage Systems (William S. Curran et al.), Using Cover Crops to Improve Soil and Water Quality (James J. Hoorman).	**21**
		The investment required for the crops is higher than when normal crops are used.	There are some acts in Trinidad and Tobago regarding the agricultural sector, but none of them approach cover crops.	The institutional mandate in this case is held by the Ministry of Food Production. Regarding policies, there is a Strategic Plan 2011-2015 of the Ministry of Food Production, but it does not include any concrete actions on cover crops.		Cover crops are used in other countries, it is a technology that is already known in the past, but, it is not currently widely used.	This action can be complicated in social terms because, even if it would be beneficial for the farmers, it is sometimes controversial because it implies additional costs for the crops as well as additional effort. Furthermore, both the development and the financial costs of the action would be assumed by the farmers.			
		2	1	1	3	1	2	1		
Desalination technology	4. Guarantee the water supply to the human settlements,	High CB	Partially developed framework	Considered in governmental plans without concrete actions	Partially defined institutional mandate	Technology already implemented in T&T	Not supported by the general population	Low or no investment and participation of the private sector required	California (Angela Haren Kelley), The Economics of Desalination for Various Uses	**24**

Action	Attended priorities	Economic evaluation	Capacities				Previous experiences and success cases	Weighted score
			Legal	Institutional	Technological	Social		
	industry and agriculture.	The infrastructure investment and the operation costs are very high.	There are several acts regarding water management in Trinidad and Tobago, but an integration of all of them is needed.	The National Integrated Water Resources Management Policy of Trinidad and Tobago focuses on the importance of guaranteeing water supplies but does not include concrete actions to do so. The responsibility of water management is held by the Ministry of the Environment and Water Resources, but the construction of the infrastructure may be a responsibility of the Ministry of Works and Infrastructure.	There is already a plant producing water with this technology in Trinidad and Tobago.	These types of plants are usually controversial because of their high costs and their effects on the environment. Other ways of guaranteeing water resources are usually chosen before the desalination technology. Depending on the scheme chosen, the plant may have a private or public owner. In the case that it is private, the construction cost may be assumed by the private sector.	(Carlos Campos), Water Desalination: When and Where Will it Make Sense? (Joachim Koschikowski), Perth and Melbourne (Michael G. Porte).	
		1	2	2 2	3	1 2		

Based on the results from the table above, all the actions with a weighted mark equal or higher than 22 points, which was considered the threshold for the implementation of the action, would considered to not face too many difficulties and were selected. Only one exception was made in the case of desalination technology. Even though it received a score of 24 points, it was discarded because the technology is already installed in the country, it has a very high cost-benefit, and there are certain issues related to its operation, environmentally speaking, that make it less suitable than other actions from a sustainability perspective.

In the table below, a summary of the results is shown. As can be seen, all the not - selected actions have a lower mark than 22, except for the desalination technology, which was not included for the reasons mentioned above.

Table 61: Summary of the action prioritization.
Source: Prepared by the authors.

Action	Weighted score	Selected
National Building Code	29	**Yes**
Construction of dikes in coastal areas	23	**Yes**
Meteorological Alert System connected to the Monitoring System	30	**Yes**
Emergency Protocols	29	**Yes**
Social Awareness Program	33	**Yes**
Institutional Training Program	33	**Yes**
Rainwater harvesting	27	**Yes**
Infrastructure and Building Reinforcement	22	**Yes**
Retention ponds	33	**Yes**
Filter Strips	32	**Yes**
Permeable pavements	23	**Yes**
Beach nourishment	26	**Yes**
Mangrove Restoration	30	**Yes**
Parametric Insurance Scheme	30	**Yes**
Agriculture & Climate Change Research Unit	31	**Yes**
Green Roofs	26	**Yes**
Climate Change Adaptation Tool	26	**Yes**
Sustainable Drainage Systems	29	**Yes**
Coral Reef Protection and Restoration	33	**Yes**
Resettlement of population	15	**No**
Elevation of infrastructure	18	**No**
Pumping systems	20	**No**
Cover crops	21	**No**
Desalination technology	24	**No**

In addition to these actions, one additional action was suggested during the stakeholder workshop as a possible measure to be analysed. The suggestion was to include a survey in order to help policymakers and practitioners understand the general public's basic knowledge on climate change adaptation and natural disaster risk management. This suggestion was added as measure TTA 17: Climate Change Survey for the General Public.

6.2. Review of identified actions.

Once the actions were prioritized, the shortlist of climate change adaptation actions was developed further. The list includes sixteen actions, which are classified depending on the type of action, the sector they focus on and the type of investment required. There are four different types of actions: technological/procedural optimisation responses, infrastructure and asset-based responses, systemic/behavioural responses and risk transfer via insurance and alternative financial solutions. Those actions affect the human settlements, coastal zones, human health, water resources and agriculture sectors. Finally, the investment required for each measure may be provided by public investments, private investments, or both.

The table below describes how each of these measures is defined based on these categories:

Table 62: Identified adaptation actions for Trinidad and Tobago.
Source: Prepared by the authors.

Action code	Title	Type of measure	Type of investment	Sector
TTA 1	National Building Code	Technological/procedural optimisation responses	Public investment	Human settlements
TTA 2	Coastal Zone Protection in Trinidad	Infrastructure and asset-based responses	Public investment	Coastal zones
TTA 3	Meteorological alert System connected to the Monitoring System	Systemic/behavioural responses	Public investment	Human settlements
TTA 4	Emergency Protocols	Systemic/behavioural responses	Public investment	Human settlements
TTA 5	Social Awareness Program	Systemic/behavioural responses	Public investment	Human health
TTA 6	Institutional Training Program	Systemic/behavioural responses	Public investment	Human settlements
TTA 7	Rainwater harvesting	Technological/procedural optimisation responses	Private investment	Water resources

Action code	Title	Type of measure	Type of investment	Sector
TTA 8	Infrastructure and Building Reinforcement	Infrastructure and asset-based responses	Private investment	Human settlements
TTA 9	Retention ponds	Infrastructure and asset-based responses	Public and private investment	Water resources
TTA 10	Filter Strips	Infrastructure and asset-based responses	Public and private investment	Agriculture
TTA 11	Permeable pavements	Infrastructure and asset-based responses	Public investment	Human settlements
TTA 12	Beach Restoration and Protection in Tobago	Infrastructure and asset-based responses	Public investment	Coastal zones
TTA 13	Mangrove Restoration in Trinidad	Infrastructure and asset-based responses	Public investment	Coastal zones
TTA 14	Parametric Insurance Scheme	Risk transfer via insurance and alternative financial solutions	Public and private investment	Agriculture
TTA 15	Agriculture & Climate Change Research Unit	Technological/procedural optimisation responses	Public investment	Agriculture
TTA 16	Green Roofs	Infrastructure and asset-based responses	Public and private investment	Human settlements
TTA 17	Climate Change Culture Survey for the General Public	Systemic/behavioural responses	Public investment	Human settlements
TTA 18	Mangrove Restoration in Tobago	Infrastructure and asset-based responses	Public and private investment	Coastal zones
TTA 19	Coral Reef Protection and Restoration in Tobago	Systemic/behavioural responses	Public investment	Coastal zones

Due to the paucity of technical information, there is a certain lack of detailed analysis for some of the actions. It should be stated that this report includes a first assessment of many adaptation measures that could be carried out in Trinidad and Tobago; however, before the implementation of any of these actions, a more detailed analysis should be developed retrieving as much available information as possible from relevant stakeholders, including the affected population and government agencies.

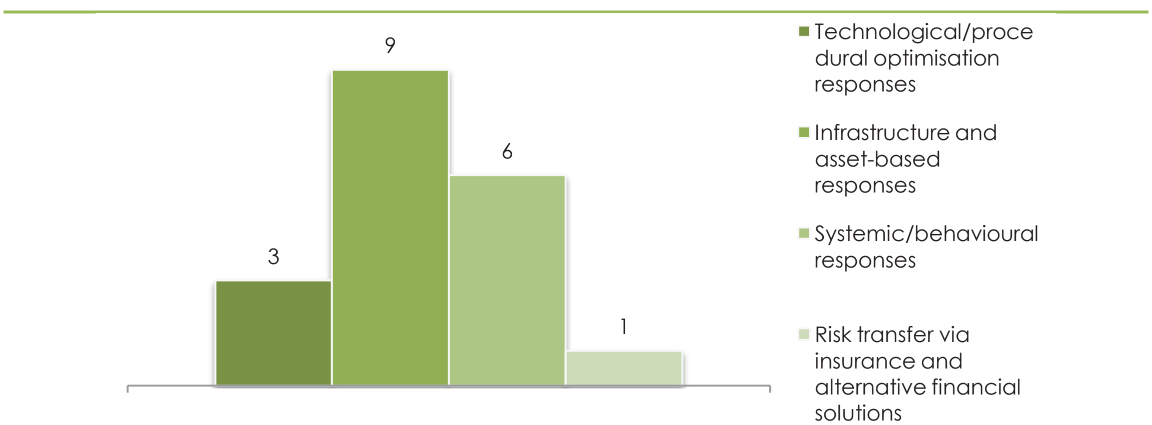
The proposed actions may face some barriers for their implementation in economic, social, institutional or technological terms; however, the factors related to these actions specifically are not the most relevant in terms of affecting the success of implementation. Due to its characteristics and economic organization, Trinidad and Tobago's structure is built around some economic mechanisms that differ from those of many other countries. The oil and natural gas resources of the country have created an environment in which taking action against climate change and its effects may seem like a very complicated task.

To change this situation, the country will have to face several challenges, which may imply changing some of the most characteristic features of its economic system. In fact, some mechanisms such as property, taxes and prices, which worked in a context without the effects of climate change, may need to be completely modified if climate change is taken into account. Otherwise, their negative effects could worsen the effects of climate change in the country.

Additional insight about the characteristics of the identified measures can be obtained by analyzing the actions using three different parameters. The first parameter is the type of action to implement. In this assessment, as explained before, four different types of actions have been defined: technological/procedural optimization responses, infrastructure and asset-based responses, systemic/behavioural responses and risk transfer via insurance and alternative financial solutions.

As shown in the graph below, nearly half of the proposed actions are infrastructure and asset-based responses. The rest of the actions are divided between the systemic/behavioural responses, with a total number of six actions, the technological/procedural optimization responses that account for three actions and one action focused on risk transfer via insurance and alternative financial solutions.

Graph 11: Actions by type.
Source: Prepared by the authors.



Another characterization is the type of investment required for the action: whether the funds are provided by the public sector, the private sector or both. Due to the features of the proposed actions, more than half of the actions would need to be funded by the public sector, while five would make use of combined public and private funding and only two actions would be funded entirely by the private sector of Trinidad and Tobago.

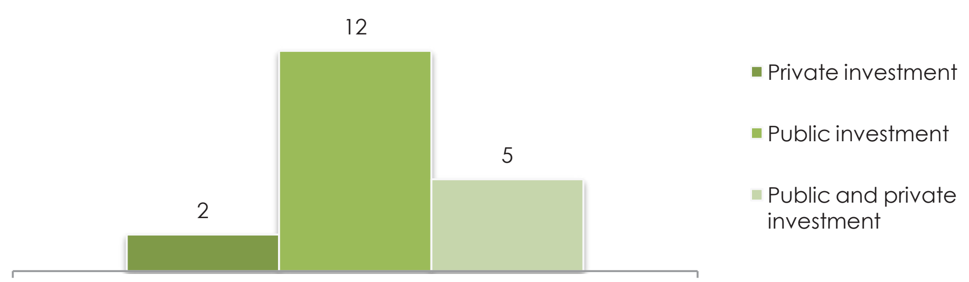
In some cases where both private and public investment is required, Public Private Partnerships may be considered to incentivize private sector investment in order to help promote a public good. Partnerships can be defined as "two or more organizations that enter into a collaborative arrangement based on (1) synergistic goals and opportunities that address particular issues or deliver specified tasks that single organizations cannot accomplish on their own as effectively, and (2) situations where individual organizations cannot purchase the appropriate resources or competencies purely through a market transaction" (Caplan, K., et al, 2007). The Pevensey Bay Sea Defence Scheme, which was the first sea defence project in the world to be funded as a Public Private Partnership, explains the Public Private Partnerships process as:

1. *Bidders are invited to provide offers for the delivery of services over an extended contract period, typically in the order of 20 to 30 years.*
2. *A successful bidder is usually expected to fund the design, construction and commissioning of all assets necessary to provide the service.*
3. *Once the service is available for use, the Contractor is paid an agreed periodic sum that is dependent on the level of service provided.*
4. *The long term contracted cash flow offers security for the Contractor to raise the finance to fund the asset construction.*
5. *Throughout the contract period the Contractor is responsible for the maintenance of the asset.*

They state that within these partnerships, "the prime objective of both is to obtain better value for money in major public procurement and to secure the provision of improved public services more quickly than would be possible under more traditional routes" (Pevensey Coastal Defence Ltd, 200?). Partnerships can be a good tool in order to promote innovation in problem solving and can bring a plethora of diverse resources to the table. They also, however can be quite complex given that each partner often has a different view on how to achieve the partnership's goal and often have different drivers for being part of the partnership (Caplan, K., et al, 2007). Public Private Partnerships require a significant amount of resources to develop and maintain and therefore should only be considered in cases where traditional contractual relationships are not possible.

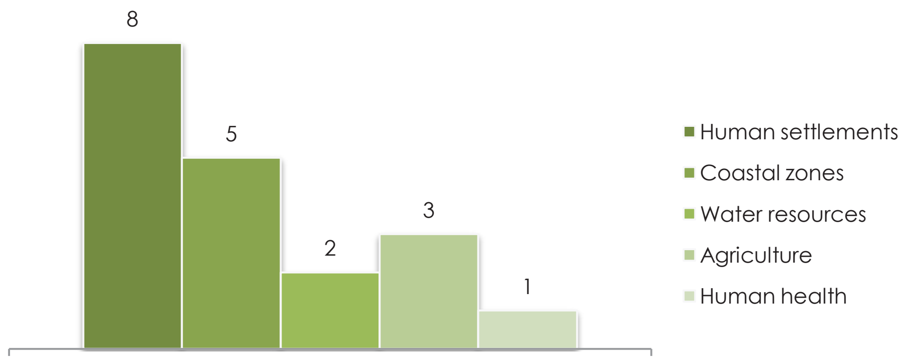
For the several measures presented in this study which could require both public and private investment, most of these initiatives involve investments on both private and public land and therefore incentivization may be required in order to motivate private owners to invest in adaptive measures. This incentivization could be made through subsidy or tax exemption programs thereby having both the public and private sectors jointly investing in the projects. Other measures could include using community based projects in which Nongovernmental Organizations (NGOs) and Community Based Organizations (CBOs) work to promote the activity as a community adaptation measure, involving in-kind resources from the community, such as labour and organizational management, and the public sector providing funding for larger infrastructure related investments. In measures where these types of investment structures and relationships are possible, some specific options are discussed in the measure´s description detailed in the next section.

Graph 12: Actions by type of funding.
Source: Prepared by the authors.



The last classification of the measures is based on the sector they affect. It should be noted that the same actions may have effects on several sectors; however, for the assessment, the sector which the action would affect the most was chosen. As shown below, the human settlements sector includes the most actions. In the case of the coastal zones, five actions have been developed. Three actions have been developed for the agriculture sector, while two actions focus on the water resources of the country and one action is focused on human health.

Graph 13: Actions by sector.
Source: Prepared by the authors.



6.3. Description of the actions.

For every action, an assessment of its implementation and consequences was developed. Below, a detailed analysis of the actions is included. The analysis includes the objective of the action, an explanation of success cases in implementing this action in other countries, the preliminary considerations for the action and a detailed description of every action. Additionally, the description provides the implementation period and expected impacts of every action and the economic, technologic, social, institutional and legal capacity required for the implementation of every action. In the last part of every sheet, the results of the cost-benefit analysis are shown, including the benefit-cost ratios of the actions and the pay-back, as well as the total benefit and total cost of every measure.

For a better understanding of this section, it should be mentioned that the economic assessment of actions TTA 4 and TTA 6 was carried out jointly due to the features of these actions. Therefore, the results of the costs and benefits of these actions are displayed in the sheet of the action TTA 6.

Additionally, it should be noted that TTA 14 does not have any measureable economic benefits, as it is considered that insurance programmes do not modify the overall damage caused by the extreme events. They are useful from a cost-efficiency perspective, but not from a cost-benefit approach, because the economic damage is the same whether or not the insurance programme is developed; the only difference is the way in which that economic damage is covered.

TTA 17 also does not have any economic benefits that can be calculated. The survey will provide information to both policy makers and practitioners, yet without knowing the results of the survey, it is impossible to determine the impact of this information in economic terms.

6.3.1. *TTA 1: National Building Code*

Objective

To develop and implement a code that establishes the building specifications needed in Trinidad and Tobago in order to provide new constructions that are resilient to tropical storms, floods, earthquakes, landslides and rainfall.

Previous experiences and success cases

The use of building codes is a worldwide accepted measure in order to prevent losses from natural disasters. In fact, building codes have proven to be a very successful measure in terms of earthquake damage prevention in countries like Japan and Chile. In Japan for example, when the Great East Japan Earthquake took place, little damage was caused to the buildings designed under the current code by the earthquake itself.

Particularly, in terms of losses caused by tropical storms and tropical storms, in the American area of Grand Isle, located in the Gulf of Mexico, it was proven during tropical storm Isaac that making good use of a building code can prevent losses to a relevant extent. In fact, in Grand Isle, after tropical storm Katrina, the building code was enforced and elevated houses were constructed following the new guidelines. When tropical storm Isaac took place, it was found that the damage in the area was clearly reduced, and furthermore, for the elevated homes built under the current building code, no damage was done.

Building codes are also useful when energy savings are needed, as determined by the different states of the USA when analyzing the benefits of building energy codes.

Lastly, in a study done for the Florida Department of Community Affairs called "Florida Building Code Cost and Loss Reduction Benefit Comparison Study", found that the updated Florida Building Code will benefit Florida homeowners and that "the initial construction cost differential may potentially be offset with reduced deductible costs, insurance costs, and recouped market value of the Building Code improvements."

Preliminary Considerations

There is already a Building Code Committee working on the development of the Building Code. Therefore, the results of the activities carried out by the committee as well as the current status of the development of the building code need to be assessed and considered before proceeding with the sectoral analysis or the development of the code itself.

Furthermore, the decisions taken in the National Spatial Development Strategy of Trinidad of Tobago should also be considered in the design of the Building Code. The Building Code needs to be complemented by the implementation of the National Spatial Development Strategy of Trinidad and Tobago, in which the future spatial development of Trinidad and Tobago is established. This would be the first step for a good implementation of the building code, because it would avoid poorly managed or uncontrolled construction and therefore prevent the risks associated to these practices.

Additionally, before the implementation of this action, it would be necessary to ensure that the mechanisms needed for a widespread implementation are developed. If the building code is established but not enforced, its purpose would not be met.

Description of the action

Using the Small Building Code as the base and adding methodologies for big buildings, a National Building Code can be developed so that architects and engineers have a framework to provide new buildings with climate change resilience. The Association of Professional Engineers of Trinidad and Tobago (APETT), which could develop technical work for the structural components based on the International Building Code (IBC), the Trinidad and Tobago Bureau of Standards (TTBS), which could develop architectural sections and technical work for the structural components and the Trinidad and Tobago Institute of Architects (TTIA), which would focus on architectural sections, could participate in the project as they did in the Small Building Code.

This action includes assessment that needs to be carried out before developing the Building Code. A sectoral analysis should be done to define the current situation of the buildings of Trinidad and Tobago as well as the consultancy work related to the development of the building code itself.

When designing the building code, the hazards faced by Trinidad and Tobago need to be considered. Apart from tropical storms and tropical storms, earthquakes and tsunamis should also be taken into account. Furthermore, the possibility of including energy saving designs should also be assessed.

Once the building code is created, it would need to be passed into law. The full implementation of this measure would require hiring several technicians who would, on one hand, be responsible for disseminating the key features of the building code among the construction sector of Trinidad and Tobago and, on the other hand, ensure that the specifications of the code are met for all construction projects carried out in the country. The engineers would also take part in the development of the new code, providing assistance to the government.

It should be highlighted that, for this action, it is particularly important to have well trained inspectors, who can ensure that all the new buildings are built according to the specifications of the building code. Otherwise, the building code would be useless. In Grand Isle, USA, for every new construction, at least six inspections are carried out and if all the requirements of the building code are not met, the construction cannot carry on.

Implementation period

2014-2030

Impact of the action

Applying a set of simple techniques to make buildings more resilient to climate change effects (tropical storms, floods or earthquakes) could avoid thousands of dollars in infrastructure losses. In addition to infrastructure losses, there are several industry facilities that could suffer from floods, which could eventually stop their production.

There are many examples of the success of building codes in earthquake prone areas, as well as documented examples of their effectiveness when preventing tropical storm and tropical storm losses. Additionally, building codes are currently being considered as one of the paths to reduce the energy consumption of buildings.

Therefore, in Trinidad and Tobago, the establishment and enforcement of a comprehensive building code would help prevent losses by natural hazards and could also be effective in terms of reducing the energy consumption in buildings.

Economic capacity

This investment is low compared with the losses which could be prevented if the building code was enforced. It is not a capital-intensive measure and part of it is already done by means of the Small Building Code. The necessary investment is basically that of the previous analyses needed for the design of the code and the investment needed for the enforcement of the code, which would be made through the hiring of civil engineers who would supervise the construction projects of Trinidad and Tobago.

Technological capacity

Building codes for the purposes needed in Trinidad and Tobago have already been developed in several countries. In fact, there is an already existing International Building Code which could be used as the base for the development combined with the Small Building Code of Trinidad and Tobago. The International Building Code is widely used in the USA and in other countries like Japan or Chile good examples of building codes adapted to the necessities of earthquake prone countries can be found.

In terms of technological capacity, it is crucial to ensure that the analyses carried out before the development of the building code provides the necessary data for the development of the code in terms of the hazards faced. Otherwise, the design of the building code would be incomplete and the objectives intended by its development not met.

Social capacity

Once the National Building Code is written, its publication and distribution is one of the key phases of the program. Architects, engineers and agents who would make use of this code need to receive enough information on its implementation and requirements. The general public should know about its existence too, so they can demand the adaptation of their buildings to the code.

Building codes are many times seen as useless codes which only increase the costs of construction. It has been proven even in places where natural disasters cause high losses and building codes are a very useful tool. For instance, in Grand Isle, many voices criticized the new building code, because it was considered as an extra burden in the construction costs. Therefore, it is important to raise awareness among the population on the usefulness of the code, to convince them about the good effects of its enforcement.

Institutional capacity

On one hand, the governmental must fully support the project due to the large impact it could have in the adaptation to climate change in the country. On the other hand, other institutions participating in the project (TTIA, TTBS and APETT) are the ones who would define the quality level of the final product by their commitment. Having already developed a Draft Small Building Code, there is already some experience in the country and the previous experience would be very valuable in the implementation of a comprehensive building code.

The institutional responsibilities to complete this action would be held by the Ministry of the Environment and Water Resources. Currently the development of a National Building Code is being discussed in Trinidad and Tobago, therefore, it is considered in governmental plans. In fact, there is a National Building Code Committee which is working in the development of the code.

However, the most important fact in terms of institutional capacity is the need of the Government of Trinidad of Tobago to ensure that the building code is enforced. The development of a building code is never complete if the building code is not used, and in many places, when doing so, several difficulties were found. Therefore, only a firm response from the Government, ensuring that if the building code is not respected, construction cannot carry on, would facilitate its enforcement and foster its effectiveness.

Legal capacity

Even if there was a Draft for a Small Building Code, in Trinidad and Tobago, currently, there is not a legal framework regarding building codes. Additionally, once the National Building Code is finished, it would need to be passed into a law. Otherwise, the objectives expected with the building code would not be met; when not mandatory, building codes are rarely put into effect.

Benefit-Cost ratio	**15.9**	**-**	**Total cost**	**4,529,327**	**$**
Pay-back	**1.9**	**Year(s)**	**Total benefit**	**72,151,025**	**$**

6.3.2. *TTA 2: Dike Construction in Trinidad*

Objective

To build barriers that can provide protection against 1.5 meter sea level rise to avoid floods in coastal zones.

Previous experiences and success cases

Dikes are a widely used method worldwide for the prevention of flooding. In fact, in The Netherlands, the river flows have been managed by more than a thousand years. These structures have been used as a protective measure in several countries even before the hazards caused by climate change were taken into account, as proven by the already mentioned example of The Netherlands or the infrastructure in other flood prone areas like New Orleans (USA) or the Mekong River (Vietnam).

In the Netherlands, the flood prevention system is built with the objective of being able to face storms that would occur only once in 10,000 years. To do so, the prevention systems are reinforced and supervised continuously to prevent damage instead of working after the damage is done. In the flood prone regions, such as the already mentioned areas or others like the British Columbia in Canada, currently the efforts are devoted into adapting the existing systems to the predicted future conditions, taking into consideration the effects of climate change. The Economics of Adaptation to Climate Change developed by the World Bank for Vietnam also considers the reinforcement of the coastal and river defences as a key necessity of the adaptation strategy of the country.

Additionally, in Barbados, a Coastal Zone Management Unit was established to carry out and monitor the shoreline protection program, guided by the Coastal Zone Management Plan. The Unit looks at the impacts on coasts from commercial and housing development, drainage, ocean tides and currents, storm and hurricane probabilities, coral reef ecosystems and the rising sea level caused by global warming. It promotes engagement from all stakeholder groups involved in coastal management. Seawall construction, including rip raps, is one of its main infrastructure choices for intervention (Scruggs, G. and Bassett, T, 2013). These construction projects "involve either a riprap design of large rocks or a flat, concrete seawall that can create public space attractive to both tourists and residents, such as the Richard Haynes Boardwalk, partially funded by an IDB loan. Because these techniques can sometimes exacerbate erosion and require more expensive maintenance than natural interventions, their long-term efficacy is up for debate, but, in the short term, they protect the coastline and the tourism industry" (Scruggs, G. and Bassett, T, 2013).

The validity of those systems is proven when extreme events take place in terms of the consequences of those events. For instance, in New Orleans, the effects of tropical storm Katrina proved that the existing system was not valid to ensure the security of the city, and, subsequently, they are being modification to provide better results. This path of action is similar to that observed in The Netherlands, where after a devastating flood in 1953, the dike system was widely reinforced and became a country-level priority.

Preliminary Considerations

The areas in which the barriers are proposed have been chosen for their high population-density and, therefore, vulnerability. However, before the implementation of the action, a more detailed assessment would need to be carried out to determine the needs for every particular area and the best construction solution. To do so, a country-level assessment on flood risks is necessary in order to identify the most vulnerable areas. It should not be forgotten that the assessment should also include the effects of climate change, both in terms of sea level rise and recurrence of tropical storms and tropical storms. Therefore, a long term Coastal Management Plan would be required before the development of this action or any similar initiative. In fact, the need for a Coastal Management Plan is also observed in the Draft of the National Action Programme to Combat Land Degradation in Trinidad and Tobago 2006-2020.

Consultation should also be made with the Integrated Coastal Zone Management Steering Committee, in order to ensure that the activities undertaken in this measure are in line with the integrated Coastal Zone Management policy framework, strategies, and plan currently under development by this entity. This analysis should also include looking holistically at the other measures detailed in this study and understanding where and how they should be integrated together. While the measures are analyzed individually in this study, many of these measures would have increased impacts if they were implemented in conjunction with other proposed measures. Many of the measures regarding coastal management, including the construction of dikes (described here), the restoration of mangroves (TTA 13 and TTA 18) and the protection of coral reefs (TTA 19), will have improved results if jointly implemented. These measures should therefore be looked at holistically and strategically when deciding which activities to implement, ensuring that possible mutual and re-enforcing benefits are captured.

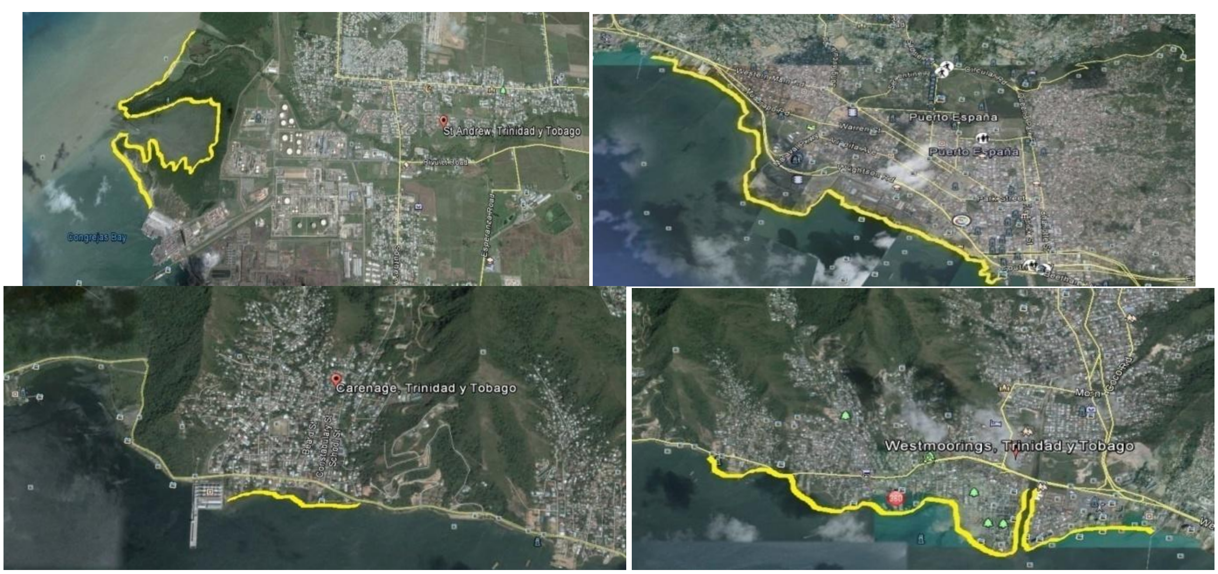
Also, possible Best Practices regarding coastal management planning and stakeholder engagement could be looked at, including the Coastal Management Unit in Barbados, as described in the previous subsection on Previous Experiences and Success Cases.

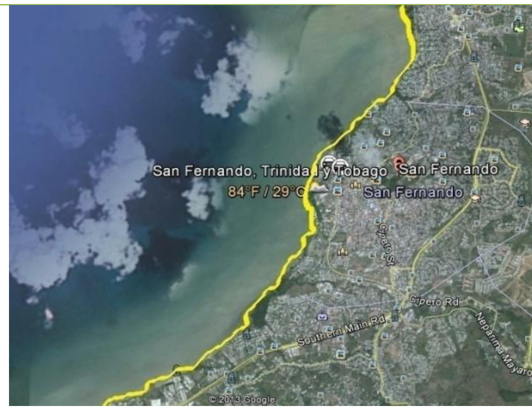
Due to the lack of more detailed flooding information of Trinidad and Tobago (detailed information for Port of Spain is available, for not for other areas), the areas were chosen in order to obtain the necessary information for the economic assessment of the action, but a comprehensive analysis in terms of coastal management was not carried out. As a result, some of the selected areas may already have protection systems and some areas not considered in this action may also require reinforcement. In fact, as stated above, a Coastal Management Plan including a complete local assessment considering the flood regime of the island and the effects of climate change is necessary to detect the areas in which this action would be the most suitable and the best way to implement coastal reinforcement, considering other types of dikes or measures available.

Description of the action

The example action consists in building barriers in coastal zones. Due to its cost-benefit ratio, the barrier type chosen is the riprap. This action includes excavation of a dike root, transportation of the riprap, filling with gravel and revegetation of the area. The dike has a 5 meter width root, 2 meter deep, 1 meter on top and it is 3.7 meter high. The barriers would be set in six different areas: City of Port of Spain (6.5 km), City of San Fernando (8.5 km), Westmoorings - Diego Martin (5 km), St. Andrews (5.03 km), Diego Martin river (1.2 km) and Carenage (0.5 km).

The action would be developed progressively, taking place the construction of the infrastructure in several years. In fact, the action, under these conditions, would not be completed until 2030. However, some sections would be operative in 2020, which means that the benefits of the action, that is, the losses avoided by the improvement of the dikes, would be observed already in 2020.





Implementation period

2014-2030

Impact of the action

The most significant natural hazard risk in the Caribbean is tropical storm risk. Particularly because of the possible large span of territories that could be impacted by any single event (CCRIF, 2013a). Although Trinidad and Tobago is not in the main Atlantic hurricane belt, the potential to be hit by tropical storms still remains, as has happened in the past from a number of tropical cyclones and from the direct impact of two hurricanes since 1850. Strong winds, heavy rainfall and storm surge are some direct hazards associated with tropical storms. Other secondary hazards which can generate important damages are inland flooding generated by the intense rainfall, coastal flooding caused by the storm surge or landslides as a result of the combination of rainfall and flooding. In fact, these risks are the main impacts of tropical storms that affect the Republic of Trinidad and Tobago.

The proposed barrier would protect the coastal zone avoiding the sea water flooding the areas close to coast line buildings and other infrastructure. It would also provide protection to agricultural areas set near the sea line. As an indirect effect, the dike construction would also stimulate the employment, especially in the construction area. The negative aspects of the implementation of this action are mainly its disruption of the coastal dynamics, which may have adverse effects on the ecosystems.

As stated previously, this is a widely implemented action in flood prone areas, having proven its usefulness in many cases. It is important to highlight that the impact of the action will only truly be observed after the extreme events take place, when it is possible to compare to the consequences of other similar events that happened previously.

Economic capacity

The investment required for this adaptation measure is high in absolute terms; however, compared to its benefits, it is definitely a more than reasonable investment. Sea level rise will happen, yet there is still plenty of time to prepare the country, meaning that the investment can be distributed throughout the next 10-15 years. This implies that the action does not require a very intensive economic investment as it can be carried out gradually. The participation of the APETT and the TTIA could be established as a social cooperation plan so a lower budget could be required in exchange for social benefits for the APETT and the TTIA.

It should be noted that, regarding the benefits of the action, until 2020 no benefits are obtained from it since there is not any completed rip-rap section until that year. Therefore, for this action, a wider time-frame would provide a better result in the cost-benefit analysis, because after all the construction work is over, the benefits would overcome the costs.

It should also be considered that, in terms of economic capacity, the experience obtained from the implementation of this action in other countries. A key feature of this kind of action is that benefits are only observed if extreme events take place. Therefore, many times, due to the volume of the required investment, this type of infrastructure is observed as unnecessary. However, as it has been shown in previous experiences through the case studies, the development of this kind of infrastructure as a part of a long term coastal management plan provides more benefits than costs.

This measure is likely not a good candidate for public private partnership given that the incentives for private owners and companies does not warrant private ownership or contractual agreement of the public good. In fact, as explained in the Pevensey Coastal Defence scheme, which was the first sea defence project funded ad a Public private Partnership, "in order for the Contractor to be able to innovate and assume risk, a project needs to comprise a suitable asset/operational split. If the vast majority of the whole life project cost is attributable to the early provision of an asset, for instance a concrete sea wall, value for money is unlikely to be achieved and the project may be little more than a hire purchase scheme. As a general rule at least 50% of the Present Value (PV) costs of a PFI/PPP project need to be made up of annual maintenance and the provision of auxiliary services" (Pevensey Coastal Defence Ltd, 200?).

Technological capacity

This technology was already developed in some of the coastal areas of Trinidad and Tobago. Therefore, there is experience in the country in terms of constructing dikes. However, it would be interesting to consider, when analysing the implementation of the action in depth, the latest technologies implemented in countries that can be regarded as the path to follow, such as The Netherlands. The technologies might not be directly exportable, but would help define the best options for Trinidad and Tobago considering the latest advances in the development of coastal protection measures.

Social capacity

Even if it is regarded as the best example for the implementation of this technology, the construction of dikes is many times regarded as a controversial issue - even in The Netherlands. The visual effect, in aesthetic terms, of this kind of infrastructure is evident and many times the population does not cope well with the construction of dikes. However, if the effect in terms of disaster risk reduction and prevention of losses is well understood, the negative attitudes are usually less. For instance, in the Bulgarian municipality of Shabla, various structures were built to safeguard the coastline and ensure the livelihoods of the local communities. The measures proved effective to "hold the line", stopping the erosion problems of the area, and the increased safety has allowed other economic activities to develop e.g. eco-tourism.

The most negative effects found in Bulgaria are those connected with the aesthetics because the concrete walls and the stony dykes are not compatible with the normal natural landscapes in this area. However, a conscious decision was taken to compromise the natural landscapes in favour of the coastal protection facilities, reaching a compromise between the negative effects in terms of aesthetics and the positive effects in terms of disaster risk reduction. A similar approach could be used in terms of social capacity for Trinidad and Tobago.

In some cases, this project may run into private lands in which, public private agreements will need to be made in order to continue. These agreements will need to be undertaken on a case by case basis, as some private owners may be interested in working with the public sector to protect their own property, while others may not agree to the construction of a dike along their coastal property. In some cases, compensation for land acquisition may be required and in others, although unlikely for this action, resettlement may need to be considered. It is recommended that this process be done through stakeholder dialogue, and be incorporated within the larger integrated coastal management framework in order to ensure that all private owners are heard and understand the bigger picture within which their participation is required.

Institutional capacity

For this action, the institutional capacity is important, firstly, in economic terms, because the investments need to be assumed by the government. However, the role of the Government of Trinidad of Tobago would need to deliver other aspects as well. As stated previously, this measure focuses its benefits in the prevention of risks, that is, on acting before the disaster takes place. Therefore, it is important to change the perspective on how to act when natural disasters take place.

For instance, when tropical storm Shandy reached the east coast of the USA, it was proven that even if in terms of disaster management the USA is one of the leading countries, in terms of disaster prevention their procedures need to be improved. That is the change of attitude that the Government of Trinidad and

Tobago needs to promote both within the authorities and the general population, going from repairing the damage after it has taken place, to preventing the damage before it happens.

Furthermore, the institutional capacity is required also for the development of the action within a national strategy in terms of coastal areas protection. There is already a National Action Programme to Combat Land Degradation in Trinidad and Tobago 2006-2020, which should be considered. The action programme is defined in broad terms and it would be necessary to establish the appropriateness of this action within the objectives set in the programme. In fact, in the programme, the need of a Coastal Zone Development Plan is stated, and it would be necessary to define that plan before this action can be carried out. There is also an Integrated Coastal Zone Management (ICZM) Steering Committee of Trinidad and Tobago which is working on the development of Integrated Coastal Zone Management (ICZM) Policy Framework, Strategies, and Action Plan for Trinidad and Tobago. The results of this work could impact the institutional framework for this measure.

Legal capacity

The legal framework for the protection of the coastal areas of Trinidad and Tobago is poorly defined at the moment. Thus, it would be necessary to develop, as stated before, a Coastal Zone Development Plan, with well defined actions. If necessary, developing a strict legal framework to ensure that the objectives are fulfilled is recommended.

In some cases, this project may run into private lands in which, could cause some legal issues. Agreements with private owners will need to be made. These agreements will need to be undertaken on a case by case basis, as some private owners may be interested in working with the public sector to protect their own property, while others may not agree to the construction of a dike along their coastal property. In some cases, compensation for land acquisition may be required and in others, although unlikely for this action, resettlement may need to be considered. It is recommended that this process be done through stakeholder dialogue, and be incorporated within the larger integrated coastal management framework in order to ensure that all private owners are heard and understand the bigger picture within which their participation is required.

Additionally, when considering the development of the action, in the planning and construction phases, the effects of the action should be considered regarding the legal framework established by the following laws: the Environmental Management Act; the Certificate of Environmental Clearance Rules; the Town and Country Planning Act; and the Public Health Ordinance and the Marine Areas (Preservation and Enhancement) Act. This action implies the construction of infrastructure, which may have negative effects on the environment and, therefore, the laws of Trinidad and Tobago need to be respected when designing and developing the action.

Benefit-Cost ratio	**0.03**	**-**	**Total cost**	**115,554,303**	**$**
Pay-back	**61.6**	**Year(s)**	**Total benefit**	**4,033,247**	**$**

6.3.3. *TTA 3: Meteorological Alert System connected to the Monitoring System*

Objective

To develop an alert system connected to the monitoring systems of two specific parameter groups: 1. Temperature, precipitation and wind speed 2. Sea level. This would help the population of Trinidad and Tobago be prepared in the case of emergency due to tropical storms, rainfall, droughts or floods.

Previous experiences and success cases

Early Warning Systems have proven to be successful at reducing loss of life and injury. In the case of Trinidad and Tobago, early warning systems will likely be the most effective at reducing deaths and injury due to heat waves, flooding, and tropical storms. Analysis presented in the study "A Cost Effective Solution to Reduce

Disaster Losses in Developing Countries: Hydro-Meteorological Services, Early Warning, and Evacuation" by Stéphane Hallegatte estimates that, "in Europe, hydro-meteorological information and early warning systems save several hundred lives per year, avoid between 460 million and 2.7 billion Euros of disaster asset losses per year, and produce between 3.4 and 34 billion additional benefits per year through the optimization of economic production in weather-sensitive sectors (agriculture, energy, and others)." In a specific study done by David Rogers and Vladimir Tsirkunov titled "Costs and Benefits of Early Warning Systems", they explain that in France, early warning systems, along with awareness raising campaigns, are estimated to have saved 4000 deaths during the July 2006 heat wave (this study is described further in TTA 4).

In addition to the reduction of loss of life and injury, Hallegatte notes other benefits that can come with early warning systems, including accelerated economic growth (due to less damages to economic infrastructure), and increased economic benefits to farmers if this infrastructure is also used to provide more accurate weather predictions. They cite a study done by Wills et Wolfe (1998) in which they investigated how the use of forecasts to can help to optimize lettuce production in the state of New York. They find a $900 to $1,000 gain per hectare and per year, or a 10% increase in productivity. Improved weather forecasts have also shown to help improve the efficiency of wind power production, improve predications on energy demand for the energy sector, improve air and sea shipping routes, and reduced road accidents due to preventative measures taken (In Croatia, the socio-economic benefit of hydromet information showed a reduced number of accidents with an estimated economic benefit of 4.3–8.7 million € per year), to name a few benefits mentioned within the study.

Preliminary Considerations

The action focuses on spreading the information related to extreme climate events, but it does not consider the detection of those events, as procedures for this are already in place. Therefore, the procedures at a country level for the detection of extreme events and improvement of the meteorological services should be reviewed and, if needed, improved before carrying out this action to obtain the best results from the implementation of the alert systems, because if the information to feed the system is not good, the system would not have any positive effects. It is also important to understand other programs or initiatives that may overlap in some way with the implementation of this measure, including the "South-South Cooperation Initiative" organized by the Caribbean Risk Management Initiative in which the Cuban Risk Reduction Management Centre model is being studied and piloted in five Caribbean countries, including Trinidad and Tobago, in order to see how this model could be incorporated within mechanisms in these countries. Other programs that should be taken into consideration in the preliminary stages are programs working on the development of emergency protocols and awareness raising campaigns (like those explained in TTA 4 and 5), which would need to be integrated into the development of this measure. Any awareness campaigns and emergency protocols developed should refer to the types of information that will be made available by the alert systems, and the alert systems need to know what type of awareness campaigns are being given in order to understand what type of information the population will be expecting to hear from them.

Description of the action

For the first parameter group (temperature, precipitation and wind speed) weather stations systems are already installed in different strategic places of the country and managed by the Trinidad and Tobago Meteorological Services. For sea level rise, four stations are already installed (Scarborough, Cedros Bay, Charlottesville and Port of Spain). By working closely with the Trinidad and Tobago Meteorological Systems, an alert system would be created to provide information to the population.

The alert system would transfer information from these monitoring systems to the population through 3 different channels: television, internet and radio. The information transmission would take place only when emergencies take place using the radio and the television. The website would always be available and would contain information related to climate, emergency protocols and emergency situations available for any users.

Additionally, it would be interesting to improve the already existing weather system of Trinidad and Tobago in order to obtain meteorological information for more locations of the country, since this could help improve the quality of the information provided.

Impact of the action

This alert system would allow the population to be informed through different communication channels about climate forecasts so the local authorities can be prepared to mobilize the population in case of climate disaster risk. When an ecologic disaster happens, time is the most valuable asset for the emergency services and time is exactly what this system would provide.

Economic capacity

The installation of this system does not require an extraordinary investment. Apart from the infrastructure losses, climate risks involve a large risk of loss of human life, especially in the case of tropical storms. For this reason, when focused on the prevention of human lives, the benefit-cost ratio of this measure is relatively high. This action does not include the installation of new weather stations. If that investment were to be made, an assessment of its cost would be necessary.

This technology is used worldwide and they are currently being installed in many developing countries due to their benefits. As stated previously, many countries have shown that they have more benefits than costs, both in monetary terms and in terms of human lives - as shown in France.

Technological capacity

The meteorological system required for the implementation of the alert system is currently developed. It would require some revision and improvements, but that should not pose difficulties considering that it is an already existing technology in Trinidad and Tobago and that in almost every country of the world meteorological systems are installed.

Regarding the alert system itself, its development is basically a website and TV and radio ads, which are widely used and developed in Trinidad and Tobago.

In fact, in terms of technological capacity, the crucial step is the transmission and processing of the data retrieved in the meteorological stations to determine the alerts that need to be announced. This task would correspond to the Trinidad and Tobago Meteorological Systems, and if necessary, they should be provided with additional training.

Social capacity

The implementation and results of alert systems in other countries show that, in social terms, if the systems are well developed, they are well accepted. It is important to make the system accessible and easy to understand and the messages delivered need to be clear and adapted for the general population.

The system would not require any investments from the general population or the private sector. However, it is important to make them aware of its existence and how does it work to obtain the best results from its implementation.

Institutional capacity

Trinidad and Tobago has the Trinidad and Tobago Meteorological Systems, which would be responsible for the development of the meteorological information. Regarding the disaster management, the country has an Office of Disaster Preparedness and Management, but there is not a developed policy framework for this matter. It would be important to have a clearly defined framework to create the right base for the correct functioning of the system.

According to the Caribbean Risk Management Initiative (CRMI), which received support from the UNDP, the organization is promoting a "South-South Cooperation Initiative" in which they are currently implementing a pilot project for the replication and adaptation of the Cuban Risk Reduction Management Centre model in the five Caribbean countries, including Trinidad and Tobago. The main function of Risk Reduction Management Centres (RRMCs) is "to create better access, documentation and transmission of critical information. To do this, RRMCs use existing and appropriate suitable technologies to help local governments make decisions" (Guerra, J. et al., 2010). This model is considered a best practice by the CRMI, and should be consulted when implementing this measure. It is recommended that this initiative and the actions in this measure be integrated in order to avoid creating separate systems with duplicate information, or worse, systems that provide conflicting procedures/authorities.

Legal capacity

There is an act that covers disaster management in Trinidad and Tobago, the Disasters Measures Act Chapter 16:50 (Act 47 of 1978), but it was developed in 1978, making it obsolete for the current needs of the country. A revision of that act considering the current situation in terms of the development of the country, the hazards faced nowadays, and those expected in the future caused by climate change is needed.

Impact of the action

This alert system would allow the population to be informed through different communication channels about climate forecasts so the local authorities can be prepared to mobilize the population in case of climate disaster risk. When an ecologic disaster happens, time is the most valuable asset for the emergency services and time is exactly what this system would provide.

Benefit-Cost ratio	**96.0**	**-**	**Total cost**	**41,000**	**$**
Pay-back	**0.05**	**Year(s)**	**Total benefit**	**3,935,834**	**$**

6.3.4. TTA 4: Emergency Protocols

Objective

To create emergency protocols in order to teach people how to behave in the case of emergency due to floods, heavy rain falls, tropical storms and heat waves.

Previous experiences and success cases

Capacity Building and Awareness Raising Programs are an integral part of any preventative measures program. The understanding of the importance of capacity building at the local level has become widely accepted and understood within the last several decades amongst all development organizations and institutions. According to the World Food Programme, "Globally, disaster risk is increasing due to climate change and population growth and disaster frequently bring with them a food crisis. Yet there is increasing evidence that investments in reducing risk are cost effective. Studies show that one dollar invested today in disaster risk reduction saves four dollars or more in relief and rehabilitation costs in the future".

In a case study looking at the Reducing Vulnerabilities in Ahuachapán and Sonsonate Programme (PRVAS) in El Salvador (within the report titled "Local governments and disaster risk reduction: good practices and lessons learned" from UNISDR), which focuses on building collaboration between stakeholder groups and providing capacity building amongst stakeholders, found that "communities are always the first responders to emergencies, and it falls to local government to help communities respond. It is critical to build local capacity for this".

In a study done by David Rogers and Vladimir Tsirkunov titled "Costs and Benefits of Early Warning Systems", they explain the case of the French National Heat Wave Plan (NHWP) which was evaluated for its impact during the July 2006 heat wave. The alert system gives public authorities three days' prior warning and preventative awareness raising measures included modifying the behaviour of the public, health institutions and health authorities in times of high temperatures. The analysis suggests that about 4,000 deaths were avoided during the 2006 event, mainly due to the public awareness and the NWHP.

Preliminary Considerations

Trinidad and Tobago already has some national and local emergency plans, including the Draft Disaster/Emergency Standard Operating Procedures & Contingency Plans, the National Flood Contingency Plan and the City of Port-of-Spain Mass Egress Plan. Furthermore, there are currently some draft plans which are being developed, for events such as tsunamis, earthquakes, storm surge or oil spills.

For the development of the emergency protocols indicated in this measure, an in-depth revision of the current situation in terms of emergency protocols would first be needed, revising the already existing plans to make them suitable to the impacts of climate change and developing a comprehensive framework that would cover all the risks faced by Trinidad and Tobago and, at the same time, would clearly establish the area covered by each plan.

Also, any programs related to the development of alert systems and social awareness campaigns should also be looked into in order to ensure that the development of emergency protocols is congruent with the programs and procedures developed in these areas (like TTA 3 and 5). Any awareness campaigns and emergency protocols developed should refer to the type of information that will be made available by the alert systems. Conversely, the alert systems need to know what type of awareness campaigns are being given in order to understand what type of information the population will be expecting to hear from them.

Description of the action

Using the national and local plans of Trinidad and Tobago as the starting point, this action would focus on developing accessible protocols that would include prevention measures, information related to food and water supply, communication channels and emergency services and first aid kit and procedures. As stated above, to enhance the results of the action, it would be necessary to have a well defined framework in terms of emergency procedures both at the national and local level, because the emergency protocols for the general population would be developed based on the information from the national and local plans.

It is important to highlight that the objective of the protocols is to facilitate the understanding of the national plans, taking into account that they need to be understood by all the inhabitants of the country. Therefore, they would be developed using simple language, clear indications and pictures when possible.

Once the protocols are developed, it is crucial to make them available to the population. In this action, the website created for the alert system would be improved to include also the information regarding the protocols. In addition, TV and radio ads would be created informing citizens about the existence of the protocols, the most important information contained in them, and how to obtain them. In fact, yearly, a campaign would be launched in both radio and TV to keep the population educated and up to date about the emergency protocols.

Implementation period

2014-2030

Impact of the action

People knowing how to act in the case of emergency can save time, which is often the most valuable asset in emergency cases. These protocols would allow people to take care of themselves so that they do not need special services to help them. This in turn would mean that emergency services would have to devote less effort to help the general population and allow them to focus on the people and places where they are really needed.

Currently, as stated before, there are already some plans implemented in Trinidad and Tobago for emergency situations. However, the action focuses not only on developing plans but also on making them accessible for the general population, which is the key for their success. The action would facilitate the process of spreading the emergency protocols of the country, making the general population aware of the best procedures in case extreme events take place.

Economic capacity

This action, as stated before, focuses on spreading the procedures of the national and local emergency plans, in order to teach the population on how to behave when climate change related emergencies take place in Trinidad and Tobago. Therefore, the economic costs of this action are mainly those related to the development of the protocols and their diffusion, which do not imply high economic investments.

Furthermore, from the experiences of the implementation of emergency protocols in other countries, it can be stated that, in general, the benefits provided by them are higher than their costs, greatly facilitating the management of emergency situations and avoiding losses in terms of money and human lives.

Technological capacity

The development of this action in itself does not imply technological challenges. Emergency protocols are widely used, as shown in the success cases, and at the country level there are already documents developed for the general population on how to behave in emergency situations. The action would also imply adding the content of the protocols to a website and creating and emitting TV and radio ads, but none of those steps should pose any difficulties.

Social capacity

Previous experiences similar to those proposed in this measure, particularly the example of El Salvador, provide a crucial message to understand the social impact of this action. As stated above: "Communities are always the first responders to emergencies, and it falls to local government to help communities respond. It is critical to build local capacity for this". In general, the local communities and private entities are willing to cooperate, but the government needs to provide them with the tools. In this case, they need to be provided with information about emergency protocols in order for them to be able to act following the indications of the protocols.

Institutional capacity

Trinidad and Tobago has some national and local plans and several drafts on how to act in cases of emergency. However, it is important to create a well-defined framework, covering all the risks faced by the country, while, at the same time, avoiding having linked or doubled entities responsible. The Office of Disaster Preparedness and Management could act as the managing institution, coordinating all the efforts to develop a country policy in terms of emergency preparedness which would be the base for the creation of emergency protocols.

Legal capacity

Apart from the already mentioned national and local plans, there is an act that covers disaster management in Trinidad and Tobago, the Disasters Measures Act Chapter 16:50 (Act 47 of 1978), but it was developed in 1978, making it obsolete for the current needs of the country. At the moment, a revision of that act is being carried out. It is important to develop the revision considering the current situation in terms of the development of the country, the hazards faced nowadays and those expected in the future caused by climate change is needed.

The Cost Benefit Analysis for TTA 4 has been jointly calculated with TTA 6

6.3.5. *TTA 5: Social Awareness Program*

Objective

To develop a social awareness program to sensitize people about two topics: responsible water consumption and water temperature increase.

Previous experiences and success cases

As mentioned in TTA 4, capacity building and awareness raising efforts have been widely accepted as important aspects of any program working to improve the conditions, or management of natural resources, natural disaster risk management, etc. By improving the population's understanding of the importance of natural resource management, and by offering information regarding ways in which they can improve natural resource management through their own habits, the demand of natural resources, like water, can be greatly reduced. These types of campaigns have been widely used in sectors such as energy efficiency and water management, with positive results in many cases.

As an example, a capacity building project in the Philippines, by the Asia-Pacific Network for Global Change Research, had objectives to increase the awareness, knowledge and capability of Communal Irrigator's Associations on alternative irrigation water management, climate forecast application, rice production systems and social mobilization. The project reported that they successfully completed these objectives and that in addition, "aside from the lectures provided by the experts, the vulnerability assessments and the experiences that these CIAs shared helped in identification of the most appropriate recommendations and good practices they need to improve their capacity as an organization and as individual farmers".

Another good example of the effect of capacity development comes a report titled "Cross-Cutting Perspective C: Capacity Development and Social Learning" in which they mention a pilot project in Indonesia in which Water User Associations (WUAs) were empowered through capacity development, appropriate regulatory changes were made, and local staff of the Irrigation Services were trained as "facilitators". The report states that "Where conventional rehabilitation projects traditionally have had an Economic Rate of Return (ERR) of 10-18%, an economic analysis showed that, when an enhanced capacity of the WUAs was realized, the ERR rose to 30-40%. The conclusion seems to be justified that the social capital of the water sector is the 'heart of the matter' while the works are the 'vehicle' through which the capacity is built."

Preliminary Considerations

To enhance the results of this measure, the Office of Disaster Preparedness and Management has partnered with the Ministry of Local Government, other government ministries and agencies, NGOs, CBOs and the private sector in order to create CORE (Communities Organized and Ready for Emergencies), which provides localized programs in order to help prepare high risk communities against natural disasters. This institution could be consulted in order to gain experience regarding local contexts in Trinidad and Tobago and best practices found in terms of social awareness campaigns in high risk regions.

It would also be interesting to make use of the results obtained in TTA 6, the Institutional Training Program, in which key agents of Trinidad and Tobago will be taught about the climate change hazards the country faces. The results of this action would be improved if those key agents participated actively in the development of this action, providing help with the design of the program, taking part in the workshops for farmers, distributing the brochures to the general population and the farmers, and providing support and their experience.

Also, any programs related to the development of emergency protocols and early warning systems should also be looked into in order to ensure that the development of social awareness campaigns is congruent with the programs and procedures developed in these areas (like TTA 3 and 4). Any awareness campaigns and emergency protocols developed should refer to the type of information that will be made available by the alert systems. And likewise, the alert systems need to know what type of awareness campaigns are being given in order to understand what type of information the population will be expecting to hear from them.

Description of the action

This action focuses on raising awareness among the population of Trinidad of Tobago about the scarcity of water and the temperature increase caused by climate change. To do so, in this action, the development of a social awareness program is proposed. As a first step, a general communications strategy would be developed, which would then be developed in more detail to address two different target audiences: the general population and the agricultural workers of Trinidad and Tobago.

For the general population, brochures based on the contents of the program would be created and distributed, while, for the agricultural workers, apart from the creation and distribution of specific brochures, workshops in which information related to avoiding water evaporation in agriculture and health tips would be created and provided. Six different locations, five in Trinidad and one in Tobago, would be chosen for the workshops.

The program would be developed in close collaboration with the Ministry of Health in order for it to be coherent with other actions carried out within the same subject. The contents of the program would also be included on the website created for the alarm system, (more information can be found in TTA 3). The contents of the program would be updated every year depending on the needs of the population, the farmers workshops would be held every year and their contents revised every two years The same applies to the brochures, which would be revised every two years.

Implementation period

2014-2030

Impact of the action

Changing some habits could help people adapt more easily to water scarcity and temperature rise, especially during the dry season. In measure TTA 7 some rainwater harvesting techniques are advised which can also be helpful for these purposes. As stated in the success cases, raising awareness is a key factor when trying to manage climate change related hazards, such as water scarcity and the risks derived from the increase of temperature.

This action would enhance the knowledge of the general population and farmers of Trinidad and Tobago on how to prevent the effects of the temperature increase and how to fight the water scarcity that the country may face in the future due to climate change. The combined effect of this action and TTA 6 would improve the results of this action, because in that way, as stated in the success cases, the results are better because the local agents would act as "facilitators" in the implementation of the action.

Economic capacity

The costs of this measure involve the design of the program, the elaboration and printing of brochures and the development of the workshops for farmers. The investment required is not high and, if the action is applied making the best use of the "facilitators" as explained before. From the results of similar programmes carried out in other countries such as Indonesia or the Philippines, it can be stated that the benefits would be larger than the costs of developing the program in Trinidad and Tobago.

Technological capacity

This action does not involve many difficulties in technological terms, due to its design. It consists in developing a program, creating brochures and developing workshops, which technologically do not involve any special effort.

Social capacity

The social capacity is one of the key aspects for the implementation of this action, because its outcome depends highly on the social impact of the measure. As seen in the previous experiences, when the implementation of this kind of actions is well developed in social terms, their outcome is enhanced. To do so, it would be helpful to involve the key agents detected in TTA 6 in the development of the action, considering their opinions for the development of the program and having them help in the dissemination phase, taking part in the farmers' workshops, distributing the brochures among the general population, and involving the population.

Institutional capacity

For this action, the efforts of the institutions of Trinidad and Tobago need to be focused on involving the general population and the farmers to obtain the best results. Therefore, it is key to have properly identified the "facilitators", a task that would be executed in TTA 6 and for which the help of the institutions is essential.

Additionally, the Office of Disaster Preparedness and Management has partnered with the Ministry of Local Government, other government ministries and agencies, NGOs, CBOs and the private sector in order to create CORE (Communities Organized and Ready for Emergencies), which helps provide localized programs in order to help prepare high risk communities against natural disasters. The program is in its third phase, with the first two phases focused on tackling the issues of flood mitigation and safer building with residents in high risk communities. This third phase is focused on emergency planning on an individual level with particular emphasis being placed on preparedness for persons with special needs (ODPM, 2013). This program could be a very good institution through which to provide these social awareness campaigns, incorporating their knowledge of the local context into the programs design in order to ensure local "buy in" of the information being transmitted.

Regarding the institutional framework, Trinidad and Tobago counts with a Climate Change Policy, in which awareness raising is considered, stating the need to carry out actions relating to it. However, there are not any concrete actions defined, so it would be necessary to develop in more detail the policy, including concrete actions, and, if necessary, passing a climate change act in Trinidad and Tobago.

Legal capacity

There is an Environmental Management Act in Trinidad and Tobago, but is not particularly focused on Climate Change. It has a broad focus on environmental issues in general. Therefore, if it is considered that a solid legal framework is needed for the implementation of the action, the framework would have to be created.

Benefit-Cost ratio	**0.5**	**-**	**Total cost**	**198,787**	**$**
Pay-back	**∞**	**Year(s)**	**Total benefit**	**98,240**	**$**

6.3.6. *TTA 6: Institutional Training Program*

Objective

To deliver an integrated capacity-building program that provides key required knowledge and skills on climate change impacts and responses targeted at a cluster of governmental and/or municipal decision-makers and system operators/workers. The knowledge delivered focuses on "what to do" in practical sense for these actors to enable adaptation actions on the ground in their respective projects, programs and institutions. As precursors, general knowledge on climate change must be covered to ensure that recipients understand chains of causation for the chief hazards affecting a range of economic and development sectors. Clear advice would then be given on the adaptation menus and decision-making protocols and feasibility methods that improve the specific skills that they require as "implementation knowledge and skills", enabling them to be ready to act in response to both emergency situations as well as to foster longer term risk reduction and adaptation policies and actions.

Previous experiences and success cases

By ensuring that public institutions are sufficiently prepared, it ensures that processes and procedures are conducted with increased efficiency in the event of a disaster. An example of a capacity building program that has helped increase institutional capacity is the Natural Disaster Mitigation Project in Honduras, which worked to build the disaster risk management capacity of institutions at the local and the central level through a participatory approach. The project supported the implementation of disaster risk management (DRM) programs in about one third of the countries' municipalities. The results reported included the reduction of local vulnerability by establishing 95 municipal disaster emergency committees and 375 local emergency committees. Additionally, the legal and institutional framework for Disaster Risk Management was improved. In 2009 the SINAGER Law was passed which established a formal DRM system for Honduras and "led to the strengthening of key agencies such as the Disaster Preparedness and Response Agency (COPECO) and the Ministry of Environment (SERNA), and the implementation of a disaster awareness campaign. All these activities have helped to promote a culture of disaster prevention in the country". As a result, when Hurricane Agatha hit the country, World Bank officials state that government officials implemented the learnings that they had received during the program and had also "followed the procedures that had been established through the SINAGER law". According to the World Bank, "Honduras was able to avoid a significant number of deaths because project-supported early warning systems and the SINAGER law meant thousands of people were evacuated from areas subsequently flooded by the storm, especially from among the poorer population living in vulnerable informal settlements (12 people died in Honduras, while 160 died in Guatemala)".

Another example comes from Colombia, which has been recognized for its success in integrating a dedicated climate change unit within the government in order to advise on climate change topics. One important aspect of this teams' development is the continual education and capacity training that they receive on climate change topics. In the case study report, Michael Comstock, Ignacio Santelices and Anmol Vanamali from the Center for Clean Air Policy (CCAP) state, "having a highly qualified and stable team is critical to designing and implementing high-quality policies and giving continuity over time to the medium- and long-term climate change plans and strategies. Critical to Colombia's model are appropriate training for staff, continual updates for the team, participation in international events and negotiations (both by political authorities and technical staff), and climate change plans that adapt to always-changing international interests".

Preliminary Considerations

Before the preparation and development of the program, a gap analysis would be conducted to determine the required participants that need to be included in the workshops and training. As a first step, the key government and municipal authorities would be asked to propose a set number of their key staff that they wish to be trained via this program. These would then be contacted, questionnaires regarding the titles of their jobs, typical tasks, responsibilities in relation to disaster risk management and longer term adaptation, and "what they know" and "what they don't know" would be sent to them. Some of the participants would also be interviewed individually or in small groups to better understand their needs. These inputs would guide the problem setting and structuring of the program's contents, in terms of topics to be covered and the key learning outcomes required. In this way the program would be fit for purpose and a substantial contribution to participant's skills would be guaranteed, based on this detailed assessment of the existing degree of knowledge of the proposed participants, in order to prepare adequate material for the target audience.

Description of the action

The capacity building program includes 6 workshops in different locations of the country every year. They would each be four-day long workshops, with a maximum participant group of 40 people. The workshops would be organized targeted at the most relevant social and institutional agents, selected by the key partner organisations in the most climate impact-vulnerable sectors.

The attendants would be selected according to a range of selection criteria (to be developed) such as the participants' capacity to influence people when any of the weather/climate risk situations arise. They shall include people such as actors in the national civil risks contingencies membership, local mayors and their environmental management staff, staff of Risk Management Units (in agricultural ministries, in municipal bodies, water resources managers), police agents, community leaders, key social workers working with vulnerable groups and so on. Workshops should be carried out at different levels according to the identified needs of Central Ministries, Regional Corporations, Municipalities and other local-level actors.

The trainers would be selected from a "pool" of respected climate change and sectoral experts, as well as project management practitioners. These workshops would be coherent around two learning objectives. Firstly, the training team will provide the participants with general information about global and regional climate change, how it is being researched, the key results of Intergovernmental Panel on Climate Change (IPCC) assessments and of regional bodies such as the Caribbean Community Climate Change Centre (CCCCC) and its programs. The current realities of already-experienced impacts and expected ones on Trinidad and Tobago would be careful analysed. Second, with a more practical focus, training would cover information about the design of a series of sector-based alert and monitoring systems (sea surge, flash flooding, landslides, tropical storm, drought etc), and we would discuss institutional roles along the chain of response as expressed in emergency response protocols. Attendant social awareness programs for all vulnerable sectors would be examined. Coordination with the Office of Disaster Planning would be sought in order to obtain the best results. As well, the range of longer term adaptation policies and measures covered in this IDB program would be explained, and potential roles of the participants explored.

Implementation period

2014-2030

Impact of the action

Disaster risk management and climate change adaptation measures depend critically on the "human factor". In understanding of the nature of vulnerability (which is a function of exposure, sensitivity and adaptive capacity), in many cases little can be done to reduce the key component of exposure, whereas much can be done to build up the capabilities of human agents, their livelihoods and institutions to enable better management of natural and social systems. That is why, apart from providing information for the general population, it is important to have well-trained professionals who can manage situations as they arise, distribute responsibilities for delegated responses across society and in some cases provide direct instructions to potentially-affected population on how to act when in danger due to extreme events, or when impacted on longer time scales by other consequences of climate change. In this way, substantial material and human losses can be avoided.

Economic capacity

This action has a low investment requirement since the only costs are those due to the gap analysis, and for the preparation, development and evaluation of the workshops. As well there are costs related to follow on evaluations of the impacts and benefits of the training to improved performance, as part of institutional assessments. Therefore, economic factors should not be a barrier to development.

Technological capacity

Almost no technology is needed to develop the action. What would be needed it access to good quality training facility with computing equipment and other facilities for modern training provision.

Social capacity

In social terms, a key factor for this action is the selection of the participants in the workshops. Participants of the workshops need to be picked carefully. It would be a good practice to invite the core government institutions to propose their most relevant candidates and employ a selection protocol in which the potential participants are required to submit an Application Form that describes their current and future professional roles and how they would make use of the skills and knowledge from the course to better fulfil their responsibilities.

Institutional capacity

Government has several roles in this action. On the one hand, it determines how this program can be applied to the modernization of its organisations and how to the program can contribute to better Climate Risk

Management integration into the strategic planning and thinking of government. They provide the core funding for hiring the training technical assistance, steering design and delivery of the workshops, as well as evaluation of outcomes. As well, Government, either at Central, Regional Corporation or Municipal levels, would be encouraged to rigorously select the most appropriate participants.

Regarding the disaster management, the country has an Office of Disaster Preparedness and Management, but there is not a developed policy framework for this matter. It would be important to have a clearly defined framework to create the right base for the correct functioning of the system.

Additionally, in the National Climate Change Policy of Trinidad and Tobago, capacity building is considered, but there are not any concrete actions included.

Legal capacity

There is an Environmental Management Act in Trinidad and Tobago, but is not particularly focused on Climate Change, having a broad focus on environmental issues in general. Therefore, if it is considered that a solid legal framework is needed for the implementation of the action, the framework would have to be created.

In terms of disaster management, apart from the national and local plans, there is an act that covers disaster management in Trinidad and Tobago, the Disasters Measures Act Chapter 16:50 (Act 47 of 1978), but it was developed in 1978, making it obsolete for the current needs of the country. At the moment, a revision of that act is being carried out. It is important to develop the revision considering the needs for capacity building in Trinidad and Tobago.

These Costs and Benefits are for both TTA 4 and TTA 6.					
Benefit-Cost ratio	2.1	-	Total cost	1,659,793	$
Pay-back	0.9	Year(s)	Total benefit	3,545,712	$

6.3.7. *TTA 7: Rainwater Harvesting*

Objective

To install rainwater harvest systems and storage tanks in some of the households in Trinidad and Tobago in both in urban and agricultural areas in order to fight droughts.

Previous experiences and success cases

Rainforest harvesting has proven to help reduce water demand pressures on the public utilities, and help increase water security within the country.

According to a publication from the Organisation of American States, rainfall harvesting technology has proven to be very affective in several Latin American Countries and most of the Caribbean Islands where cisterns are the main source of water for residents. In the British Virgins Islands, for example, rainwater harvesting has proven to be very effective at reducing the demand for water from the public water system. They also note that rainwater harvesting provides a buffer in times of water scarcity and natural disasters, or other emergencies. Due to the specific terrain challenges in the British Virgin Islands, rainwater harvesting has also helped communities which have been hard to access by the public water utility.

Additionally, in a study titled "Rainwater Harvesting for Sustainable Drainage and Non Potable Use in the Schools of Rio de Janeiro, Brazil", they found that the school board showed significant enthusiasm for implementing rainwater harvesting systems. In addition, preliminary studies regarding water quality did not show any problems related with using the rain water for non potable purposes. They also noted that the project should have significant impact in reducing the risk of flooding in the near area, which is an often significant problem.

In St. Thomas, US Virgin Islands, the building code stipulates the mandatory installation of a rainwater harvesting tank on every new residential building. There is no requirement to the design or construction materials for these systems. Many of the homes are constructed so that at least a portion of the rainwater is collected into tanks typically stored under the house. Water testing has shown that the water captured from these tanks can only be used for non-potable uses.

Preliminary Considerations

In order to reduce the water consumption in Trinidad and Tobago, water harvesting is a good practice, but it would not be totally effective unless enough information is given to the population regarding the adequate use of the water resources in the country.

Furthermore, one of the problems faced for the implementation of this action is that it needs to be profitable for the agent who would carry it out. Therefore, the government would need to work on the development of water tariffs adapted to the water resources of the country, in order to provide profit for those who install this kind of system.

Description of the action

This action would be developed through the installation of rainwater harvesting systems in the households of Trinidad and Tobago. A complete installation of rainwater harvesting systems and storage tanks in each household roof could provide water for irrigation and for other domestic activities such as cleaning or doing the laundry.

In the action, the calculations are based on the installation of one tank which can hold a volume of 2 m3 of water in each system. The cost of the tank represents an important part of the total system's cost and there are large economies of scale in tank costs as their volume increases. Furthermore, other associated costs are also included in the economic assessment of the action, such as the installation of the harvest system and the filters.

The action would be implemented progressively in the already existing households of the country, with the objective of having tanks installed in the 1% of the total households of Trinidad and Tobago by 2030. To enhance the implementation of this action, in the Building Code proposed in TTA 1, this action could be demanded for every new house constructed in Trinidad and Tobago.

Implementation period

2014-2030

Impact of the action

The wet season in Trinidad and Tobago takes place from June to December. During this period, the rainfall goes from 144 mm (September) to 269 mm (June). This means an average rainfall of 231 litres during this season. This action aims to harvest as much of that water as possible, to store it, and to use it for laundry, agricultural use or other activities. That way, the dependence of the households on the water system would be reduced. In addition, if the harvested water substitutes water produced by means of desalination technology, the energy use and polluting consequences of the activity would be avoided because the water would be obtained using a sustainable and low-impact solution.

Similar actions carried out in Caribbean countries and Brazil have had good results in terms of water harvesting and its use, proving that they can be helpful to avoid water scarcity in drought times, as well as prevent flooding when heavy rains take place. In fact, it was proven that it can help communities with complicated access to freshwater obtain water from other sources, which can have a beneficial effect particularly on those most vulnerable.

Economic capacity

If the action is considered as a whole, the investment needed for its implementation, compared to that of other actions, would range as medium. However, in this case, since the investment would be carried out by private owners, the economic capacity should not be regarded only as the whole cost of the action but the cost of the installation of a single system should also be assessed. This would range around 425 USD for the type of system proposed in the action, considering the average area of the households of the country.

The stated cost is not a very high investment, but it can be significant for part of the population. To facilitate the implementation of the action, the government could subsidize a small percentage of the purchase or the maintenance of these systems, or provide lines of credit for those who are not able to afford the costs of the installation.

Technological capacity

The installation of the systems does not imply any technological challenges. These systems are used worldwide, and, as shown in the previous examples it can be installed even in not very developed areas. In Trinidad and Tobago, there are companies which currently have these systems as part of their product catalogue.

Additionally, there are many standardized tank types (thatch, tarpaulin, tube, mud, dome, thai, plate, pumpkin, open frame ferrocement, etc…) and also many different materials to build the harvest system and the filters.

Social capacity

The application of this action would depend highly on the social factor. People who are not aware of the water scarcity would probably not be willing to spend money on this kind of technology. Also, people who are economically prosperous are less likely to try to save money using these kinds of techniques. However, this action would be beneficial for all the inhabitants of Trinidad and Tobago because it would help fight the water scarcity problem and would also prevent damage caused by intense rainfall.

Therefore, it is important for the success of the action to raise awareness among the population on the water scarcity issues in the country. TTA 5 could help greatly with this. That way, the importance of this action would be better understood and its implementation would be greater.

Institutional capacity

In terms of an institutional framework, Trinidad and Tobago has a National Integrated Water Resources Management Policy, which establishes the principles of water management in the country, but does not include particular actions in terms of the management of water supply in the country.

Regarding the economic aspects of the action, the institutional capacity is also important. In order to promote its implementation, the government may be required to finance the installation of the system in the most vulnerable households. This could imply funding part of the costs or providing credit with low interest rates.

Legal capacity

When it comes to water management in Trinidad and Tobago, the major legislative instruments are the Water and Sewerage Act (1980 Revised); the Waterworks and Water Conservation Act (1980 Revised); the Environmental Management Act (2000 Revised); and the Public Health Act (1950). There is however a need for a new legislative framework to create a new paradigm of integrated water resources management.

Regarding the installation of the systems, an option to promote their implementation would be to include this action within the new Building Code proposed in TTA 1, creating a legal framework for the water harvest systems. However, the need for an integrated water management legal framework would still exist and that framework would need to be aligned with the integration of the water harvest systems in the National Building Code.

Benefit-Cost ratio	**0.7**	**-**	**Total cost**	**1,714,977**	**$**
Pay-back	**24.9**	**Year(s)**	**Total benefit**	**1,180,476**	**$**

6.3.8. *TTA 8: Infrastructure and Building Reinforcement*

Objective

To reinforce 10% of the total households by isolating the ceiling and the walls and reinforcing concrete roofs in order to make them resilient to floods, rainfall, tropical storms and heat waves.

Previous experiences and success cases

Reinforcing homes by improving insulation and reinforcing roofs can prove to have an immense impact in reducing damages during natural disasters and reducing energy demand. Success cases are similar to those found in TTA 1, as reinforcing houses makes them more structurally sound, and hence they will be structurally more similar to buildings built under a more stringent building code. As explained in TTA 1, in the American area of Grand Isle, located in the Gulf of Mexico, it was proven during tropical storm Isaac that making good use of a building code can prevent losses to a relevant extent. Damage in the area was clearly reduced, and furthermore, for the homes built under the current building code, no damage was reported. Additionally, in a study done for the Florida Department of Community Affairs called "Florida Building Code Cost and Loss Reduction Benefit Comparison Study", found that the updated Florida Building Code will benefit Florida homeowners and that "the initial construction cost differential may potentially be offset with reduced deductible costs, insurance costs, and recouped market value of the Building Code improvements."

In terms of energy efficiency, isolating homes has proven to reduce energy consumption by 11 kWh per m2 in Seville, mainly due to reduced use of air conditioning units during heat wave and summer months. Additionally, according to an energy efficiency project done Scottish and Southern Energy aimed at reducing energy, the program worked to help 63% of surveyed households improve insulation in their homes in order to improve energy efficiency. The project reported that "the average energy efficiency of households has increased by 21% as a result of the insulation measures".

Preliminary Considerations

This measure focuses on retrofitting the already existing homes and having a Building Code in which measures against tropical storms are included for new buildings. However, it would be necessary, in addition to these actions, to provide information to the population about the need to install tropical storm straps in households to prevent losses caused by extreme wind.

Additionally, before the implementation of this action, it would be necessary to ensure that the mechanisms needed for a widespread implementation are developed. If the building code is established but not enforced, the purpose of this action would not be met.

Description of the action

The action is focused on reducing the losses created by floods, rainfalls, tropical storms and heat waves. To do so, it focuses on two different aspects of the households: the insulation and the reinforcement. On the one hand, it implies the installation of insulation on the walls and ceiling. On the other hand, the action implies reinforcing the roof with concrete.

The isolation of household walls and ceilings would maintain the temperature of the building and keep the inside area of the walls dry - avoiding any moisture. The reinforcement would prevent the possible detachment of the ceilings in adverse wind conditions such as when a tropical storm takes place.

Regarding the economic terms of the action, it focuses on creating an economic program to retrofit the already existing households, which would need to be financed by the government. Additionally, the action includes the implementation within the Building Code of these reinforcement requisites in order to ensure that all new buildings obtain the same high level of resilience.

Implementation period

2014-2030

Impact of the action

As seen in the success cases detailed previously, when reinforcement actions are applied in households, the damage caused by extreme events is reduced. In this case particularly, that would mean reducing the damage caused by the wind when tropical storms hit Trinidad and Tobago.

Furthermore, the installation of the isolation in ceiling and walls would help avoid heat losses, having an important effect on the energy expenses in households with an air conditioning system, because the better insulated ceiling and walls would reduce the energy consumption of those devices.

One of the relevant aspects of this action is that it focuses on acting before the extreme event takes place, instead of doing so once the damage is done. That is an advantage compared to other actions, because, that way, economic losses are avoided.

Economic capacity

The total cost of isolation of walls and ceiling, and reinforcement of the roof for a household is around 1,500 USD. However, this measure is not especially expensive compared to the losses that the household owner could face in the case of extreme weather events. The implementation of this action would imply the government developing an economic programme in order to facilitate the financing necessary for the investment of retrofitting the already existing houses in the country.

The economic programme would need to be developed taking into consideration the fact that providing funding from the government may prevent the implementation of the action making use of private economic resources. That is, it needs to be ensured that the funding provided is used if no other options are available and that it does not collide with more efficient autonomous mechanisms by which the action could be implemented.

In fact, the funding provided by the programme would only be available for already existing households, while for the new buildings no funding would be provided, but the implementation of the action would be compulsory because it would be required by the National Building Code.

Technological capacity

In technological terms, the implementation of the action is not complicated. Both the reinforcement and the installation of the insulation are executed through well known techniques and they are not strange to the construction sector of Trinidad and Tobago. Furthermore, as stated previously, those technologies are widely used in many countries.

Social capacity

One of the key factors for the implementation of this action is the involvement of the population. Many times, these activities are ineffective because the general population does not believe in their effectiveness. Therefore, even if it is economically funded, it is necessary to inform the population about the purpose of the action's importance - for both new and existing buildings.

Preventive actions like this are many times seen as useless and only increase the costs of construction. This has been proven even in places where natural disasters cause high losses and building codes are a very useful tool. For instance, in Grand Isle, many voices criticized the requirements in terms of reinforcement of the new building code, because it was considered as an extra burden in the construction costs, even if it was proven to be effective in terms of damage prevention. Therefore, it is important to raise awareness among the population on the usefulness of this action, not only by funding it but also by promoting its benefits, to convince them about the good effects of its implementation.

Institutional capacity

The institutional capacity regarding the enforcement of this action needs to focus on two aspects: the economic funding and awareness raising. There is not clear policy on how to minimise the effects of climate change on households in Trinidad and Tobago, therefore, the government would need to work on that in order to define a path of action. It would also be necessary to define the rights and responsibilities regarding the implementation on the action, determining who will be responsible for the evaluation of its implementation.

Furthermore, in order to obtain the best results from the action, it would very important to highlight the benefits obtained from it, both on already existing buildings and new buildings. A particular focus should be given to relevant for new buildings, given that funding would not be provided by the government, but rather by the private sector.

Legal capacity

The legal framework for this action would be the National Building Code of Trinidad and Tobago. Nowadays, there is a Small Building Code in the country, but it would be necessary to create a comprehensive code to create a legal background and ensure the implementation of the action through legal tools.

Benefit-Cost ratio	**0.5**	**-**	**Total cost**	**61,820,734**	**$**
Pay-back	**35.4**	**Year(s)**	**Total benefit**	**27,911,274**	**$**

6.3.9. *TTA 9: Retention ponds*

Objective

To build water retention reservoirs that can harvest rainwater for industrial, agricultural and domestic use in the most drought-risk and vulnerable areas with high proportions of the local population relying on rain-fed agriculture. These would follow best practices: reservoirs lined with impermeable lining and with water inflow and outflow infrastructure installed. This is to ensure that the maximum quantities of water can be harvested in the latter part of the dry-season, and then distributed to users after conservation and during dry seasons, to augment supply for local uses. The management of these would be tied to use of seasonal forecasts, with stricter use regimes imposed when more severe drought conditions are forecasted as likely.

As a secondary program, unlined retention ponds on a larger-scale sited in locations set along river courses, can serve to extend floodplain capacity, and would be built to augment capacities to store large volumes of water along river courses. These would usually exceed local community capacities and require co-financing by the private sector or municipal actors. The construction of unlined retention ponds is not included in the economic quantification of the action and would need to be assessed separately.

Previous experiences and success cases

Retention Pond technology increases water supply for irrigation purposes and livestock watering in areas with chronic water shortages.

According to a report done by Organization of America States, Paraguay has used this technology extensively, in which areas of low topography used for rainwater storage are known as tajamares. These are served by distribution canals that take water from the storage area to its point of use.

Additionally, in 2008, FLAR and CIAT initiated a project called "Transformation of upland to irrigated rice through use of water harvesting in Costa Rica, Mexico, and Nicaragua" in which the objective was to introduce water harvesting techniques, training of local staff, and demonstration of economic benefits of a diversified rice-based production system under irrigation. According to Zorilla et al. (2010) in "10 Improving Rice Production Systems in Latin America and the Caribbean", "in Jalapa Department in north-central Nicaragua, one farmer planting irrigated rice during the dry season reported a yield of 10.5 t/ha, and a net profit of US$2,000/ha. This compares with net profits of less than US$100/ha for rainfed maize and less than US$50/ha for rainfed beans grown during the rainy season".

Preliminary Considerations

Due to the spatial and temporal availability of the water across the two islands, localised imbalances occur, resulting in water shortages being experienced by the population. The ability to supply all the competing demands for water is further affected by bottlenecks in the water supply infrastructure. At the moment, Royal Haskoning is working on the development of a flooding map for Port of Spain. In this map, all the information related to the water cycle of the city is displayed. As a preliminary stage, prior to carrying out this action, the tools used for this assessment should be extended to the whole country, in order to determine the most suitable positions for the ponds, as well as the required pond volumes.

Description of the action

The key initial measure involves building pilot 21 ponds in different areas to catch rainwater, along the lined, high-capacity water storage reservoir model explained in Images 1 and 2 below, which would constitute the second phase of the project. The ponds are distributed between 4 different areas, three of them located in Trinidad: North eastern North Range (6 ponds), Piarco (6 ponds) and Gulf of Paria (6 ponds); and one Tobago: Scarborough (3 ponds). The ponds would have dimensions to be determined by site characteristics but typically could be of approx 10 m length and width (or 14m diameter, if circular), with a depth of at least 2 m, making them suitable for most locations even when the land availability may be scarce. Therefore, the volume of the proposed ponds would be of approximately 157 m^3, with a surface area of 78.5 m^2. The action includes maintenance of these ponds on a reoccurring basis. Maintenance includes removal of silt accumulation, repairs to any infrastructure of the ponds.


Implementation period

2014-2030

Impact of the action

Harvesting rainwater via reservoirs could mean saving thousands of dollars every year, especially in agro-industrial uses given the large demand for water in these processes. Furthermore, due to the water supply difficulties of the Trinidadian system, the ponds could help reduce the dependence on the desalination systems, thus, reducing the impact of this process on the environment. For ground water, these ponds, once scaled-up beyond these planned pilot-investment actions, can help water recharge and positively impact down-valley water supplies. This would act against scenarios of reduced rainfall that would produce less ground water recharge.

As lined reservoirs, the proposed ponds are surface water systems that can help ameliorate the issue of rising temperatures increasing evapotranspiration rate, which together with less available precipitation would negatively impact storage in reservoir systems. Given that water demand is rising, these few ponds are only expected to have demonstration roles, as to tackle the larger challenges, of greater overall demand and less per capita water availability, programs must meet rising water demand by reducing over-abstraction from aquifer systems. Additionally, a further benefit of ponds (especially when combined with check dams) when located in higher parts of the catchments, is that these can increase the resilience to flooding, which is why they would be distributed in areas where the rainfall is especially intense and floods could produce more damage. The Trinidad & Tobago water authorities are not currently prepared to provide water for agricultural activities since this is not considered a priority, or an economically viable sector. Additionally, the level of demand in most locations outstrips the level of available resources. Shortfalls might otherwise, for high value crops, require exploring additional desalination to mitigate the shortfall, which is a very costly option.

Economic capacity

Given that there is a certain investment required and the private sector would benefit from the project, a good option to finance the investment would be proposing a joint investment between the government and the private sector in order to share the total cost of the ponds. Another model is to work with community water organisations and NGOs to propose these reservoirs as Community Based Adaptation measures, and to request support from municipal authorities to provide funds and machinery for the larger scale excavations needed. A possible third model would be joint investment with organizations such as producer cooperatives or produce buyers along the agricultural value chain, which could also be a suitable solution for farmers that use the harvested water for agricultural land irrigation.

The previous experiences, as in the example from Nicaragua, show that the ponds can be beneficial for the agricultural sector, because they improve the water supply.

Technological capacity

There would be a considerable need to draw on learnings and best practices from other Caribbean nations about the kinds of technology best suited to different kinds of reservoirs and ponds. These, when lined and planned to be used for water supply under drought risk, require careful placement (for example avoiding sites under flood risk or landslip risk) and a staged construction process is needed to properly excavate the land, compact layers and ensure that linings are successful in eliminating risk of future leakages. As for machinery, the excavation machines are readily available in Trinidad and Tobago, but these may need to be supplied by partners such as municipal governments. Other inputs are concrete channels to collect incoming water from the catchment and direct this to the reservoir, sand and gravel filters, and distribution tubing to end users. Operation and maintenance would require activities such litter and debris removal, grass cutting, vegetation pruning and weeding and aquatic vegetation management.

Social capacity

Each project, on a case by case basis, would need a coalition of stakeholders and support agencies to enable its correct development. When end users are farming communities, then these need to be affiliated and supported in estimating their needs, which can be articulated for example via local NGOs or other actors, such as socially-skilled municipal authorities. Construction requires complex sharing of responsibilities as well as procurement of inputs such as the plastic material for reservoir lining. Later, it is important to use the harvested water responsibly, both in industries, farms and households. Therefore the use of the harvested water should be regulated and all the users of water should be aware of its scarcity and the need to use it responsibly.

Institutional capacity

As explained previously, the institutions or parties involved in this project would be the government of Trinidad and Tobago, the farms or companies that would benefit from the water harvested in these ponds, municipal authorities, NGOs and farming inputs support and product purchasing enterprises. The action is not likely to cause conflicts other than those derived from the selection of the construction sites of the ponds, which would need to be chosen depending on the expected final use of the harvested water. Additionally, if a joint investment approach is chosen with other parties, the government would have to work out the details of agreements. However, this should not pose much difficulty.

In terms of an institutional framework, Trinidad and Tobago has a National Integrated Water Resources Management Policy, which establishes the principles of water management in the country, but does not include particular actions in terms of the management of water supply in the country.

Legal capacity

When it comes to water management in Trinidad and Tobago, the major legislative instruments are the Water and Sewerage Act (1980 Revised); the Waterworks and Water Conservation Act (1980 Revised); the Environmental Management Act (2000 Revised); and the Public Health Act (1950). There is however a need for a new legislative framework to create a new paradigm of integrated water resources management.

Benefit-Cost ratio	**0.2**	**-**	**Total cost**	**279,616**	**$**
Pay-back	**∞**	**Year(s)**	**Total benefit**	**47,027**	**$**

6.3.10. TTA 10: Filter Strips

Objective

To build filter strips in order to avoid floods in agricultural areas. These filters also remove the pollutants that are diluted in the water stream by filtering them out.

Previous experiences and success cases

According to the summary report of watershed projects in Iowa, many of the projects in terms of watershed management include filter strips as a measure to reduce erosion, reduce flooding, and improve water quality. Briggs Woods Lake Watershed Management Project, for example, noted that "The lake at Briggs Woods Park, built in 1968, was filled with algae blooms and submergent plant growth because of sediment and nutrient loading. The lake was losing capacity much earlier than its planned life span". They reported that "filter strips and upland buffers were… helpful in reducing the amount of sediment and nutrients reaching the lake". In addition, the Hacklebarney Watershed Protection Project was aimed at "reducing sheet and rill erosion, improving water quality in Viking Lake, reducing flooding, and improving water quality in the Nowadays River Basin". They reported that "nearly $2 million was spent to apply more than 24 miles of terraces, 33 grade stabilization structures, 27 water and sediment control basins, 58 acres of riparian forest buffers, and almost 500 acres of filter strips and buffer strips".

Another report done by C.H. Green and R. Haney from the USDA-ARS states a case study that looked at the effectiveness of vegetative filter strips to limit feedlot runoff pollution. The results showed that cropped buffer strips "reduced runoff on a 4 percent slope by 67 percent and decreased total solids transport by 79 percent. Total phosphorus was reduced by 80 percent. They also cited a study done by the Nebraska Cooperative Extension in which they found that filter strips are "more effective in removing sediment than nutrients, are more effective when runoff is of a shallow depth, more effective with sod-forming vegetation, less effective when the cropland area drained is increased as compared to the filter strip area, less effective as more sediments and nutrients are kept in the filter strip and less effective when the filter strip is not appropriately maintained". The document summarizes the ecological benefits of filter strips as being "the roots of plants stabilize the soil by increasing soil aggregation; the shoots of plants protect soil from absorbing forces of wind, water and raindrop impact; vegetation provides shade that impacts soil moisture content; strips act as a noise filter; nutrients are recycled, limiting stress to crops and animals caused by dry summer winds and cold winter winds that can cause reduced production".

Preliminary Considerations

Even though the technology required for this action is low, a previous assessment on the land conditions should be carried out to assess where to build the filter strips. Furthermore, those in charge of building them should have enough knowledge about their characteristics and design in order to construct them appropriately and with the best results.

Description of the action

This action consists in building filter strips in the 0.01% of the agricultural area of Trinidad and Tobago (it represents the 10.5% of the total surface of the country, that is, 540,000,000 km2). Those strips prevent the effects of heavy rainfall in terms of flooding and erosion, as well as reducing the pollutants contained in the water. The action would be carried out gradually along the whole period, being the same surface of filter strips being built every year.

This type of strips are gently sloped, vegetated strips that can be very helpful in areas that are not steep, being are also a helpful tool to prevent the negative effects of heavy rain on agricultural land. In the design of the action, it was considered a ratio of 1 m2 of strip for every 50 m2 of agricultural land. However, that ratio can be modified to adapt it to the characteristics of the land and the climate conditions in order to enhance the results obtained by the use of the filter strips.

Implementation period

2014-2030

Impact of the action

Given the fact that 99.1% of agricultural holders were individuals, households or sole proprietors, 86.6% of owners worked on a permanent basis on their holdings, and 58% percent of all agricultural holders reported that farming was their only occupation (15.5 % had farming as their first occupation while for 24.8% farming was their second occupation), ensuring the quality and protection of agricultural land has a large, direct impact on the population that works within the agricultural sector (CSO TT, 2004).

As shown in the previous experiences carried out in the USA, the setting of filter strips would increase the resilience of the agricultural land against floods, thereby reducing the quantity of losses every year. They would also slow the rate of runoff, allowing sediments, organic matter, and other pollutants that are being carried by the water to be removed by filtering them out. With this action, apart from limiting the effects of flooding, the risk of landslide can be reduced because the water runoff is slowed down.

Economic capacity

The investment required for this action is low; however, the economic capacity is a key factor because it would be carried out by the land owners. This technology has been used effectively in other countries, therefore, its implementation should be promoted on the basis that, even if it means an economic effort, its benefits outcome the costs for the farmers.

Technological capacity

Even if Trinidad and Tobago's agricultural land may not count with filter strips, in the country, the technological development of the country allows constructing them easily without the need for any special tools. It is key, in terms of technological capacity, to provide the farmers with enough information on how to build them, detailing the design features that need to be considered when building them and, if necessary, organizing workshops to provide the farmers with enough information. Both TTA 5 and TTA 15 include within their development the organization or workshops for farmers. If necessary, the information on filter strips could be included in the workshops of those actions.

Social capacity

The effectiveness of the action will depend on the willingness of the farmers to implement it and that needs to be enhanced by providing them with enough information on how will the filter strips help them. As stated above, if necessary, workshops could be organized to provide information to the farmers. This type of action is not controversial itself, but, since it implies the efforts of the farmers for its construction, it may require some efforts to foster the construction of the filter strips.

Institutional capacity

The climate change policy of Trinidad and Tobago includes information on the vulnerability of the agricultural sector, but does not define concrete actions on how to minimise it. Additionally, the National Action Programme to Combat Land Degradation in Trinidad and Tobago 2006-2020 includes actions to combat land degradation but not as specific as this one. Therefore, on the one hand, it would be necessary for the institutions to develop a framework, with concrete actions and milestones on how to fight the effects of climate change on the agricultural land.

Furthermore, particularly for the implementation of this action, the institutions would also need to devote efforts to showing the farmers the benefits of the filter strips, because, otherwise, it might be complicated to implement the action.

Legal capacity

There is an Environmental Management Act in Trinidad and Tobago, but is not particularly focused on Climate Change. It has a broad focus on environmental issues in general. In the National Action Programme to Combat Land Degradation in Trinidad and Tobago 2006-2020, strengthening environmental regulation and enforcement support structures at the national and regional levels are considered, but observed as a tool of last resort. However, it is also mentioned that, sometimes, it is the only way to obtain the expected results, and that, if necessary, the legal framework would be created.

Benefit-Cost ratio	**0.7**	**-**	**Total cost**	**487,080**	**$**
Pay-back	**24.9**	**Year(s)**	**Total benefit**	**356,132**	**$**

6.3.11. *TTA 11: Permeable Pavements*

Objective

To build permeable pavements on 10% of the total road network of the country - targeting the busiest roads - in order to make them more resilient to floods and therefore safer for drivers.

Previous experiences and success cases

According to a study done in Lamb Drove specifically designed to understand the benefits of sustainable urban drainage systems (SUDS) measures, the program has reported significant benefits. In the study, the specific SUDS implemented included water butts, permeable paving, a green roof, swales, filter strips, detention and wetland basins and a retention pond. The study included a separate permeable pavement infiltration study, done by Cranfield University, which demonstrated "the robustness of the performance of this feature to limited maintenance" and that the permeable pavement was able to "adequately cope with the highest recorded rainfall intensity at the Study Site".

Additionally, in a study done in Italy titled "Freeway Crashes in Wet Weather: the Comparative Influence of Porous and Conventional Asphalt Surfacing", which looked at the crash rates due to the replacement of dense asphalt to porous asphalt, found that "the circumstances have proved, despite little maintenance over the years, the effectiveness of the surface drainage thanks to the macrotexture presence which facilitated the expulsion of water by the wayside. There was also an increase in safety due to the drivers' behaviour with the elimination of the water film, even in non-adverse meteoric conditions, increasing the real perception of tire adherence on the road surface."

Lastly, in a report looking at the benefits of Permeable Friction Course (PFC) Hot Mix Asphalt On Interstate Highways In Texas, benefits were explained in detail, with examples from Texas and other states in the US. The report listed benefits from permeable pavements as being: enhanced safety, reduced pavement noise, improved ride quality, improved vehicle fuel efficiency and improvement in the quality of storm water runoff. As an example, the report states that "in one case study conducted over a 7 year time span, Texas reported that by replacing a conventional surface with a PFC, wet weather accidents were reduced by 93% and fatalities were reduced by 75%. Another study on IH-35 in Texas, where PFC was placed as an overlay on an existing concrete pavement, resulted in more than 50% reduction in wet weather accidents."

Preliminary Considerations

Before carrying out the pavement substitution, a good practice would be to inspect the drainage system of the roads and improve it if necessary. This preliminary action is recommended due to the fact that, even if the permeable pavement helps avoid flooding problems, a good functioning drainage system is even more important. If not working properly, the use of permeable pavements is not as effective as it could be. Furthermore, this action would help in times of heavy rainfall, yet it would not be a complete solution for the flooding of roads; a functioning drainage system is compulsory in order to achieve that objective.

Description of the action

The action consists in building permeable pavements on 10% of the road network in order to ensure the safe driving. The roads chosen would be part of the main roads of the road network. These include: Eastern main road, Southern main road, Naparima Mayaro road, Uriah Butler highway, Churchill Roosevelt highway. The reason for focusing on those roads is the fact that they are the busiest roads in the country. Therefore, they are the ones in which the improvements would reach the largest amount of citizens. The pavement would be used to replace the current pavements when renovation is needed in the roads; the new types of pavement are to be applied only in those roads where the old pavement needs to be changed. This action does not include the installation of permeable pavement in roads where the current pavement is in good state, but only on those requiring renovation actions.

Depending on the vehicles that use each road, different pavements may be required. There are many different pavements that are adapted specifically to industrial application or commercial traffic. Pavement types include: previous concrete (can bear frequent traffic), plastic grids (allows for a 100% of porous system), porous asphalt (mixed at conventional asphalt plants, but fine aggregate is omitted from the mixture), single-sized aggregate and many others. Therefore, for every road the most suitable technology needs to be chosen, considering the climate conditions of the road, the traffic rates and other characteristics.

Implementation period

2014-2030

Impact of the action

Rain and floods make the roads slippery and difficult to drive on. Many times, this leads to traffic accidents that could have been avoided if the conditions of the road were better. In Trinidad and Tobago, the traffic accidents are responsible for 2.58% of total deaths, or 200 deaths a year. There are 3.000 motor vehicle accidents a year. Applying these statistics to the main roads, it is estimated that at least 10% of the total traffic accidents could be avoided if the conditions in bad weather are improved. That would mean less fatal accidents as well as less injured people.

In fact, the experiences from other countries such as UK, Italy or the USA show that permeable pavements are useful for this purpose, reducing the accidents up to a 93% in Texas. Even if the figures obtained of the application of this action in Trinidad and Tobago are not as high as the ones obtained in Texas, any improvement is good, because traffic accidents are a major cause of deaths and cause as well a high number of casualties.

Economic capacity

This technology requires a high investment, even if it is used only when renovation actions in the roads are needed. However, given the results obtained in other countries with its development, which include increase in safety, reduced pavement noise, improved ride quality, improved vehicle fuel efficiency and improvement in the quality of storm water runoff, their installation needs to be considered. Furthermore, this activity has as the objective to save human lives, which makes its cost more justifiable.

Technological capacity

This technology is not used in the country at the moment. However, as shown in the success cases, it has been successfully used in several countries, from which the know-how for its application could be transferred to Trinidad and Tobago.

Social capacity

In social terms, the improvement of roads is rarely observed as a controversial issue. In fact, on the contrary, an improvement in the state of the roads is highly beneficial in social terms, because it reduces the number and severity of traffic accidents.

Institutional capacity

In terms of policies or plans, apart from the inclusion of the need to prioritise sustainable transport as a policy in the National Spatial Development Strategy for Trinidad and Tobago, there is not a particular framework regarding the improvement of road safety at a country level. The mandate in this matter is divided, because even if the Ministry of Works and Infrastructure, particularly the Highways Division for the roads, is considered in this measure, it is responsible for the maintenance of the roads; there is a National Road Safety Council which has the goal of injury prevention and collision reduction on Trinidad and Tobago's roadways.

Legal capacity

There is not a legal framework for the road maintenance and safety in Trinidad and Tobago. The National Road Safety Council and the Ministry of Works and the Environment would need to develop one if it is considered necessary once a clear policy is defined for the development of the road system of the country.

Benefit-Cost ratio	0.1	-	Total cost	375,536,762	$
Pay-back	∞	Year(s)	Total benefit	38,897,785	$

6.3.12. *TTA 12: Beach Nourishment in Tobago*

Objective

To replenish beach areas with sand in order to avoid the beach erosion caused by the sea level rise and storms.

Previous experiences and success cases

Beach Nourishment is one of the most widely used forms of beach protection and rehabilitation used today. According to a report by Coastal and Hydraulics Laboratory, Engineer Research and Development Centre (ERDC), in 1930, the US Congress authorized the U.S. Army Corps of Engineers to help with shore protection. From 1950 through 2006, the Corps has helped implement beach nourishment projects on approximately 350 miles of U.S. shoreline, mostly on the Atlantic and Gulf coasts. The report states that "beach nourishment projects constructed by the Corps have reduced damages to coastal development caused by erosion, tropical storms, and flooding; protected and renewed the natural habitat; and provided recreation and economic benefits".

In addition, beach Nourishment can have a positive impact on Biodiversity. According to a report titled "Synthesis of adaptation options for coastal areas" by the US EPA, the Delaware Department of Natural Resources and Environmental Control and the U.S. Army Corps of Engineers conducted a study to understand the impact of beach nourishment on horshoe crabs in the Delaware Bay. According to the report, "habitats that received beach nourishment were shown to increase horseshoe crab spawning and abundance". The study did mention that the type of sediment used for nourishment plays a crucial role on the positive impacts on biodiversity achieved.

Additionally, in Barbados, a Coastal Zone Management Unit was established to carry out and monitor the shoreline protection program, guided by the Coastal Zone Management Plan. The Unit looks at the impacts on coasts from commercial and housing development, drainage, ocean tides and currents, storm and hurricane probabilities, coral reef ecosystems and the rising sea level caused by global warming. It promotes engagement from all stakeholder groups involved in coastal management. (Scruggs, G. and Bassett, T, 2013)

Preliminary Considerations

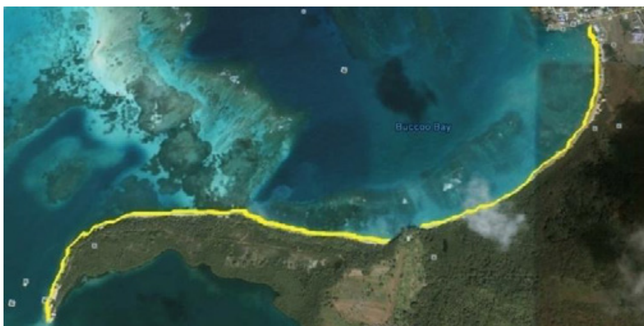
At the moment, a coastal management program is being developed under the Coastal Zone Management Steering Committee. Therefore, the implementation of this action should only be carried out if recommended by the developed program. In that case, the selected areas would also need to be revised to ensure they fit the needs detected. Also, possible Best Practices regarding coastal management planning and stakeholder engagement could be looked at from the Coastal Management Unit in Barbados, as described in the previous subsection on Previous Experiences and Success Cases.

The selected areas are the most vulnerable to land erosion in Tobago, but, unless more detailed local information is provided, those areas need to be considered just as an example of possible implementation of the action and not as the definite sites. Furthermore, for every selected area, the coastal dynamics would need to be assessed to define the sand nourishment areas, the regeneration phases, the beach stability, and so on. An additional assessment on the adequate sediment to be used will need to be done. Additionally, the sand stocks or the possibilities or using imported sand would need to be analysed.

Description of the action

The beach nourishment would take place in three different areas: Buccoo Bay (5 km), Store Bay (6.65) and Little Rockley Bay (2.5). These three areas are the most vulnerable to beach land erosion in Tobago. The development of the project would be divided into ten annual phases, carrying out progressively the nourishment of the selected areas.

The nourishment consists of replenishing the selected areas with extra sand, with the objective of preventing the erosion of the coastal areas. It is not included in this action, however, the use of additional sand in case existing sand needs to be replaced. If this needs to be done after the first nourishment phase considered in this action, the economic cost of this further replenishment would need to be assessed separately for the considered terrain.



Implementation period

2014-2023

Impact of the action

The tourism industry represents 36.7% of Tobago's GDP. There are approximately 14.000 jobs in this industry. According to the World Travel and Tourism Council (2005), witch such high economic figures related to Tourism, Tobago is considered "one of the most tourism-intensive economies in the world". Losing the beach main zones could mean decreasing Tobago's GDP by 11-18%. Therefore, implementing actions that prevent economic damage in the tourism industry have a direct positive effect on Tobago's economy. Beaches are a particularly important asset to protect due to the characteristics of tourism in Tobago, which heavily rely on the "sun, sea, and sand" product.

The success cases of the implementation of similar actions in the USA prove that beach nourishment can be beneficial to prevent the erosion of coastal areas and reduce the damage caused by tropical storms and flooding, but not only that, it does also protect and renew the natural habitats of the nourished areas.

Economic capacity

From the implementation of beach nourishment in the USA, as mentioned in the success cases, it has been observed that it provides economic benefits in the selected areas. To fund the implementation of the action, considering it would benefit the tourism sector of Tobago, the use of the Tobago Tourism Development Fund (more than 39,000,000$ are available) could be considered.

Technological capacity

Beach nourishment has been widely developed in the USA since 1950. In fact, for any coastal state, the operations carried out for the beach nourishment are usually well known, because even if they are not used to nourish beaches, they might be used for other purposes, such as construction projects or cleaning of coastal areas. In fact, it is often used to replenish the sand in areas where it may be scarce due to storm or the tidal influence. Therefore, the technological capacity of Trinidad and Tobago should not be difficult for the implementation of this action.

Social capacity

The benefits of this action for the society are evident, because it would improve the quality of the beaches, which is beneficial for all the inhabitants of the country directly, as they are potential users and, indirectly, because it improves the tourism sector of the country, which is good for the economy of Trinidad and Tobago.

However, one of the biggest problems this project faces is the illegal sand mining that takes place in the beaches of Tobago. If this persists, replenishing the beaches with sand would not be a useful action. They key factor to avoid this is to ensure that the population is educated on the touristic and economic potential of the beaches of Tobago.

Institutional capacity

On the one hand, the government should focus its efforts on convincing the population about the importance, in economic terms, of preventing the illegal mining in the beaches of Tobago due to its negative effect on tourism.

Furthermore, the institutional capacity is required also for the development of the action within a national strategy in terms of coastal areas protection. There is already a National Action Programme to Combat Land Degradation in Trinidad and Tobago 2006-2020 should be considered. The action programme is defined in broad terms and it would be necessary to establish the adequacy of this action within the objectives set in the programme. In fact, in the programme, the need of a Coastal Zone Development Plan is stated, and it would be necessary to define that plan before this action can be carried out.

There is also a National Tourism Policy in Trinidad and Tobago, in which the strategy for the future development of the sector in Trinidad and Tobago is included. However, it does not include any particular action on the prevention of the erosion of the beaches of Tobago.

Furthermore, the Comprehensive Economic Development Plan for Tobago has as one of its Strategic Priority Areas the Environmental Sustainability, for which the Division of Infrastructure and Public Utilities is responsible for the physical planning and development control. However, no concrete actions regarding the beaches of Tobago are included in this plan.

Legal capacity

The legal framework for the protection of the coastal areas of Trinidad and Tobago is poorly defined at the moment. Thus, it would be necessary to develop, as stated before, a Coastal Zone Development Plan, with well defined actions, which should need to be implemented, if necessary, developing a strict legal framework to ensure that the objectives are fulfilled.

Benefit-Cost ratio	**1.0**	**-**	**Total cost**	**23,688,332**	**$**
Pay-back	**19.4**	**Year(s)**	**Total benefit**	**20,736,386**	**$**

6.3.13. TTA 13: Mangrove Restoration in Trinidad

Objective

Restoring and maintaining mangrove forests that are able to attenuate wind and swell waves in order to improve resilience against coastal erosion and infrastructure losses.

Previous experiences and success cases

Mangroves provide significant benefits to society including increased biodiversity, coastal protection from cyclones, and increased uptake of carbon, amongst others. In a report by Prof. K. Kathiresan titled, "3.5. Importance of Mangrove Ecosystem", Kathiresan summarized the benefits reported by several different studies and projects worldwide. The report notes the significant benefits that have been found due to mangrove restoration including increased supply of forestry products (firewood, charcoal, timber, honey etc.) and fishery products (fish, prawn, crab, mollusc etc.). Mangroves also provide seeds for aquaculture industries. The report cites an example in which "40,000 fishers get an annual yield of about 540 million seeds of Penaeus monodon for aquaculture, in the Sundarban mangroves of West Bengal".

Ecological services that have been found in mangrove projects have included "solar UV-B radiation, 'green house' effects, and fury of cyclones, floods, sea level rise, wave action and coastal erosion". As an example of carbon sequestration the report cites the Rhizophora forest, which is a 20-year old plantation of mangroves that stores 11.6 kg m-2 of carbon with C burial rate of 580 g m-2 yr-1.

Mangroves have also proven to help in the trapping of sediments. A previous study done by the author is cited in the report in which it was estimated that "mangroves help in trapping the sediment up to 25 % at low tide as compared to high tide".

It is also important to note the significant coastal protection benefits offered by mangroves. In the report by Prof. K. Kathiresan, it states an example in which "the super-cyclone ... on the 29th October 1999 with a wind speed of 310 km hr-1 along the Orissa coast (India) and played havoc largely in the areas devoid of mangroves. On the contrary, practically no damage occurred in regions with luxuriant mangrove growth. Similarly, in the Mahanadi delta, where large scale deforestation and reclamation of mangrove land for other purposes have been undertaken, maximum losses of life and property have been reported from time to time during stormy weather".

Mangroves also help reduce coastal flooding and prevent coastal erosion. The higher the density of vegetation and the depth of the water, the higher the reduction of waves. The report by Kathiresan cites on example from Vietnam, in which "in the tall mangrove forests, the rate of wave reduction per 100 m is as large as 20%". Kathiresan also cites work that proves that mangroves act as "live sea walls" which have proven to be more economically beneficial than artificial concrete sea walls for coastal protection, in some cases.

The technique proposed by this measure (Hydrologic Restoration) is considered a good practice in terms of mangrove restoration. In fact, in a paper titled "Mangrove Restoration - Costs and Benefits of Successful Ecological Restoration" by Roy R. Lewis III (2001), he explained this process stating that:

> *Because mangrove forests may recover without active restoration efforts, it has been recommended that restoration planning should first look at the potential existence of stresses such as blocked tidal inundation that might prevent secondary succession from occurring, and plan on removing that stress before attempting restoration (Hamilton and Snedaker 1985[8], Cintron-Molero 1992[9]). The second step is determined by observation if natural seedling recruitment is occurring once the stress has been removed. Only if natural recovery is not occurring should the third step of considering assisting natural recovery through planting be considered.*

Lewis states many examples of projects that started directly by planting mangroves, without assessing the potential existence of stresses, which inevitably failed given the inability of the new plants to survive in the modified environments. Lewis also gives several cases where the technique of Hydrologic Restoration was

[8] Hamilton, L. S. and S.C. Snedaker (eds.) (1984), Handbook of Mangrove Area Management, Honolulu: East West Centre.
[9] Cintron-Molero, G. (1992), 'Restoring mangrove systems', in G. W. Thayer, ed., Restoring the Nation's Marine Environment, College Park: Maryland Seagrant Program, 223-277.

successful. He states:

> *Successful ecological restoration requires the successful creation or restoration by construction of tidal creeks and intertidal wetland platforms frequently inundated by tidal waters (Lewis 1999[10], 2000a[11], b[12]). This excavation to restore the normal hydrology of the historical tidal creeks will be similar to efforts described in Roberts (1991), Whitman and Gilmore (1993) and Kurz et al. (1998). All three publications document the rapid recruitment to restored or created tidal marshes or mangrove/marsh plant communities in Florida, (the latter two publications concentrating on such projects in Tampa Bay) of 40 species of adult and juvenile fish species including red drum (Sciaenops ocellatus), spotted seatrout (Cynoscion nebulosus), snook (Centropomus undecimalis), spot (Leiostomus xanthurus), black drum (Pogonias cromis) and tarpon (Megalops atlanticus).*

Preliminary Considerations

For mangrove restoration to work, it is necessary to ensure that there is no water pollution and that the ecosystem is able to restore itself. Therefore, the selected areas need to be analysed first to find out whether restoration is viable or not. Otherwise, other coastal strips more suitable for the action would need to be analysed.

Consultation should also be made with the Integrated Coastal Zone Management Steering Committee, in order to ensure that the activities undertaken in this measure are in line with the integrated Coastal Zone Management policy framework, strategies, and plan currently under development by this entity. This analysis should also include looking holistically at the other measures detailed in this study and understanding where and how they should be integrated together. While the measures are analyzed individually in this study, many of these measures would have increased impacts if they were implemented in conjunction with other proposed measures. Many of the measures regarding coastal management, including the construction of dikes (TTA 2) and the restoration of mangroves (described here), will have improved results if jointly implemented. These measures should therefore be looked at holistically and strategically when deciding which activities to implement, ensuring that possible mutual and re-enforcing benefits are captured.

Description of the action

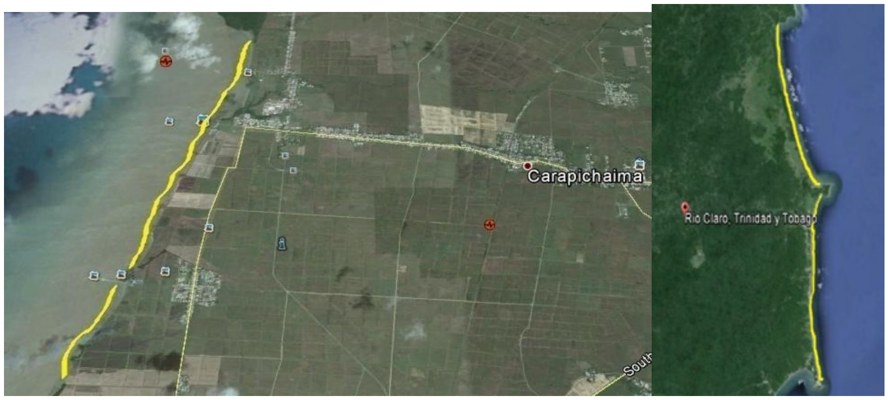
In order to be less vulnerable to sea level rise and flooding in Carapichaima's agricultural areas and the south-east coast of the island of Trinidad, the Government would plant mangroves in 4.7 km of the west coast and 39.5 km of the east coast, creating a 750 meter width mangrove forest all along the agricultural area. This means planting 3.5 km^2 of mangrove forest in the west coast and 29.6 km_2 of mangrove forest in the east coast. The technique proposed to do this is Hydrologic Restoration, rather than planting. Hydrologic Restoration consists of connecting impounded mangroves to normal tidal influence, that is, instead of planting mangroves, the efforts would be focusing on restoring the previous state of the coastal areas, restoring the tidal schemes previous to the human influence. That way, if the environmental conditions are adequate, mangroves are restored without the need of planting, but rather just by the natural diffusion process which takes place due to the coastal tides.

The development of the action would focus at first on achieving natural restoration. If this is not possible, mangroves would be planted. In the case that planting needs to occur, additional costs may have to be assumed, which are not considered in the economic analysis of this measure. The width of 750 m is chosen based on bibliographic data which states that a width of more than 500 m highly prevents the erosion of the coast.

[10] Lewis, R. R. (1999), 'Key concepts in successful ecological restoration of mangrove forests', in Proceedings of the TCE-Workshop No. II, Coastal Environmental Improvement in Mangrove/Wetland Ecosystems, Bangkok: Network of Aquaculture Coordination in Asia, 19-32.

[11] Lewis, R. R. (2000a), 'Don't forget wetland habitat protection and restoration for Florida's fisheries', National Wetlands Newsletter 22(6): 9-10 + 20.

[12] Lewis, R. R. (2000b), 'Ecologically based goal setting in mangrove forest and tidal marsh restoration in Florida', Ecological Engineering 15(3-4): 191-198



Implementation period
2014-2023

Impact of the action

The mangrove forest would provide protection against floods in the 3.5 km2 of agricultural land of the Carapichaima coastal zone and 21.6 km2 in the south-east coast of Trinidad, avoiding large economic losses and contributing to the sustainability of the agricultural sector. Mangroves are highly beneficial because they can provide forestry and fishery products. Furthermore they enhance the sustainability of the area protecting the coast from solar UV-B radiation, 'greenhouse' effects, and fury of cyclones, floods, sea level rise, wave action and coastal erosion. Mangrove swamps act as traps for sediments, and sinks for nutrients. The root systems of the plants keep the substrate firm, and thus contribute to a lasting stability of the coast.

As shown in the success cases section, mangrove restoration is a beneficial action in economic terms and provides many advantages for the environment, not only those derived from the prevention of the damage caused by the climate change hazards, but also options for the development of the local communities in terms of firewood, charcoal or timber procurement, improvement of fisheries, and so on.

Economic capacity

The implementation of this action in other countries shows that its benefits are much higher than the costs of the mangrove restoration. The investment is low for this action because the mangrove restoration is selected instead of mangrove planting. Planting should only be considered when the restoration is not viable, but it is not very recommendable due to the difficulty to obtain good growth rates and its higher cost.

In this analysis, the benefits due to coastal protection have not been included due to the lack of information in calculating them. The direct benefits from mangroves (fisheries, wood, etc), and the benefits they have in terms of climate change mitigation (acting as a carbon sink) have been included.

Technological capacity

In Trinidad and Tobago, efforts regarding the restoration of the mangroves are already being carried out. Therefore, it is not an unknown matter in the country. Additionally, the lessons learnt from the mangrove restoration projects carried out in other countries should be analysed and adapted to the characteristics of the selected coastal areas.

The success of this action depends on the capacity to carry out the hydrologic restoration technique. Therefore, if in a first assessment it is found that the conditions for the hydrologic restoration are not met, the use of other techniques should be analysed.

Social capacity

The restoration of the mangroves does not have any harmful effects in social terms. On the contrary, it can provide several benefits to the communities because it would make the agricultural area more resilient to floods. For this reason, people who own these lands could be interested in cooperating in the restoration process. This activity would also improve the fishery and wood resources of the area and improve biodiversity, positively affecting the surrounding areas.

Institutional capacity

The institutional capacity is required in order to promote the development of the action within a national strategy on coastal areas protection. There is already a National Action Programme to Combat Land Degradation in Trinidad and Tobago 2006-2020, which should be considered. The action programme is defined in broad terms and it would be necessary to establish the adequacy of this action within the objectives set in the programme. In fact, in the programme, the need of a Coastal Zone Development Plan is stated, and it would be necessary to define that plan before this action can be carried out.

In a similar way, the National Biodiversity Strategy and Action Plan focuses on the conservation and sustainable use of the country's biodiversity, but it does not include a particular mention of the management of the country's mangroves.

There is also a National Policy and Programmes on Wetland Conservation in Trinidad and Tobago, which includes the management of some of the mangroves of the countries. It includes among its objectives the restoration of damaged but important wetlands, but no additional information on how the objective will be achieved is included.

Legal capacity

The legal framework for the protection of the coastal areas and wetlands of Trinidad and Tobago is poorly defined at the moment. Thus, it would be necessary to develop, as stated before, a Coastal Zone Development Plan, with well defined actions, which should need to be implemented. If necessary, the development of a strict legal framework to ensure that the objectives are fulfilled should be done.

Mangrove Restoration in Tobago is slightly complicated in terms of legal capacity given that existing land use management policy dictates that "the local government such as the County Council has responsibilities up to the high water mark while land administration, rather than land management, is undertaken from the high water mark seawards to the extent of the EEZ by the Commissioner of State Lands under the Ministry of Planning and Development. Further, if beach facilities are constructed they are the responsibility of the Tourist Board under the Ministry of Enterprise Development, Foreign Affairs and Tourism; the construction and maintenance of coastal protection structures fall under the jurisdiction of the Ministry of Works and Transport; construction of fish landing facilities is the responsibility of the Fisheries Division of the Ministry of Agriculture Land and Marine Resources, and if the beach is fringed by mangroves or a site for turtle nesting the area is the responsibility of the Forestry Division in the Ministry of Public Utilities and the Environment. Additional jurisdictions involved may be the Ministry of Energy with regards to exploited petroleum and gas reserves" (Soomai, S., 2005). This interlinkage of authoritative figures will need to be looked into in order to determine the frameworks under which this measure falls.

Benefit-Cost ratio	**95.9**	**-**	**Total cost**	**744,188**	**$**
Pay-back	**4.4**	**Year(s)**	**Total benefit**	**71,348,613**	**$**

6.3.14. TTA 14: Parametric Insurance Scheme

Objective

To create an insurance program with the aim of reducing the risks of economic losses for those whose incomes may be affected by climate change in Trinidad and Tobago.

Previous experiences and success cases

An example of a government implementing private insurance program can be seen in Spain. In 1980, Spain created a limited company with private capital, called AGROSEGURO (Spanish Association Underwriters of the Agricultural Insurance SA) which was created after the Government enacted legislation obligating private insurers to be grouped into a society in order to produce a combined agricultural insurance program. The system has three pillars which include: the government, which subsidizes a portion of the insurance for agricultural farmers; AGROSEGURO, which receives its capital from private insurers (private companies can change their position within the society, including their portion of equity as they wish); and the Insurance Compensation Consortium, which provides reinsurance services. AGROSEGURO is the only provider of agriculture insurance in Spain. AGROSEGURO develops agricultural insurance coverage and acts in all matters related to the establishment tariffs, payment of claims, etc. In 2012, there were 484,513 insurance policies for crop and livestock valued at € 11,200 million. The sector had a premium volume of € 675.29 million with 128,000 claims processed.

Another interesting private insurance program that is taking off in the Caribbean has been the Livelihood Protection Policy (LPP), which is part of a broader program being developed by the Munich Climate Insurance Initiative (MCII) and supported by the Caribbean Catastrophe Risk Insurance Facility (CCRIF), MicroEnsure and Munich Re, called Climate Risk Adaptation and Insurance in the Caribbean. LPP was recently launched in Jamaica, and is being offered by "GraceKennedy through its insurance subsidiary, Jamaica International Insurance Company (JIIC), which is partnering with select credit unions and the People's Co-operative Bank to distribute the policies". Saint Lucia and Grenada are the additional two first countries in the region to pilot these insurance products under this project, which will later be followed by Guyana and Belize (CCRIF, 2013b). The policy offers pay outs to clients in function with the severity of the natural disaster (wind speeds, rainfall, etc.) rather than the actual damages to the client's property. This type of insurance program is called "Trigger-based parametric index insurance" and promotes the implementation of risk prevention strategies by farmers due to the fact that they could benefit from the policy if their damages are lower than the pay outs. MCII cited the benefits of this program to include "quick cash payouts enable affected households to rebuild their lives soon after a weather event; SMS-based notifications alert policy holders to approaching weather events, allowing them to take precautionary measures and reduce exposure..." and improvement in "the credit worthiness of individuals in the long-term, giving them access to financial services that they previously may not have had access to". Trigger-based parametric index insurance programs are considered viable and interesting policy options. In a report written by The International Fund for Agricultural Development (IFAD), they state that these types of insurance programs "can be used as a tool to promote agricultural and rural development. [they] can help households, financial service providers (FSPs) and input suppliers manage low-to-medium-frequency covariate risks such as drought or excess rainfall". Additionally, IFAD states that they can also "provide an alternative method of funding disaster recovery assistance or relief programmes'. IFAD considered these types of programs good for economies in which "traditional agricultural insurance may not always be feasible". Feasibility will need to be looked at in relation to the ability of farmers to pay insurance premiums and the types of coverage that best fit their needs, specifically considering the small holders in Trinidad and Tobago who, according to Central Statistics Office Trinidad and Tobago 2004 Agricultural Census, have an average holding size of 4.5 hectares and that 86.6% worked on a permanent basis on their holdings.

Lastly, CCRIF is also working on implementing Loan Portfolio Cover (LPC) insurance, which is "a loan portfolio hedge that can help create a space of certainty for institutions with credit portfolios exposed to natural disaster risk. As loan portfolios are insured against climate risk, investment can reach areas previously considered too risky for traditional lending. In the short run, this creates a win-win situation for the lender and the borrower, while also contributing to economic development in the region in the long run" (CCRIF, 2013b). The LPC for financial institutions in St. Lucia, Jamaica, and Grenada is "well on its way to being finalized" (CCRIF, 2013b) and should be closely monitored to see if this form of insurance could also work in Trinidad and Tobago.

In terms of fisherfolk, In a document titled "Review of the current state of world capture fisheries insurance" written by Anrooy, R. et al (2009) for the FAO, the Peruvian and Chilean Fishing sectors were analyzed as examples in order to understand insurance for the fishery sector. The report states that both the demand for and supply of capture fisheries insurance are widely influenced by natural disasters; the availability and affordability of substitutes for fish products; and the availability of and access to insurance services by small scale artisanal fishers. The report talks extensively about the issues related to accessing small scaled fisherfolk, and the lack of interest in these groups by large insurance companies. It sites some cases, as in India for example, where cooperatives have a higher uptake rate of insurance programs, due to the improved accessibility to information regarding insurance plans by the fisherfolk. They state that insurance products that are "designed to promote insurance in the artisanal/small scale commercial arena will need to be kept simple and easy to operate. Claims and assessment procedures will need to be transparent and straightforward…" According to a document written by Harnarine Lalla (2001) of the Ministry of Food production and Marine Services for the FAO, "the fishing industry in Trinidad is largely artisanal, but includes multipurpose vessels, semi-industrial and industrial trawlers and is characterised by multi-species and multi-gear fisheries. Most vessels operate out of the west coast of Trinidad, but some operate on the other coasts. It has been estimated that 13,000 persons are directly involved in the fishing industry with 50,000 persons indirectly involved".

Preliminary Considerations

For this analysis, this measure details the institutional, social, legal, etc. requirements for a parametric insurance scheme focused on the agricultural and fishery sectors; however, it is also a very possible solution for other economic sectors who will likely be affected by natural hazards due to climate change.

Nowadays, when any extreme event happens in Trinidad and Tobago, the losses caused to the agricultural sector are compensated by the government. As a result, the workers of the agriculture sector are used to being protected by the government without having to make any effort themselves. To obtain the best results from this action, an attitude change needs to take place – from the passive mindset of the current system to the proactive behaviour of implementing an insurance program. This attitude change needs to be developed with the encouragement of the government before the implementation of the action in order to obtain the best results.

It should also be considered that insurance programmes do not modify the overall damage caused by the extreme events. They are useful from a cost-efficiency perspective but not from a cost-benefit approach, because the economic damage is the same even if insurance programmes are not developed, the only difference is the way in which that economic damage is covered.

Description of the action

As previously mentioned, for this analysis, this measure details the institutional, social, legal, etc. requirements for a parametric insurance scheme focused on the agricultural and fishery sectors; however, it is also a very possible solution for other economic sectors who will likely be affected by natural hazards due to climate change.

Cooperating with the Central Bank of Trinidad and Tobago and industry organizations, such as the the Association of Trinidad and Tobago Insurance Companies (ATTIC), this action consists of developing an insurance program to transfer the risk derived from the possible economic losses due to flooding, droughts, or extreme events in the agricultural and fishing sectors of Trinidad and Tobago.

This could be done using different approaches, as shown in the success cases. The particularity of the system developed for the Caribbean is that it promotes the implementation of adaptation measures, a feature that can be very interesting for its implantation in Trinidad and Tobago.

In addition, regarding insurance options in Trinidad and Tobago, it would be also interesting to create a new product proposal for the CCRIF's future Strategic Plan related to the future vulnerability of the Caribbean countries facing sea level rise. In the current Strategic Plan, a product proposal for torrential rainstorm, similar to this, has already been included. However, this proposal is not included in the economic quantification of this action.

Implementation period

2014-2030

Impact of the action

With this insurance program, the economic activity of the country, including agricultural and fishery activity – which are two of the main sectors toward which this measure is directed-, would be less risky economically speaking, which could encourage people to work in these sectors. Risk transfer provides safety and resilience to the economy; in the case of unexpected disasters, the economic damage borne by the farmers and fisherfolk is much lower.

Additionally, if a similar scheme to that implemented in Jamaica is selected, the implementation of adaptation measures in the agricultural and fishing sector would also be improved, because the system benefits those who are more resilient to climate change.

Furthermore, if the CCRIF decided to include sea rise among its products, the vulnerability of Trinidad and Tobago and its inhabitants due to this risk would be lowered. It may not be necessary to consider this action at the present moment, but possibly in the medium term.

Economic capacity

The cost of developing this program is quite low. Depending on the management of the program, the government would have to create an insurance fund in order to attend to future possible payments. The key issue of the action is the decision of the institution who would be responsible for the creation and management of the fund.

There are several examples of how to manage those funds, as shown in the success cases. The best option would be to choose the one which best adapts to the needs of Trinidad and Tobago and its agricultural and fishery sectors.

Technological capacity

The most important technology to develop the program is the financial models commonly used in the insurance industries. In Trinidad and Tobago, insurance is a widely used tool in many sectors. Therefore, the development of this program should not pose any difficulties. In fact, the Central Bank could provide the methods required.

Technical support may also come from regional and international institutions including the Caribbean Agriculture Research & Development Institute (CARDI), the Caribbean Institute for Meteorology and Hydrology (CIMH), the University of the West Indies, the Technical Management Advisory Committee (TMAC) and the Food and Agriculture Organization of the United Nations (FAO).

Social capacity

The insurance program needs to be adapted to the economic capability of the target group, otherwise farmers and fisherfolk would not be able to buy the insurance and the program would not be successful. Therefore, in its design, the economic terms need to be carefully planned in order to obtain a highly effective program.

There are different ways to obtain a better implementation of the action. As shown previously, it can be based on a legislative framework, like in Spain, or a different approach, like the one used in Jamaica, can be developed. In the end, the objective of both is the same: reducing the damage assumed by the farmers when extreme events take place. Both systems have advantages and disadvantages.

Institutional capacity

The institution with a mandate for this issue is the Ministry of Food Production. The Ministry developed a Strategic Plan 2011-2015, in which general objectives regarding the development of the agricultural sector, including its vulnerability, are addressed. However, there is not a concrete plan on the development of insurance for the agricultural sector of Trinidad and Tobago.

Legal capacity

There are some acts regarding the agricultural sector in Trinidad and Tobago, such as the Agricultural Contracts Act or the Agricultural Development Bank Act. However, there is not a legal framework regarding the use of insurance policies in the agricultural and fishery sectors.

Benefit-Cost ratio	**N/A**	**-**	**Total cost**	**62,850**	**$**
Pay-back	**N/A**	**Year(s)**	**Total benefit**	**N/A**	**$**

6.3.15. TTA 15: Agriculture & Climate Change Research Unit

Objective

To adapt the agricultural activity to the different future climate scenarios and reduce the risks related to these new climate conditions.

Previous experiences and success cases

The Tasmanian Government has established The Climate Change Adaptation Unit in order to "provide resources and information and coordinate programs and initiatives to assist farmers and other agricultural enterprises in adapting to climate change". Their objectives include: providing information to farmers, other agricultural enterprises and agricultural consultants on the projected impacts of climate change; undertaking further analysis to determine how climate change will impact on a number of Tasmania's key agricultural sectors and regions, and where necessary develop adaptation plans; developing regional and land-use adaptation plans, taking account of projected climate change impacts, and developing case studies of farmers and other agricultural enterprises. As an example of some of the work completed, along with the Tasmanian Institute of Agriculture they have created several information sheets that focus on opportunities and risks to various agricultural sectors associated with climate change. These sectors include: Dryland pastures (red meat production), extensive dryland pastures (wool production); irrigated pastures (dairy production); wheat production (cereals); wine grape production; and Meander Valley - barley, poppies, pyrethrum, blueberries and hazelnuts under irrigation.

Another example comes from the report titled "Technologies for Climate Change Adaptation– Agriculture Sector" from the UNEP Risø Centre, which explains various adaptation techniques for agriculture, and specific case studies showing where these techniques have proven successful around the world. As an example, the report explains the benefits that agro-forestry can have on reducing the risks of climate change on individual farmers. It explains that "trees have an important role in reducing vulnerability, increasing resilience of farming systems and buffering agricultural production against climate-related risks". They can also reduce the risks of droughts and heavy rainfall. The report cites an example of a project carried out by the coffee company Cafe Direct and GTZ in order to improve climate change adaptation among coffee producers in Mexico, Nicaragua and Peru. Coffee farmers had reported an increase in deforestation and forest fires, an increased incidence of heavy rainfall, an impoverishment of soils, and an increase in pests and diseases. The project worked on implementing reforestation methods in order to improve shade in the coffee plantations and in the surrounding area, among other capacity building activities. Farmers learned how shade trees affect the impact of climate on the coffee. They also learned techniques to help preserve the soil, improve yields in years of drought and excess rainfall, and conditions that can help slow the development of pests and diseases.

Another example from the report comes from the technology of using Slow-forming terraces. This technology has been used in several countries, such as the Philippines and Nepal, and has shown to reduce soil erosion to less than 5 per cent of that of the baseline. According to the report, "a ten year economic study of the system showed that farmer income increased by three-fold after adoption of the [Sloping Agricultural Land Technology] system. Investment in establishing the system is higher than simple maize production during the first two or three years, but generated a net profit by the fifth year".

Preliminary Considerations

Before creating the Agriculture & Climate Change Research Unit, conversations with the Caribbean Agriculture Research & Development Institute (CARDI), the Caribbean Institute for Meteorology and Hydrology (CIMH), and the University of the West Indies should be held in order to define the best research lines and other aspects including the location of the unit and its integration within both institutions. Additionally, this action would fall under the framework of the Technical Management Advisory Committee (TMAC) set up by CARICOM. TMAC was established to address one of the ten key constraints identified in the Jadgeo Initiative, "Inadequate Research and Development", and therefore looks to coordinate agricultural research and development in the region. Efforts to develop this action should be linked with the main objectives and strategies set forth by the TMAC.

Description of the action

To achieve this goal, the Agriculture & Climate Change Research Unit would be created. It would be integrated in the Caribbean Agriculture Research & Development Institute and the University of the West Indies. The unit would carry out research projects related to agricultural topics with a focus on the mitigation of the consequences of climate change on agriculture. This unit would fund the research of 5 scientists specialised in the agriculture area.

Regarding the location of the unit, the scientists would carry out their research in the centres of the Caribbean Agriculture Research & Development Institute or the University of the West Indies in Trinidad.

Additionally, the knowledge obtained during this research needs to be widespread among the farmers. To do so, a series of two-day workshops would be offered every 6 months for farmers to attend and obtain knowledge related to the adaptation of their crops to the new climate conditions.

Implementation period

2014-2030

Impact of the action

Research about the effects of climate change on the agricultural sector of Trinidad is needed in order to improve the sector's economy. The research unit would particularly focus on developing projects to find out information about different agricultural issues such as the best sowing crops for the climate conditions, the effects of drought on the crops, the effects caused by heavy rainfall, and so on. Additionally, it would also teach the farmers how to obtain the best results taking into account the climate change effects. This would help avoid losses caused by the climate change on agriculture. Furthermore, the research centre would help enhance the knowledge about the agricultural conditions of Trinidad and Tobago and collaborate with other countries in its research.

The experience from previous cases shows that providing valuable and useful information to the farmers on how to adapt to climate change usually helps improve the results of their work. That can be seen particularly on the case study example from the coffee producers, who benefitted from the efforts carried out to reduce the effects of climate change.

Economic capacity

There is certain economic investment required, mainly related to the construction of the centre and the salaries of the scientists. However, the benefits produced by this measure can help facilitate the conditions of the most disfavoured farmers of Trinidad and Tobago. In fact, this action could be particularly helpful for subsistence farmers whose income depends solely on the production on their lands and can be very affected by the conditions of climate change.

It would also be interesting to consider the option of cooperating with the local universities like the University of West Indies to improve the results. This could be done through financial collaboration, like the Research and Development Impact Fund of the university. Additionally, collaboration in terms of knowledge transmission would also take place, providing the university its knowledge and staff to work actively in the research centre.

Technological capacity

The technology needed for this action is not especially relevant when compared to the scientists' skills and knowledge and their ability to obtain fruitful research. As a first step, if needed, international experts could be hired to take part of the unit and facilitate the initial development while providing knowledge to local scientists that would finally be responsible for the whole project. These experts, however, have not been considered in the economic calculations for this measure.

Social capacity

A key factor for the success of this action is the participation of farmers and agricultural workers of Trinidad and Tobago. They need to feel involved and important as their cooperation can be very helpful for the research centre in terms of ideas, proposals and data collection. Furthermore, they would be the ones who would make use of the results of the research. So, if they do not collaborate, the scientific effort would be useless.

Previous experiences related to the action show that research in terms of climate change adaptation in the agricultural sector can improve the knowledge of farmers and enhance their techniques.

Institutional capacity

The institutional mandate for this issue is held by the Ministry of Food Production. The Ministry developed a Strategic Plan 2011-2015 in which general objectives regarding the development of the agricultural sector, including its vulnerability, are addressed. However, there is not a concrete plan on the research relating climate change for the agricultural sector of Trinidad and Tobago.

Similarly, Trinidad and Tobago has a national climate change policy, but it does not include any particular actions on how to reduce the effects of climate change on the agricultural sector.

There are several regional and international existing entities that could be incorporated into this initiative in order to increase its effectiveness. These institutions include, but are not limited to, the Caribbean Agriculture Research & Development Institute (CARDI), the Caribbean Institute for Meteorology and Hydrology (CIMH), and the University of the West Indies. Also, International organizations, such as the Food and Agriculture Organization of the United Nations (FAO), could provide technical support.

This action would fall under the framework of the Technical Management Advisory Committee (TMAC) set up by CARICOM. TMAC was established to address one of the ten key constraints identified in the Jadgeo Initiative, "Inadequate Research and Development", and therefore looks to coordinate agricultural research and development in the region. Efforts to develop this Unit should be linked with the main objectives and strategies set forth by the TMAC.

Another key factor for the institutions in this action is to ensure that there is enough diffusion of the information so as to guarantee that the farmers have access to it.

Legal capacity

There are some acts regarding the agricultural sector in Trinidad and Tobago, such as the Agricultural Contracts Act or the Agricultural Development Bank Act and others regarding environmental issues such as the Environmental Act. However, there is no legal framework for the effects and prevention of climate change.

Benefit-Cost ratio	0.2	-	Total cost	4,455,439	$
Pay-back	∞	Year(s)	Total benefit	986,772	$

6.3.16. *TTA 16: Green Roofs*

Objective

To build green roofs on top of some of the buildings of the country in order to reduce the risk of flooding due to heavy rain.

Previous experiences and success cases

Green Roofs offer several different benefits including providing insulation services for the buildings on which they are installed, improves storm water management, reducing air pollutants, providing carbon storage, and many others. In a report publishes by the U.S. Department of Energy, Energy, Efficiency and Renewable Energy titled "Federal Technology Alert: Green Roofs DOE-EE0298", the Department detailed several benefits reported from green roofs, and studies done in order to quantify these benefits. In this document, they state that Scientists at the U.S. Department of Energy's Lawrence Berkeley National Laboratory (LBNL) estimate that using alternative surfaces to reduce the temperature of ambient air in cities by just 3°C would save up to $6 billion per year in energy costs in the US. They state, "green roofs could help cities achieve these temperature reductions". They report that studies by the National Research Council of Canada have shown that green roofs are "very effective in reducing heat transfer through a roof". One green roof studied, with a 400 square feet roof (37.2 square meters), reduced the average daily energy demand by 75%.

According to the report, The National Research Council of Canada conducted a field study from 2000 to 2002 in order to evaluate the thermal performance of green roofs. The facility was located in Ottawa, and included a 72 square meter roof divided into two sections: one section had an extensive green roof and the other section, the reference roof, had a modified bituminous roof covered with light gray gravel. They found that the daily maximum membrane temperature underneath the green roof was significantly lower than the daily maximum membrane temperature of the reference roof, meaning that the green roof helped keep the building cooler. The results showed that, during a monitoring period of 660 days, the temperature of the green roof exceeded 30°C on only 18 days, whereas the ambient air temperature exceeded 30°C on 63 days. Moreover, the temperature of the reference roof was significantly higher throughout the monitoring period. Temperatures were reported to be above 50°C on more than 219 days.

Preliminary Considerations

The implementation of this action depends highly on finding suitable buildings in which green roofs can be installed. Therefore, before carrying out the action, an assessment of which roofs are the best for the installation of these green roofs is needed.

Description of the action

The action is planned to be developed in 4 phases: building 25% of the 12,000 m^2 of proposed green roofs in each of the first 4 years (3,000 m^2 per year). The 12,000 m^2 would be installed on institutional buildings of the country such as buildings where Ministries are located or the Twin Towers, as long as their roofs are suitable for this technology. The exposed roof type of green roof is the chosen model for this project due to its characteristics.

Since, in buildings with private owners the development of the action will depend on the willingness of the owners to carry out the investment, its implementation could be fostered by including it in the National Building Code, in that way that, for buildings with certain characteristics it would be compulsory to install green roofs.

Implementation period

2014-2017

Impact of the action

Green roofs reduce the risk of flooding events when rainfall levels are high. Vegetation can also remove the pollutants from the air and from the rain. Therefore green roofs help to eliminate pollution from the environment. Green roofs also provide energy consumption reduction advantages, which takes place due to the fact that green roofs isolate the ceilings of buildings, minimising energy loss.

This can be particularly profitable in buildings with high air conditioning use, such as those institutional buildings containing several offices and with high occupancy. Another advantage provided by green roofs is their visual attractiveness, creating green areas in the city centre. Furthermore, as seen in the examples, green roofs can help cities reduce the temperature and are way more effective than other types of roofs in terms of insulation.

Economic capacity

The installation of green roofs implies an economic investment, but, as seen in the previous experiences, it provides benefits in terms of insulation and, therefore, reduction in energy consumption in the buildings. In economic terms, this action poses some difficulties in buildings with private owners, because implementation it will depend on the owners' decisions.

Technological capacity

This kind of sustainable technology is already installed in some areas of Trinidad and Tobago like National Library in Port of Spain or the Hyatt Regency Hotel also in Port of Spain. Therefore the technology level is easily attainable within the country.

Furthermore, as shown in the previous experiences, it has been widely used worldwide and many examples of its application can be found and used to determine the best practices for the installation of this kind of roofs in Trinidad and Tobago.

Social capacity

Regarding the installation of green roofs, it is usually well considered by the general population because it improves the environment of cities. However, this action can imply some difficulties in social terms because the investment, in privately owned buildings, would depend on the owners.

Institutional capacity

The institutional mandate for this action would be held by the Ministry of the Environment and Water Resources. Regarding the inclusion of this action in the building code, currently the development of a National Building Code is being discussed in Trinidad and Tobago, therefore, it is considered in governmental plans. In fact, there is a National Building Code Committee which is working in the development of the code.

In terms of other policies or plans which can affect the action, there are no concrete actions regarding the implementation of green roofs in Trinidad and Tobago.

Legal capacity

Regarding the inclusion of this measure in building codes, there is not a legal framework at the moment in terms of building codes in Trinidad and Tobago. The same applies to climate change legislation, because there is not a well-defined legal framework in Trinidad and Tobago in terms of climate change.

Therefore, for the implementation of this action, at the moment, there is not a legal framework defining the installation of green roofs in the buildings of Trinidad and Tobago.

Benefit-Cost ratio	**1.7**	**-**	**Total cost**	**1,055,220**	**$**
Pay-back	**9.9**	**Year(s)**	**Total benefit**	**1,786,554**	**$**

6.3.17. TTA 17: Climate Change Survey for the General Public

Objective

To implement a climate change survey in order to understand the population's understanding and knowledge of climate change both terms of general knowledge and adaptation capabilities.

Previous experiences and success cases

Surveys on public opinion are used widely in public policy and government administrations and many countries have already implemented surveys regarding the public perception of Climate Change. In a survey done in Australia, for example, the results showed that "well over one half of respondents (61%) reported being prepared to greatly reduce their energy use to help tackle climate change (61%) and many are psychologically adapting to the threat of climate change and changing their behaviours and lifestyle with respect to reducing their own carbon footprint" (Reser, 2011). This information helps the Australian Government understand the willingness of the public to implement mitigation policies, such as energy efficiency.

Another great example comes from the UK, when, amongst a "reframing of political debate" around the construction of nuclear energy as a measure towards climate change mitigation, the government did a survey to understand the public's perceptions of nuclear energy in the context of climate change. The study found that while "it is sometimes argued that public beliefs about the risks of technologies are driven by ignorance of the scientific and technical issues involved. By contrast, the survey findings paint a picture of understandings of nuclear energy and climate change embedded within a consistent set of wider beliefs about the environment and energy... One of the most interesting survey findings is that responses about future energy options were not significantly affected by this statement. This suggests that many people may have already formed quite strong beliefs about both the nuclear and climate change issues. 54% were willing to accept the building of new nuclear power stations in Britain if this would help tackle climate change. However, results from other questions on the survey indicate that very few would actively prefer nuclear power as an energy source over renewable sources, given the choice" (Pidgeon, 2006). This information can help the government make decisions that better align with the beliefs of their constituents.

Preliminary Considerations

A strategy will need to be developed in order to decide not only the scope of the survey, but also the means to which polling will be done in order to provide statistically representative data. This activity falls under the mandate of the Central Statistics Office and therefore their integration into, or leadership of, this initiative should be considered.

Description of the action

This measure will look to study the perceptions and understanding of the population of Trinidad and Tobago regarding climate change and adaptation. It will include the development of a strategy and survey that will be disseminated to the public via personal telephone interviews and an online survey form. All randomly selected contacts will be called by telephone and asked to answer some simple questions regarding their opinions and knowledge about Climate Change. Whenever a telephone interview is not preferred by an interviewee, the online survey will be offered. The design of the strategy and survey will be done by experts in the fields of statistics and surveying, and 15 temporary workers will be hired in order to make the phone calls. The data collection through telephone calls and the online survey will occur during a two month period. Once the data is collected and organized, the results will be analyzed in order to see what conclusions can be drawn from the survey. The objective of the survey is to design questions that help policy makers and scientists understand the main concerns of the public in terms of climate change adaptation, their level of willingness to take on individual measures at the household level to prepare, and their basic understanding of disaster risk management related to the risks affecting Trinidad and Tobago due to Climate Change.

Implementation period

2014-2015

Impact of the action

This action is directed towards the old management adage: “What gets measured gets managed.” Without measuring certain variables, it is hard to understand them. Without real understanding of the people’s understanding of adaptation, it is hard to effectively set up programs on the topic.

In the case of Climate Change, policy makers and practitioners need to understand the population’s level of knowledge and understanding on the issues related to Climate Change, in order to understand the base from which they are working. In a paper titled, "Public Perceptions of global warming: United Stated and international perspectives", Board, Fisher and O'Conner (1998) go further to argue that "Scientists need to know how the public is likely to respond to climate impacts or initiatives, because those responses can attenuate or amplify the impacts."

Without physical information regarding the levels of knowledge that people have regarding, for example, their risks related to climate change in their personal and professional lives, we cannot expect people to make rational decisions about how much adaptation and preventative measures they should undertake. Assuming that people have little, or a lot, of information without undertaking a study means that policy makers and practitioners are relying on intuition or other subjective tools in order to make decisions in these areas. This measure will help provide these groups with the data needed in order to make informed decisions on strategies, policies and programmes.

Economic capacity

The economic costs of this action are mainly those related to the development of the survey, the survey strategy, the implementation of the survey, and the analyzation of the results. The main area that will incur the most costs will be the implementation stage of the project. This action does not imply relatively high economic investments.

This measure´s benefit is the knowledge that it provides to policy makers and practitioners who work in the fields of Climate Change Adaptation, Climate Change Mitigation, Capacity Building/Social Awareness, and Disaster Risk Management. The survey will provide insight into the thoughts and perceptions of the population of Trinidad and Tobago and offers ideas on where the gaps in knowledge are, if certain awareness campaigns and capacity building tactics have been successful, and to what extent policy makers can expect approval or rejection of policies and programs related to Climate Change. The economic benefits for this measure have not been calculated, given the fact that, without an idea of the kind of information and results that come from the survey, it is hard to determine the specific impacts it will have on future strategies and programs in the country.

Technological capacity

The development of this action in itself does not imply technological challenges. Trinidad and Tobago has the skills and infrastructure necessary for this project. Information gathering tools are widely used in Trinidad and Tobago in order to collect data in order areas, as shown in the level of information collected by the Central Statistics Office. Whether this initiative is undertaken through a public procurement procedure, involving outside consultants in the implementation of this measure, or it is taken up by the Central Statistic Office, the project could be undertaken by local organizations and entities.

Social capacity

This measure does not show signs of posing strong social opposition. While some people may be slightly bothered by receiving the phone call, they have the option to not continue with the survey. No significant negative impacts should come from implementing this measure.

Institutional capacity

Trinidad and Tobago has the skills and infrastructure necessary for this project. The Central Statistic Office, who is responsible for the collection, compilation, analyzation, and publication of statistical information relating to all social and economic activities for the country has all of the technical competencies necessary to implement this measure.

Legal capacity

The Central Statistics Office is a Division of the Ministry of Planning and Sustainable Development charged with "the responsibility of taking censuses in the Republic of Trinidad and Tobago and collecting, compiling, analyzing and publishing statistical information relating to all social and economic activities of the people of the Republic of Trinidad and Tobago" (CSO, 2014). This type of activity undertaken by the Government would fall under their mandate.

Benefit-Cost ratio	**N/A**	**-**	**Total cost**	**24,794**	**$**
Pay-back	**N/A**	**Year(s)**	**Total benefit**	**N/A**	**$**

6.3.18. TTA 18: Mangrove Restoration in Tobago

Objective

Planting and maintaining mangrove forests that are able to attenuate wind and swell waves in order to improve resilience against coastal erosion and infrastructure losses.

Previous experiences and success cases

Mangroves provide significant benefits to society including increased biodiversity, coastal protection from cyclones, and increased uptake of carbon, amongst others. In a report by Prof. K. Kathiresan titled, "3.5.

Importance of Mangrove Ecosystem", Kathiresan summarized the benefits reported by several different studies and projects worldwide. The report notes the significant benefits that have been found due to mangrove restoration including increased supply of forestry products (firewood, charcoal, timber, honey etc.) and fishery products (fish, prawn, crab, mollusc etc.). Mangroves also provide seeds for aquaculture industries. The report cites an example in which "40,000 fishers get an annual yield of about 540 million seeds of Penaeus monodon for aquaculture, in the Sundarban mangroves of West Bengal".

Ecological services that have been found in mangrove projects have included "solar UV-B radiation, 'green house' effects, and fury of cyclones, floods, sea level rise, wave action and coastal erosion". As an example of carbon sequestration the report cites the Rhizophora forest, which is a 20-year old plantation of mangroves that stores 11.6 kg m-2 of carbon with C burial rate of 580 g m-2 yr-1.

Mangroves have also proven to help in the trapping of sediments. A previous study done by the author is cited in the report in which it was estimated that "mangroves help in trapping the sediment up to 25 % at low tide as compared to high tide".

It is also important to note the significant coastal protection benefits offered by mangroves. In the report by Prof. K. Kathiresan, it states an example in which "the super-cyclone ... on the 29th October 1999 with a wind speed of 310 km hr-1 along the Orissa coast (India) and played havoc largely in the areas devoid of mangroves. On the contrary, practically no damage occurred in regions with luxuriant mangrove growth. Similarly, in the Mahanadi delta, where large scale deforestation and reclamation of mangrove land for other purposes have been undertaken, maximum losses of life and property have been reported from time to time during stormy weather".

Mangroves also help reduce coastal flooding and prevent coastal erosion. The higher the density of vegetation and the depth of the water, the higher the reduction of waves. The report by Kathiresan cites on example from Vietnam, in which "in the tall mangrove forests, the rate of wave reduction per 100 m is as large as 20%". Kathiresan also cites work that proves that mangroves act as "live sea walls" which have proven to be more economically beneficial than artificial concrete sea walls for coastal protection, in some cases.

The technique proposed by this measure (Hydrologic Restoration) is considered a good practice in terms of mangrove restoration. In fact, in a paper titled "Mangrove Restoration - Costs and Benefits of Successful Ecological Restoration" by Roy R. Lewis III (2001), he explained this process stating that:

> *Because mangrove forests may recover without active restoration efforts, it has been recommended that restoration planning should first look at the potential existence of stresses such as blocked tidal inundation that might prevent secondary succession from occurring, and plan on removing that stress before attempting restoration (Hamilton and Snedaker 1985[13], Cintron-Molero 1992[14]). The second step is determined by observation if natural seedling recruitment is occurring once the stress has been removed. Only if natural recovery is not occurring should the third step of considering assisting natural recovery through planting be considered.*

Lewis states many examples of projects that started directly by planting mangroves, without assessing the potential existence of stresses, which inevitably failed given the inability of the new plants to survive in the modified environments. Lewis also gives several cases where the technique of Hydrologic Restoration was successful. He states:

> *Successful ecological restoration requires the successful creation or restoration by construction of tidal creeks and intertidal wetland platforms frequently inundated by tidal waters (Lewis 1999[15], 2000a[16], b[17]). This excavation to restore the normal hydrology of the historical tidal creeks will be similar to efforts described in Roberts (1991), Whitman and Gilmore (1993) and Kurz et al. (1998). All three publications document the rapid recruitment to restored or created*

[13] Hamilton, L. S. and S.C. Snedaker (eds.) (1984), Handbook of Mangrove Area Management, Honolulu: East West Centre.

[14] Cintron-Molero, G. (1992), 'Restoring mangrove systems', in G. W. Thayer, ed., Restoring the Nation's Marine Environment, College Park: Maryland Seagrant Program, 223-277.

[15] Lewis, R. R. (1999), 'Key concepts in successful ecological restoration of mangrove forests', in Proceedings of the TCE-Workshop No. II, Coastal Environmental Improvement in Mangrove/Wetland Ecosystems, Bangkok: Network of Aquaculture Coordination in Asia, 19-32.

[16] Lewis, R. R. (2000a), 'Don't forget wetland habitat protection and restoration for Florida's fisheries', National Wetlands Newsletter 22(6): 9-10 + 20.

[17] Lewis, R. R. (2000b), 'Ecologically based goal setting in mangrove forest and tidal marsh restoration in Florida', Ecological Engineering 15(3-4): 191-198

tidal marshes or mangrove/marsh plant communities in Florida, (the latter two publications concentrating on such projects in Tampa Bay) of 40 species of adult and juvenile fish species including red drum (Sciaenops ocellatus), spotted seatrout (Cynoscion nebulosus), snook (Centropomus undecimalis), spot (Leiostomus xanthurus), black drum (Pogonias cromis) and tarpon (Megalops atlanticus).

Preliminary Considerations

At the moment, a coastal management program project is being developed in Tobago. Therefore, the implementation of this action should only be carried out if recommended by the program once it is developed. In that case, the selected areas would also need to be revised to ensure they fit the needs detected. This analysis should also include looking holistically at the other measures detailed in this study and understanding where and how they should be integrated together. While the measures are analyzed individually in this study, many of these measures would have increased impacts if they were implemented in conjunction with other proposed measures. Many of the measures regarding coastal management, including the restoration of mangroves (described here) and the protection of coral reefs (TTA 19), will have improved results if jointly implemented. These measures should therefore be looked at holistically and strategically when deciding which activities to implement, ensuring that possible mutual and re-enforcing benefits are captured.

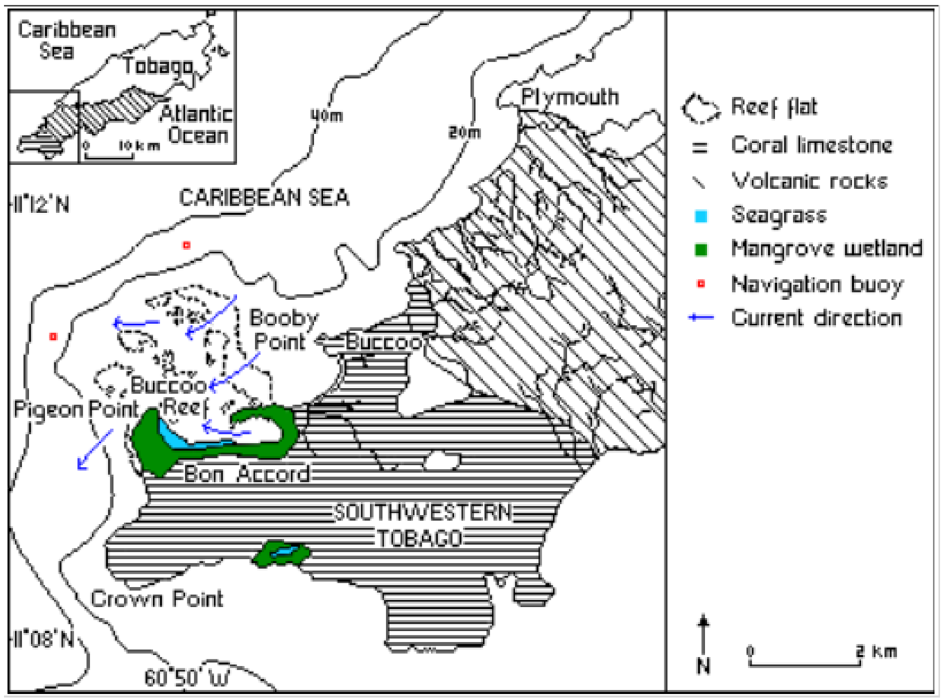
For the mangrove restoration to work, it is necessary to ensure that there is no water pollution and that the ecosystem is able to restore itself. Therefore, the selected areas need to be analysed first to find out whether restoration is viable or not. Otherwise, other coastal strips more suitable to the sites would need to be analysed.

Description of the action

Mangrove forests in Tobago are found in the southwest of the island and include the Bon Accord Lagoon, Buccoo Bay, Kilgwyn and Petit-Trou Lagoon (FAO, 2005). Mangrove restoration will occur in all of these areas: Bon Accord/Buccoo Bay with 130 ha, Kilwyn with 12 ha and Petit-Trou with 15 ha (Ministry of the Environment and Water Resources and EMA, 2011).

The technique proposed for the mangrove restoration is hydrologic restoration, rather than planting. Hydrologic restoration consists of connecting impounded mangroves to normal tidal influence. Instead of planting mangroves, the efforts would be focusing on restoring the previous state of the coastal areas, restoring the tidal schemes previous to the human influence. That way, if the environmental conditions are adequate, mangroves are restored without the need of planting, but rather just by the natural diffusion process which takes place due to the coastal tides. The development of the action would focus at first on achieving natural restoration. If this is not possible, mangroves would need to be planted. In the case that planting needs to occur, additional costs may have to be assumed, which are not considered in the economic analysis of this measure.

Source: Google Maps, the orange box is representative of the following image, its scale is approximate



(Laydoo, R. Bonair, K, Alleng, G., 1998)

Implementation period

2014-2023

Impact of the action

Mangroves are highly beneficial in that they are significant sources of forestry and fishery products. They enhance the sustainability of the area protecting the coast from solar UV-B radiation, 'greenhouse' effects, and fury of cyclones, floods, sea level rise, wave action and coastal erosion. Mangrove swamps act as traps for sediments, and sinks for nutrients. The root systems of the plants keep the substrate firm, and thus contribute to a lasting stability of the coast. Therefore, they can help protect the coastal areas from erosion.

As shown in the success cases section, mangrove restoration is a beneficial action in economic terms and provides many advantages for the environment, not only those derived from the prevention of the damage caused by the climate change hazards, but also options for the development of the local communities in terms of firewood, charcoal or timber procurement, improvement of fisheries, and so on.

Economic capacity

The implementation of this action in other countries shows that its benefits are much higher than the costs of the mangrove restoration. The investment is low for this action because the mangrove restoration is selected instead of mangrove planting. Planting should only be considered when the restoration is not viable, but it is not very recommendable due to the difficulty to obtain good growth rates and its higher cost.

In this analysis, the benefits due to coastal protection have not been included due to the lack of information in calculating them. The direct benefits from mangroves (fisheries, wood, etc), and the benefits they have in terms of climate change mitigation (acting as a carbon sink) have been included.

Technological capacity

In Trinidad and Tobago, efforts regarding the restoration of the mangroves are already being carried out. Therefore, it is not an unknown matter in the country. Additionally, the lessons learnt from the mangrove restoration projects carried out in other countries should be analysed and adapted to the characteristics of the selected coastal areas. The success of this action depends on the capacity to carry out the hydrologic restoration technique. Therefore, if in a first assessment it is found that the conditions for the hydrologic restoration are not met, the use of other techniques should be analysed.

Social capacity

The restoration of the mangroves does not have any harmful effects in social terms. On the contrary, it can provide several benefits to the communities because it would make the agricultural area more resilient to floods. For this reason, people who own these lands could be interested in cooperating in the restoration process. This activity would also improve the fishery and wood resources of the area and improve biodiversity, positively affecting the surrounding areas.

Institutional capacity

The institutional capacity is required in order to promote the development of the action within a national strategy on coastal areas protection. There is already a National Action Programme to Combat Land Degradation in Trinidad and Tobago 2006-2020, which should be considered. The action programme is defined in broad terms and it would be necessary to establish the adequacy of this action within the objectives set in the programme. At the moment, a coastal management program project is being developed in Tobago. Therefore, the implementation of this action should only be carried out if recommended by the developed program. In that case, the selected areas would also need to be revised to ensure they fit the needs detected.

In a similar way, the National Biodiversity Strategy and Action Plan focuses on the conservation and sustainable use of the country's biodiversity, but it does not include a particular mention of the management of the country's mangroves.

There is also a National Policy and Programmes on Wetland Conservation in Trinidad and Tobago, which includes the management of some of the mangroves of the countries. It includes among its objectives the restoration of damaged but important wetlands, but no additional information on how the objective will be achieved is included.

Legal capacity

Furthermore, the institutional capacity is required also for the development of the action within a national strategy in terms of coastal areas protection. There is already a National Action Programme to Combat Land Degradation in Trinidad and Tobago 2006-2020 should be considered. The action programme is defined in broad terms and it would be necessary to establish the adequacy of this action within the objectives set in the programme. In fact, in the programme, the need of a Coastal Zone Development Plan is stated, and it would be necessary to define that plan before this action can be carried out.

In terms of mangrove restoration, the National Biodiversity Strategy and Action Plan focuses on the conservation and sustainable use of the country's biodiversity, but it does not include a particular mention of the management of the country's mangroves. There is also a National Policy and Programmes on Wetland Conservation in Trinidad and Tobago, which includes the management of some of the mangroves of the countries. It includes among its objectives the restoration of damaged but important wetlands, but no additional information on how the objective will be achieved is included.

Buccoo Reef was designated a restricted area under the Marine Area (Restricted Area) Order in 1973, using the Marine Area (Preservation & Enhancement) Act of 1970. The Government declared the Buccoo Reef Marine Park an Environmentally Sensitive Area (ESA) under the Environmentally Sensitive Areas Rules, 2001. The Buccoo Reef Management Committee (BRMC) was established in October 2004 to oversee the establishment of this ESA. The committees include government agencies, NGOs and CBOs. This multistakeholder committee is extremely important in order to promote an integrated approach to the coastal management in this area, especially given the fact that much of the mangrove forests are not protected within the ESA due to the fact that it is privately held land. If cooperation for the protection of the mangrove cannot be dealt with successfully through this committee, given the lack of interest from the private owner, a public private partnership may need to be considered in order to help incentivize certain investments to help protect and restore the mangroves. The objective of this partnership would be to maintain the mangroves under private ownership for the greater good of the public. The distribution of the costs and benefits of this project will need to be discussed between the partners in order to determine a possible solution that benefits both the private owners and the greater public. Due to its complexity, a public private partnership should only be considered if a contractual agreement cannot be decided upon with the private owners.

Mangrove Restoration in Tobago is slightly complicated in terms of legal capacity for several reasons. Some of the mangroves on the island like for example, in the Buccoo region, are held under private ownership and mangroves fall under the jurisdiction of several agencies. Existing land use management policy dictates that "the local government such as the County Council has responsibilities up to the high water mark while land administration, rather than land management, is undertaken from the high water mark seawards to the extent of the EEZ by the Commissioner of State Lands under the Ministry of Planning and Development. Further, if beach facilities are constructed they are the responsibility of the Tourist Board under the Ministry of Enterprise Development, Foreign Affairs and Tourism; the construction and maintenance of coastal protection structures fall under the jurisdiction of the Ministry of Works and Transport; construction of fish landing facilities is the responsibility of the Fisheries Division of the Ministry of Agriculture Land and Marine Resources, and if the beach is fringed by mangroves or a site for turtle nesting the area is the responsibility of the Forestry Division in the Ministry of Public Utilities and the Environment. Additional jurisdictions involved may be the Ministry of Energy with regards to exploited petroleum and gas reserves" (Soomai, S., 2005). This interlinkage of authoritative figures will need to be looked into in order to determine the frameworks under which the measure falls.

Benefit-Cost ratio	**147.0**	**-**	**Total cost**	**35,325**	**$**
Pay-back	**4.2**	**Year(s)**	**Total benefit**	**5,193,043**	**$**

6.3.19. TTA 19: Coral Reef Protection and Restoration in Tobago

Objective

To develop a social awareness program to sensitize the local community, fisherfolk, and tourists about sustainable coral reef management.

Previous experiences and success cases

As mentioned in TTA 4 and 5, capacity building and awareness raising efforts have been widely accepted as important aspects of any program working to improve the conditions, or management of natural resources, natural disaster risk management, etc. By improving the population's understanding of the importance of natural resource management, and by offering information regarding ways in which they can improve natural resource management through their own habits, the demand of natural resources, like water, can be greatly reduced. These types of campaigns have been widely used in sectors such as energy efficiency and water management, with positive results in many cases.

As an example, a capacity building project in the Philippines, by the Asia-Pacific Network for Global Change Research, had objectives to increase the awareness, knowledge and capability of Communal Irrigator's Associations on alternative irrigation water management, climate forecast application, rice production systems and social mobilization. The project reported that they successfully completed these objectives and that in addition, "aside from the lectures provided by the experts, the vulnerability assessments and the experiences that these CIAs shared helped in identification of the most appropriate recommendations and good practices they need to improve their capacity as an organization and as individual farmers".

Another good example of the effect of capacity development comes a report titled "Cross-Cutting Perspective C: Capacity Development and Social Learning" in which they mention a pilot project in Indonesia in which Water User Associations (WUAs) were empowered through capacity development, appropriate regulatory changes were made, and local staff of the Irrigation Services were trained as "facilitators". The report states that "Where conventional rehabilitation projects traditionally have had an Economic Rate of Return (ERR) of 10-18%, an economic analysis showed that, when an enhanced capacity of the WUAs was realized, the ERR rose to 30-40%. The conclusion seems to be justified that the social capital of the water sector is the 'heart of the matter' while the works are the 'vehicle' through which the capacity is built."

In terms of creating a volunteer monitoring program, as described in this measure, this type of program was implemented in Jamaica, and is considered a Best Practice by the United Nations Environment Programme (2004). In their report, UNEP states that "about 50 fishers were officially appointed 'Honorary Game Wardens' and 'Fishery Inspectors' by Jamaica's Head of State, the Governor-General. These Acts convey powers of arrest (without warrant if the enforcement officer witnesses the offence) and powers of search, without warrant, of any vessel the enforcement officer believes has been used to commit an offence, or contains a catch obtained illegally. It also authorizes the enforcement officer to impound any vessel if any evidence is found. Such empowerment of community leaders reinforces their personal and community authority, and strengthens the effectiveness of the fisheries organizations themselves". The program was shown to be successful in helping sustainably manage the natural resources and help raise local ownership of their public lands and their natural environment.

Preliminary Considerations

At the moment, a coastal management program project is being developed in Tobago. Therefore, the implementation of this action should only be carried out if recommended by that program once it is developed. In that case, the selected areas would also need to be revised to ensure they fit the needs detected. Additionally, a project called the Speyside Marine Area Community-based Management Project involving the Tobago house of Assembly, UNDP, GEF small grants program, Buccoo Reef Trust, and Coral Cay Conservation worked to promote awareness about coral reef protection in the Speyside marine area within the local community from 2008 to 2009 was proven to be relatively successful in promoting CBOs dedicated to the protection of Speyside and providing education on marine life. Learnings from this project should be considered in the development of this project, and Community Based organizations that came from this project, including the Speyside Eco-Marine Park Rangers (SEMPR) should be consulted for their experience and knowledge.

According to several studies (Burke et al 2008, Lapointe B., et al, 2010), some of the main causes of coral reef destruction in Buccoo Reef comes from overfishing in the region and sediment and nutrient delivery into the area due to poor water and waste management and agricultural runoff. While the issues of waste and water management at the public works level is out of the scope of this measure, they should be looked into, due to their important impact on the coral reefs and the sea habitat. Waste and water management should be integrated in the coastal management plan in order to ensure that runoff and nutrient and sediment delivery has a minimized impact on the coral reefs and wetlands of Tobago.

In terms of overfishing, some legislation is in place to protect fishing stocks in certain zones, including the Buccoo Marine Park. In addition to this legislation, it is proposed that additional "no-take" Marine Protected Areas be looked into for legislation. According to a the van Bochove (2012), "these sites will help to increase commercial fish stocks, improve local fisheries through a spillover of recruits and act as a source of coral recruits to downstream reefs around Tobago and potentially its neighbouring islands".

Description of the action

Coastal Reef Protection will occur in the southern Tobago, specifically Buccoo Reef Marine Park, and the Coral reefs around Rockley Bay. The Department of Marine Resources and Fisheries has a staff of Reef Patrolmen who are in charge of patrolling the marine park at Buccoo; however, it has not been successful at deterring illegal practices. This measure will aid this department by increasing the local community´s participation in coral reef protection. Local people will be offered the opportunity to help raise awareness among their community, fisherfolk, and tourists by being part of a voluntary group of eco-awareness raisers, or eco-monitors in southern Tobago. They will be in charge of walking through tourist areas, visiting local fishing spots, and visiting the coral reefs and beaches in order to inform tourists, and fisherfolk about sustainable use of the local natural resources. Obviously, if they see any illegal activity, they will report it to the local authorities. These volunteers will be provided with a three day annual training session in order to provide them with the skills required for the position, and specific knowledge on their legal abilities as part of this organization.

Additionally, an awareness raising program will be developed in order to ensure that the local communities, fisherfolk, and tourists understand the impacts of their actions, and more importantly, the benefits associated with a well managed and protected coastal habitat. According to a the Final Report explaining the "Results of Community and Scientific Work" from the Tobago Coastal Ecosystems mapping project (van Bochove, 2012), this action was highlighted as important for the sustainability of the coral reefs in Tobago. It states, "continued community participation, education and capacity development will be important to improve awareness amongst Tobago's citizens about the benefits of well managed and protected coastal habitats to their livelihoods. Without this foundation of understanding and empowerment, it will be difficult to secure coral reefs for the future". In this action, three separate campaigns are designed targeting three groups: local communities, fisherfolk, and tourists. As a first step, a general communications strategy would be developed.

The campaign for local communities will focus more on regional radio, and print media for information diffusion on both the community meetings and opportunity to be an awareness raising volunteer. Local meetings will be held in order for the community to become involved in the initiative and discuss how they can help protect their local resources. Taking from a Best Practice called the "Culture of System-Beating" in Jamaica, stakeholders themselves will identify problems facing the resources their fisheries depend upon, and possible solutions. In Jamaica, when this approach was taken, the stakeholder's list was "remarkably similar to fisheries management strategies drawn up by fisheries biologists, but since the fishers identified the list of problems and solutions themselves, they 'owned' the list".

For fisherfolk, awareness raising will be more localized, focussing on distributing information at the offices for registration, local fishing docks, and other office/websites used by fisherfolk for information and for administrative needs.

Lastly, the campaigns for tourists will be focussed on providing information and awareness at tourist information centres, hotels, and local businesses who are interested in helping promote the campaign. These private entities will be solicited to provide the campaign's brochures and signage in areas with heavy tourism traffic, including concierge desks and brochure stands at hotels, information boards in tourist shops, etc. The objective is to make tourists aware of the impacts that occur from their activities, including the removal of corral, polluting beaches, etc.

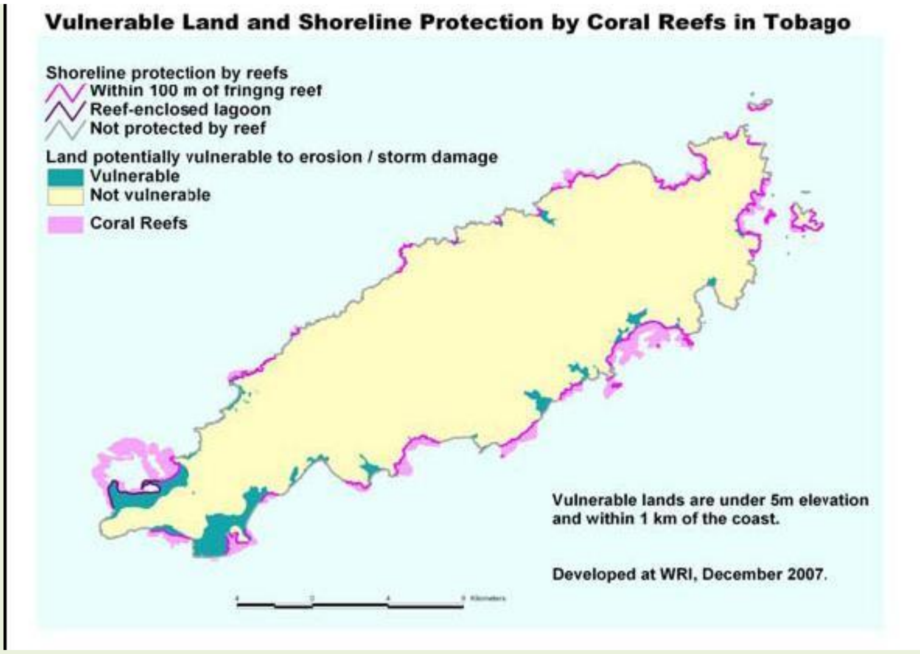
Implementation period

2014-2030

Impact of the action

The tourism industry represents 36.7% of Tobago's GDP. There are approximately 14.000 jobs in this industry. Coral Reefs provide significant benefits to tourism and protect local fisheries, which are important sources of cultural tradition, and livelihood for many people living on the island. The World Resources Institute estimated that coral reef-associated tourism on Tobago was estimated to contribute between 100 and 130 million US dollars in 2006, which the annual economic benefits associated from fishery services was between 0.8 and 1.3 million US dollars per year in Tobago. These numbers are significant given the fact that the Island´s GDP in 2006 was 286 million US dollars. (Burke et al., 2008)

Additionally, Coral Reefs also provide shoreline protection services in reduced erosion and wave damage - which was estimated to have a value of between 18 and 33 million dollars per year in Tobago in 2006 according to a study done by the World Resources Institute (Burke, et al, 2008). Two of the land areas most vulnerable to inundation in Tobago are behind the two coral reef areas which this measure aims to protect:



(World Resources Institute, 2008)

Economic capacity

The costs of this measure involve the design of the program, the design and implementation of the training workshops for the awareness raising volunteers, the elaboration and printing of brochures and radio ads, and the development of the workshops for the local community. In terms of economic benefits, this program would help protect the coral reefs in the area from destruction by tourists, and from overfishing. This will help ensure that the reefs, and their economic benefits, are preserved for future generations. These benefits include tourism, fishing, and shoreline protection, as previously described in the possible impacts of the action. The economic benefits due to tourism and shoreline protection have been estimated in this analysis; however, the benefits to fisheries have not been able to be estimated due to lack of information on losses due to overfishing in the area.

Technological capacity

This action does not involve many difficulties in technological terms. It consists in developing a program, creating brochures, a radio ad and developing workshops, which technologically do not involve any special effort.

Social capacity

Given the lessons learned in the Speyside Marine Area Community-Based Management Project (Syne, S., 2011), residents were reserved and unwilling to participate in the project at first. Face-to-face strategies, along with the assistance of local community activists proved useful in breaking this initial barrier. The report highlights "the value of liaisons with reputable and respected community members when stating that environmental challenges can only be met when there is a very strong bond between them and external agencies". Community Based Organizations, such as the Speyside Eco-Marine Park Rangers, and NGOs, such as the Buccoo Reef Trust, will likely need to be enlisted in order to help promote community involvement, facilitate the diffusion of information, and promote the participation of local hotels and businesses.

Institutional capacity

For this action, the efforts of the institutions of Trinidad and Tobago need to be focused on involving the general population in order to obtain the best results. Therefore, it is key to have properly identified the "facilitators". These people could be from public administration; however, given the lessons learned in the Speyside Marine Area Community-Based Management Project (Syne, S., 2011), residents were reserved and unwilling to participate in the project at first. Face-to-face strategies, along with the assistance of local community activists proved useful in breaking this initial barrier. Community Based organizations, such as the Speyside Eco-Marine Park Rangers, and NGOs, such as the Buccoo Reef Trust, should be enlisted order to help promote community involvement, facilitate the diffusion of information, and promote the participation of local hotels and businesses.

Regarding the institutional framework, Trinidad and Tobago counts with a Climate Change Policy, in which awareness raising is considered, stating the need to carry out actions relating to it. However, there are not any concrete actions defined, so it would be necessary to develop in more detail the policy, including concrete actions, and, if necessary, passing a climate change act in Trinidad and Tobago. In addition, the Buccoo Reef Management Committee (BRMC) may have institutional linkages with this type of work in the region.

Legal capacity

Buccoo Reef was designated a restricted area under the Marine Area (Restricted Area) Order in 1973, using the Marine Area (Preservation & Enhancement) Act of 1970. The Government declared the Buccoo Reef Marine Park an Environmentally Sensitive Area (ESA) under the Environmentally Sensitive Areas Rules, 2001. The Buccoo Reef Management Committee (BRMC) was established in October 2004 to oversee the establishment of this ESA. The committees include government agencies, NGOs and CBOs.

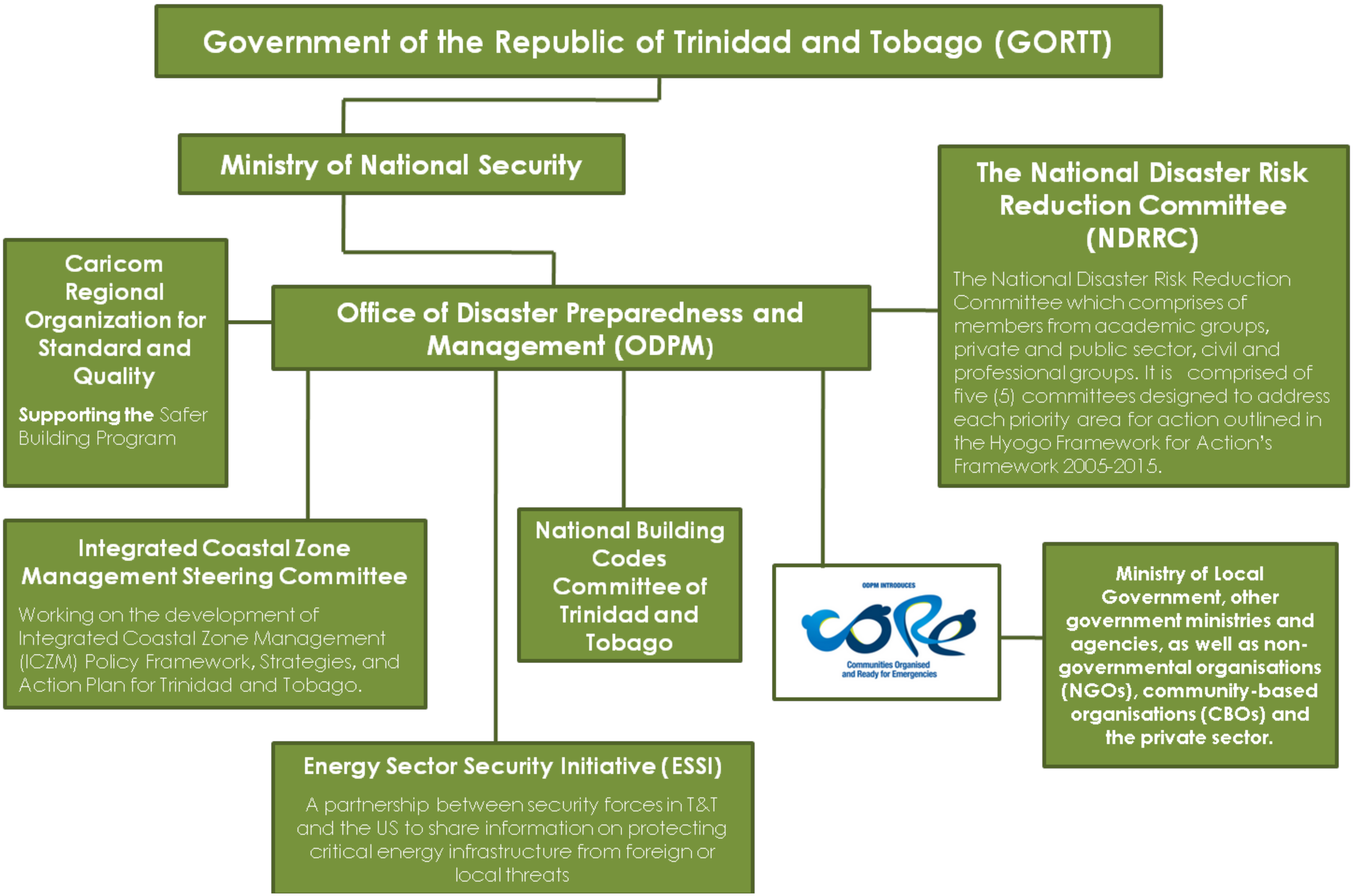
In terms of overfishing, the Buccoo Reef Marine Park (BRMP) was established in 1973 as a no-fishing area, with authorization for entrance fees. However, at present, the no-fishing restrictions are not enforced, and fees have never been instituted (Burke et al, 2008).

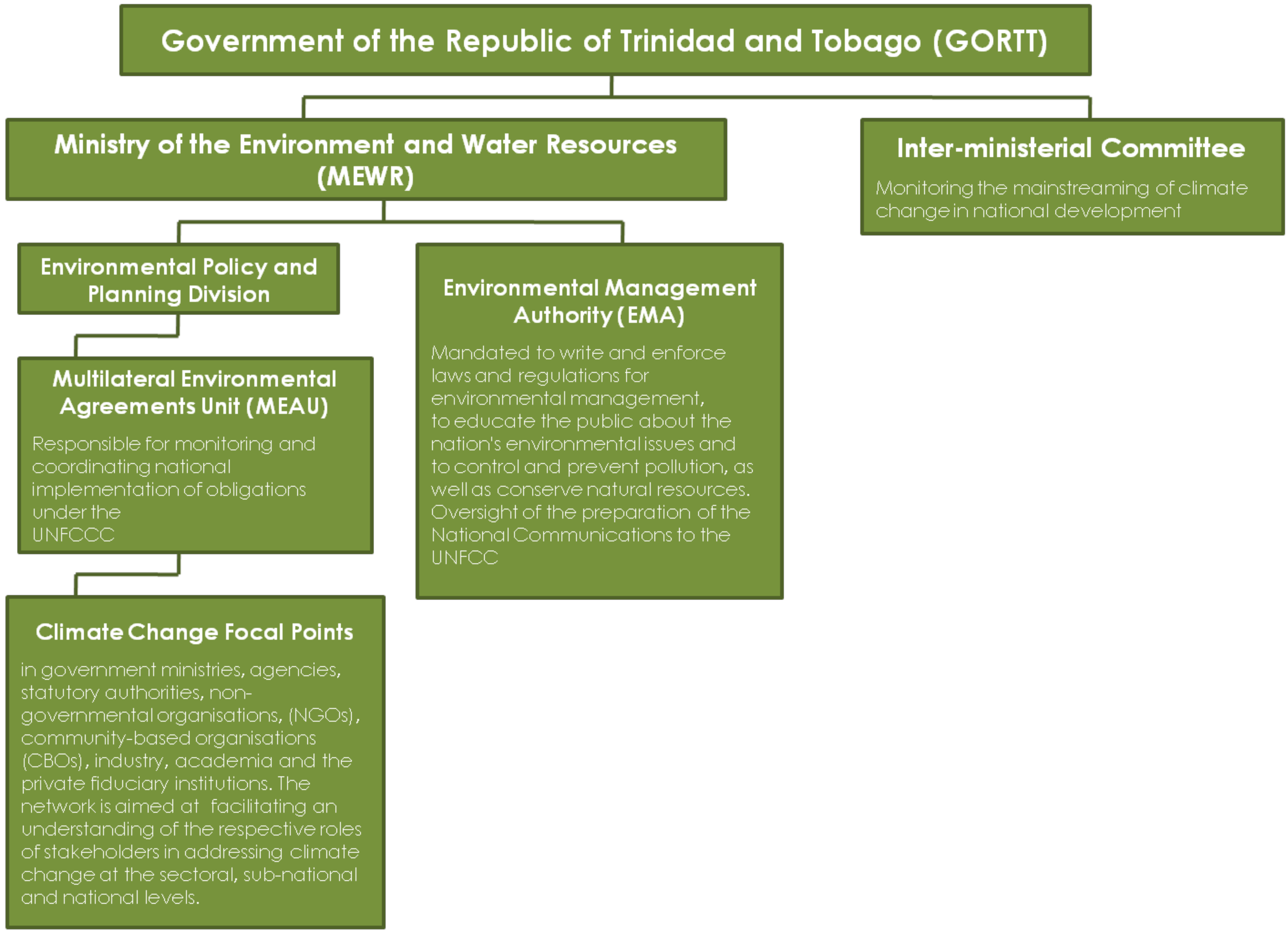
Benefit-Cost ratio	**0.8**	**-**	**Total cost**	**624,672**	**$**
Pay-back	**∞**	**Year(s)**	**Total benefit**	**523,245**	**$**

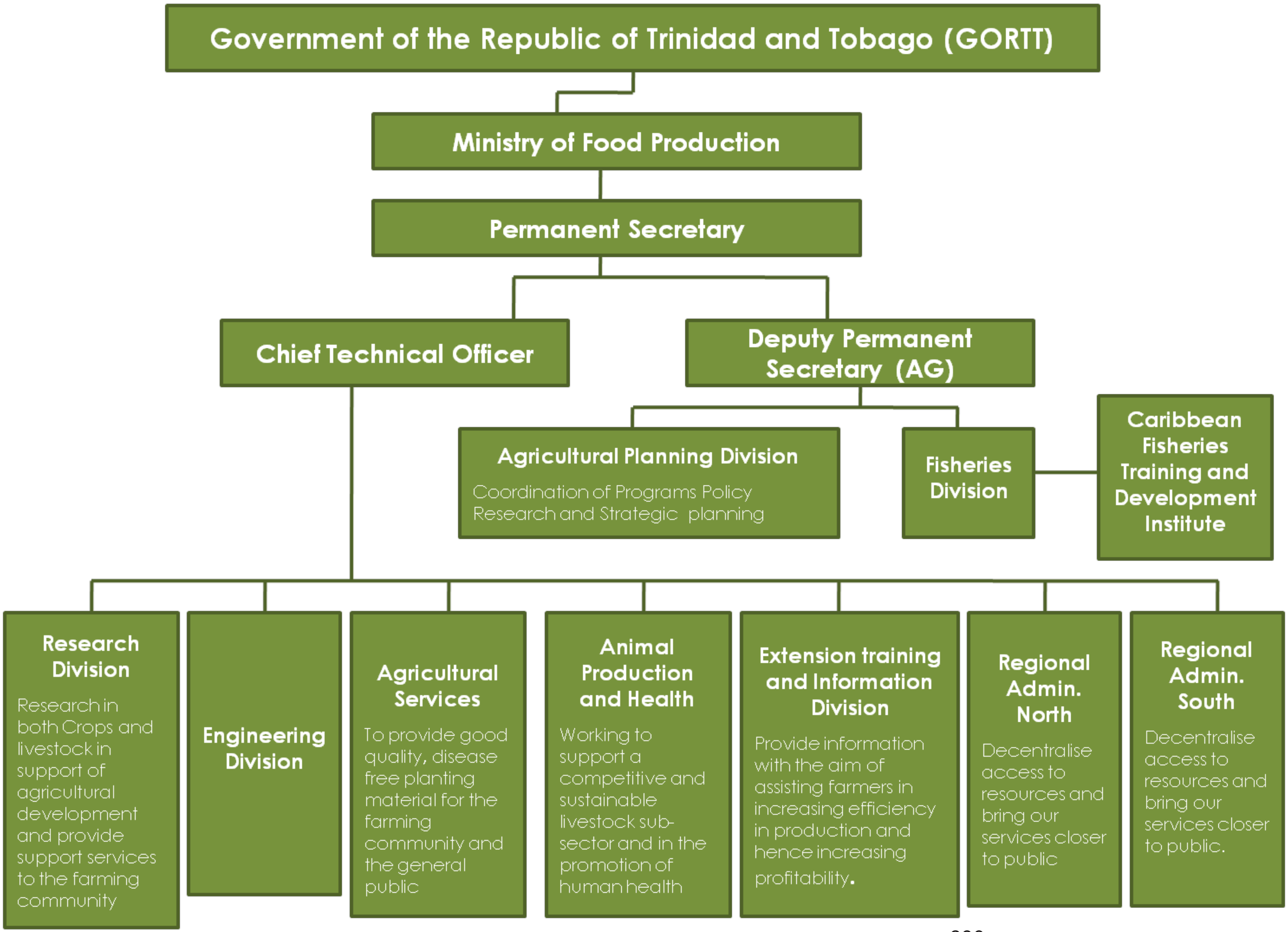
Many of these measures require the assistance of several organizations and institutions from different government departments and working groups. An integrated approach to climate change adaptation is needed in areas such as disaster risk management, emergency response, coastal management, etc. While these measures were designed as specific actions that could be implemented individually, each one improving the adaptation of the country to Climate Change risks, it is recommended that they be implemented together, integrating the actions into one program ensuring that the information is congruent across measures.

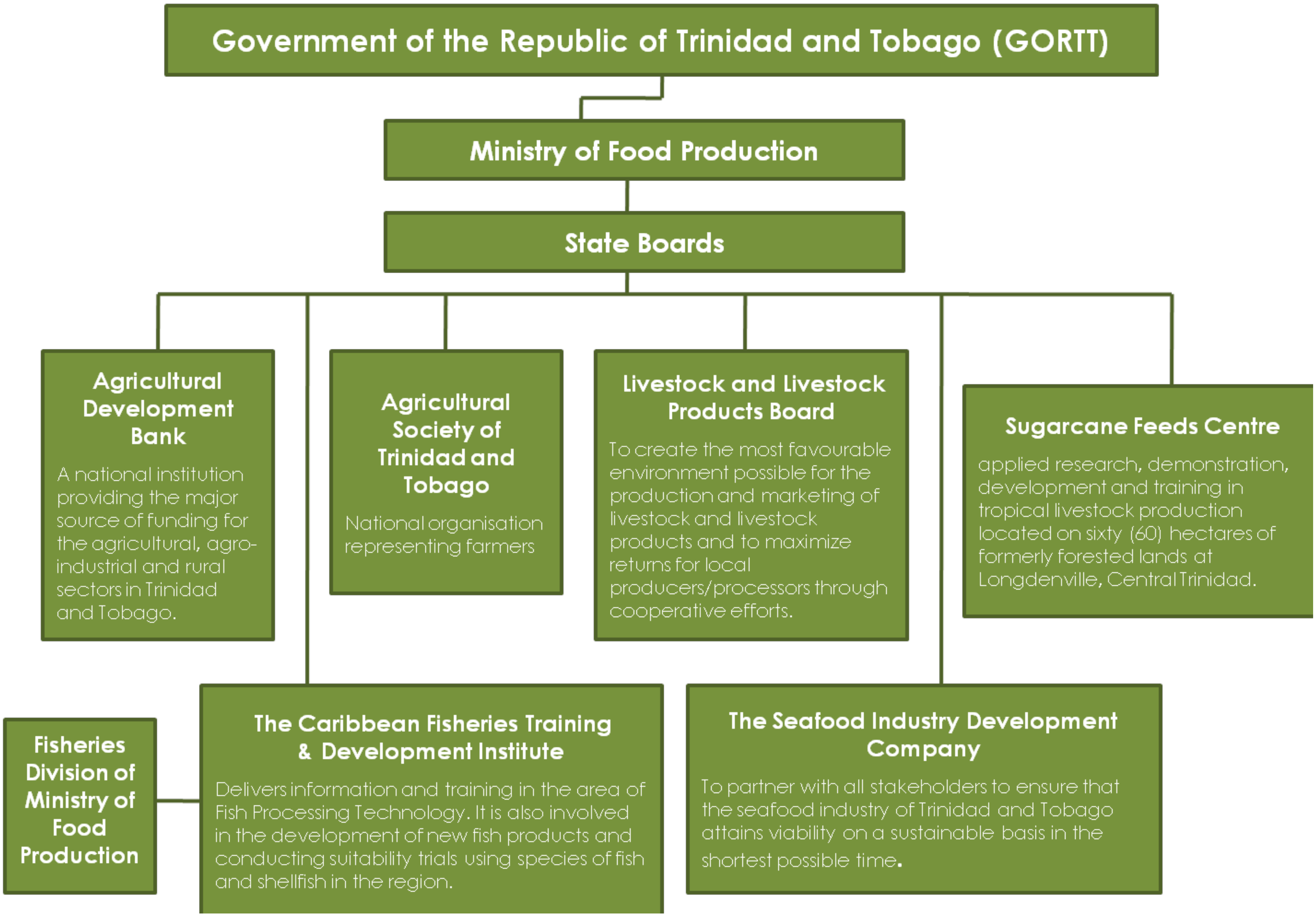
The following pages provide a basic mapping of the government departments and committees that could be involved in one or more of the measures outlined in this study. They may need to be, at some level incorporated in an action, or will need to be communicated to regarding certain actions, in order to promote integration and effective programs and procedures.

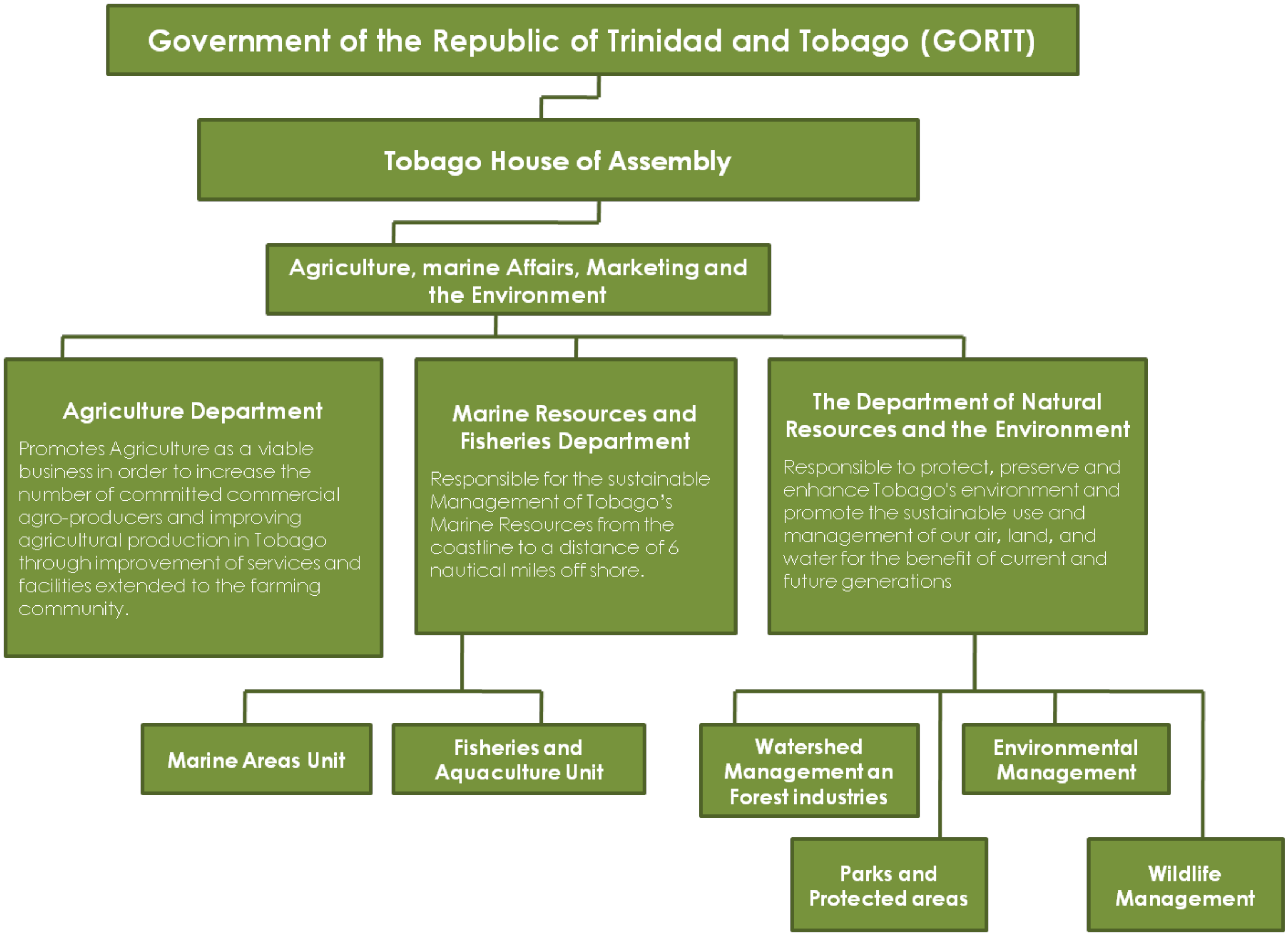
Figure 84: Schematic representations of institutional organization, showing entities that may need to be involved in, or communicated to on certain measures proposed in this report.
Source: Prepared by the authors.




Government of the Republic of Trinidad and Tobago (GORTT)
Ministry of the Environment and Water Resources (MEWR)
Inter-ministerial Committee
Monitoring the mainstreaming of climate change in national development
Environmental Policy and Planning Division
Environmental Management Authority (EMA)
Mandated to write and enforce laws and regulations for environmental management, to educate the public about the nation's environmental issues and to control and prevent pollution, as well as conserve natural resources. Oversight of the preparation of the National Communications to the UNFCC
Multilateral Environmental Agreements Unit (MEAU)
Responsible for monitoring and coordinating national implementation of obligations under the UNFCCC
Climate Change Focal Points
in government ministries, agencies, statutory authorities, non-governmental organisations, (NGOs), community-based organisations (CBOs), industry, academia and the private fiduciary institutions. The network is aimed at facilitating an understanding of the respective roles of stakeholders in addressing climate change at the sectoral, sub-national and national levels.


Government of the Republic of Trinidad and Tobago (GORTT)
Ministry of Food Production
Permanent Secretary
Chief Technical Officer
Deputy Permanent Secretary (AG)
Agricultural Planning Division
Coordination of Programs Policy Research and Strategic planning
Fisheries Division
Caribbean Fisheries Training and Development Institute
Research Division
Research in both Crops and livestock in support of agricultural development and provide support services to the farming community
Engineering Division
Agricultural Services
To provide good quality, disease free planting material for the farming community and the general public
Animal Production and Health
Working to support a competitive and sustainable livestock sub-sector and in the promotion of human health
Extension training and Information Division
Provide information with the aim of assisting farmers in increasing efficiency in production and hence increasing profitability.
Regional Admin. North
Decentralise access to resources and bring our services closer to public
Regional Admin. South
Decentralise access to resources and bring our services closer to public.


Government of the Republic of Trinidad and Tobago (GORTT)
Ministry of Food Production
State Boards
Agricultural Development Bank
A national institution providing the major source of funding for the agricultural, agro-industrial and rural sectors in Trinidad and Tobago.
Agricultural Society of Trinidad and Tobago
National organisation representing farmers
Livestock and Livestock Products Board
To create the most favourable environment possible for the production and marketing of livestock and livestock products and to maximize returns for local producers/processors through cooperative efforts.
Sugarcane Feeds Centre
applied research, demonstration, development and training in tropical livestock production located on sixty (60) hectares of formerly forested lands at Longdenville, Central Trinidad.
Fisheries Division of Ministry of Food Production
The Caribbean Fisheries Training & Development Institute
Delivers information and training in the area of Fish Processing Technology. It is also involved in the development of new fish products and conducting suitability trials using species of fish and shellfish in the region.
The Seafood Industry Development Company
To partner with all stakeholders to ensure that the seafood industry of Trinidad and Tobago attains viability on a sustainable basis in the shortest possible time.


Government of the Republic of Trinidad and Tobago (GORTT)
Tobago House of Assembly
Agriculture, marine Affairs, Marketing and the Environment
Agriculture Department
Promotes Agriculture as a viable business in order to increase the number of committed commercial agro-producers and improving agricultural production in Tobago through improvement of services and facilities extended to the farming community.
Marine Resources and Fisheries Department
Responsible for the sustainable Management of Tobago's Marine Resources from the coastline to a distance of 6 nautical miles off shore.
The Department of Natural Resources and the Environment
Responsible to protect, preserve and enhance Tobago's environment and promote the sustainable use and management of our air, land, and water for the benefit of current and future generations
Marine Areas Unit
Fisheries and Aquaculture Unit
Watershed Management an Forest industries
Environmental Management
Parks and Protected areas
Wildlife Management

7. Decision making framework for action.

7.1. Methodological development of the cost/benefit analysis

As previously explained, for this analysis, the ECA methodology has been chosen. The steps involved in this process are:

1. Identify climate hazards facing the country, the country's vulnerability and the value of human lives and physical assets at risk under a no climate change scenario in comparison to medium and high climate change scenarios.
2. Perform cost-benefit analysis of identified adaptation measures to inform decision making.
3. Prioritize cost-effective adaptation measures for implementation and integration to the nation's development plan.

For this report, these steps have been followed. As seen in section seven of this document, the climate hazards and the risks have been identified in four different scenarios. Scenarios S0 and S1 are those in which today's vulnerability scenario is maintained, while in S2 and S3 the future vulnerability scenario is considered. Regarding the climate considered for the elaboration of the scenarios, in S0 today's climate is maintained, while in S1 and S2 a moderate change of the climate would take place and in S3 a high change.

After the risks were analyzed, this information, along with specific information related to the social and economic situations of the country, was used in order to determine a list of adaptation measures suitable for Trinidad and Tobago. Once the list of actions was identified, economic costs and benefits for each action were identified for each year from 2014 to 2030. This range was used given the fact that long term provisions of climate change scenarios have increased statistical standard deviations, and therefore, calculating the benefits further out into the future becomes less precise. That being said, in many cases, if this time frame were to be extended to 2050, or 2100, the benefits would surely outweigh the costs, and the Net Present Value of the measure would increase.

Economic costs were calculated by estimating the costs of implementing each measure, including construction costs, labour costs, material costs, and maintenance costs. Economic benefits were calculated by taking the probabilities of natural hazards occurring - including moderate climate change increases, the expected damages from these natural hazards, and the impact that these measures would have in mitigating damages. In most cases, several benefits were able to be identified and calculated for each measure. However, in some cases, given the lack of environmental and social information specific to Trinidad and Tobago, and given the nature of certain benefits, some benefits to society were not able to be calculated. These benefits often included externalities such as atmospheric contamination (SO_2 NO_2 PM_{10}), human health factors, opportunity costs, etc. It should be expected that, in those cases, the total benefits to society will be larger than the benefits calculated in this study, given that not all benefits were able to be calculated. In fact, it should be noted that non-market benefits were not calculated for any of the actions unless specifically indicated (for more information on costs and benefits for every action, see Annex IV).

Several economic and multi-criteria tools were used in order to analyse the feasibility of the measures including Net Present Value, Payback Period, Cost-Benefit Analysis Ratio, "No Regret" analysis, and a Multi-Criteria Analysis. The first four tools fall into the category of cost-benefit analysis in which environmental and social costs and benefits are looked at in terms of their subjective, or relative, scarcity. Using Cost-Benefit analysis, the benefits and costs to society are all given monetary values in order to understand their feasibility and in order to compare each measure against one another. The last tool, Multi-Criteria Analysis, looks at the environmental and social issues as a more objective scarcity, in which each societal good is looked at independently, and not given a monetarial value. Although complex and subjective, it invites other issues related to the measures to be looked at and compared.

The first tool used was the net present value of the project's revenue generation. The net present value is calculated by taking the yearly cash flows of the project, and discounting the flows by a discount rate, in order to calculate the present value of that future cash flow. This is done because of the generally accepted fact that money is valued more today than in the future. Therefore, for long term projects, the time value of money is an important factor in order to determine the economic feasibility of a project.

A discount rate has been applied due to several economic reasons such as time preference, interest rates, or expected economic growth. In the case of large public projects, the discount rate often accepted is the rate of a government issued treasury bond. The equation for calculating the Net Present Value is:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o$$

Where t is the time period, C_t is the cash flow for the given period, r is the discount rate, and T is the last period in the series. The calculation assumes that the present year is year 0.

The discount rate used for the calculation of the Net Present Value was 4% for the country level measures and 7% for the Petrotrin Pilot Case. The discount rate for the country level measures was taken from the bonds issued by the Central Government of Trinidad and Tobago in September 2013 with a maturity period of 15 years. The rate for Petrotrin was taken from the document written by the US Environmental Protection Agency (2010) called "Guidelines for Preparing Economic Analysis", in which it recommends that the Net Present Value be calculated "using the rate of return to private capital... The OMB estimates a rate of 7 percent for the opportunity cost of private capital".

If the Net Present Value is below zero, it means that the net of the cash flows, in present value, are negative, and therefore project has a net cost. If the Net Present Value is positive, that means the net of the cash flows, in present value, are positive, and therefore the project has a net benefit.

The second economic tool used to analyse this project was the payback period. The payback period is the number of years required to pay back the economic cost of the project.

The third economic tool used was the Benefit/Cost ratio. It is calculated using the following formula:

$$\text{Benefit-Cost Ratio} = \text{Total benefits} / \text{Total Costs} \qquad (44)$$

This ratio explains how many times the total benefits outweigh the total costs of the action. If the ratio is greater than 1, it means that the total benefits are greater than the total costs. For example, if the ratio is 2, that means that the total benefits are twice the total costs. If, however, the ratio is 0.5, that means that the total costs are double the total benefits.

Lastly, a "No Regret" Analysis was done for each measure. "No Regret" strategies are those in which the project can be justified in economic terms, even without climate change, however its benefits increase even more with climate change. For our analysis, we divided this idea into four categories:

- High Impact and "No Regret": Actions that have no regret, and also have a high impact in reducing damages due to natural hazards

- Low Impact and "No Regret": Actions that have no regret, and offer a lower impact in terms of reducing damages

- Low Regret: Actions that are not necessarily "No Regret" yet will produce significant benefits in the event of a natural hazard.

- Potential High Regret: Actions that are not "No Regret" yet produce lower levels of benefits in the event of a natural hazard.

Lastly, a multi-criteria analysis was made in order to weigh the economic information against additional criteria necessary for decision-making. This analysis was designed based on the work carried out by E.C. Van Ierland et al. (2007). The criteria includes importance, urgency, no regret, secondary effect and mitigation effects.

When assigning the importance to an adaptation action, it should be considered that the importance of an option reflects the level of necessity to implement the option. Important options can reduce major risks and/or preserve essential function provided by the surrounding environment. In principle, important options generate substantial benefits, though potentially at high costs.

The urgency of the option relates to the need of implementing the adaptation option immediately or whether it is possible to defer action to a later point in time. Long-lasting investments and conservation of the existing situation require early planning, and therefore a long period of waiting before implementing the option will render the option redundant (e.g. raising awareness), much more costly (e.g. for large infrastructure projects) or impossible (e.g. for conserving nature).

It should be noted that a high score on urgency does not necessarily imply that the option is important. It just means that postponing action may result in higher costs or irreversible damage.

In assessing the economic efficiency of various adaptation options a distinction is made between no-regret options and secondary effects options. No-regret options are those adaptation options for which non-climate related benefits, such as improved air quality, will exceed the costs of implementation; hence they will be beneficial irrespective of future climate change taking place. A no-regret option could be one that is determined to be worthwhile (in that it would yield economic and environmental benefits which exceed its cost), and continue to be worthwhile, irrespective of any benefits of avoided climate damages.

Secondary effect options on the other hand are specifically designed to reduce climate-change related vulnerability while also producing corollary benefits that are not related to climate change (Abramovitz et al., 2002). Secondary effects thus concern external effects which have a positive impact on policy goals unrelated to climate change policy (Metroeconomica, 2004).

Finally, the options can be ranked according to their effect on mitigation. Certain adaptation options will also induce a reduction of greenhouse gas emissions, and thus score very high on mitigation effect (i.e. are complementary to mitigation policies), while other adaptation options are substitutes to mitigation and increase greenhouse gas emissions.

These scores were then given a weighted score, with Importance having more weight (5) over urgency (4), No-Regret (3), Secondary Effects (2), and Mitigation Effects (1). The choice of scores was based on the same literature source, in which an expert consultation was carried out to establish the order for the criteria, being the one mentioned the result of the experts indications.

In the expert consultation it was overall concluded that the effect of an adaptation option on mitigation is of least importance, because the project relates to adaptation and some experts remarked that mitigation effects are part of the secondary effects. The criteria no-regret characteristic of the option was regarded as important, because it refers to the uncertainty about the right moment to implement an option and if this may lead to the misallocation of resources. However it can be seen as a conservative attitude to only implement options that are ranked highly on noregret characteristics.

According to the features described, the ranking of the actions in the multicriteria analysis is based on the table below:

Table 63: Ranking of actions for the multicriteria analysis.
Source: Prepared by the authors based on E.C. Van Ierland et al. (2007).

	Score				
	5	4	3	2	1
Importance	The option has a **very high** level of importance	The option has a **high** level of importance	The option has a **medium** level of importance	The option has a **low** level of importance	The option has **very low** level of importance
Urgency	The option has a **very high** level of urgency	The option has a **high** level of urgency	The option has a **medium** level of urgency	The option has a **low** level of urgency	The option has **very low** level of urgency
No-regret	The net benefits are **very high** irrespective of climate change	The net benefits are **high** irrespective of climate change	The net benefits are **medium** irrespective of climate change	The net benefits are **low** irrespective of climate change	The net benefits are **very low** irrespective of climate change

Secondary effects	The option generates a **very high** level of secondary effects	The option generates a **high** level of secondary effects	The option generates a **medium** level of secondary effects	The option generates a **low** level of secondary effects	The option generates a **very low** level of secondary effects
Mitigation effects	The option has a **strong positive** effect on mitigation	The option has a **positive** effect on mitigation	The option has a **neutral** effect on mitigation	The option has a **negative** effect on mitigation	The option has a **strong negative** effect on mitigation

Once a score for importance, urgency, no-regret, secondary effects and mitigation effects based on the criteria detailed above is assigned to every action, a weighted score is calculated, which allows the actions to be compared. For the weighted score, every parameter is weighted according to the experts criteria, but, quantitatively. To do so, for every parameter a weighting score is used, in the case of importance, the obtained score is multiplied by 5, that of urgency by 4, no-regret by 3, secondary effects by 2 and mitigation effects by 1.

Nevertheless, even if a weighted score is calculated and helps obtain a comprehensive picture of the results, the order determined by the experts criteria prevails over the weighted score. Therefore, if the importance score of action one is higher than that of action two, regardless of the fact that action two may have a higher weighted score, action one will have a higher priority according to the multicriteria analysis. That same scheme is applied to all the parameters following the order suggested by the experts, and, in case of having the same score in one of the parameters for one action, the next parameters are used to prioritize, being the action with a highest final result that for which a higher score is obtained in the next parameter in which the actions have the different results according to the established order.

To conclude this introduction to the results of the economic analysis, it should be notad that it was done in order to give a global picture of the costs and benefits, and feasibility, of the possible climate adaptations actions available to Trinidad and Tobago given its unique hazards and vulnerabilities due to climate change. However, given the lack of information in certain areas of the analysis, some of the calculations serve as estimations, rather than precise calculations of the real costs and benefits related to the measure. It is recommended that before the implementation of any of these actions, a more detailed analysis should be developed, retrieving as much available information as possible from relevant stakeholders, including the affected population, and government agencies. As more information becomes available, these economic estimations will need to be adapted accordingly.

7.2. Analysis of the results

The following table explains the Total Costs (not discounted), Total Benefits (not discounted), Net Present Value, the Payback period, and the Benefit-Cost Ratio for each measure defined within this project:

Table 64: Results of the Cost-Benefit Analysis of the actions.
Source: Prepared by the authors.

Action code	Title	Total cost	Total benefit	Net present value	Pay back (years)	Benefit-Cost Ratio
TTA 1	National Building Code	$4,529,327	$72,151,025	$40,675,033	3	15.9
TTA 2	Dike Construction in Trinidad	$85,977,904	$6,825,496	-$55,532,774	146	0.1
TTA 3	Meteorological alert System connected to the Monitoring System	$41,000	$4,179,913	$2,923,547	0.1	101.9
TTA 5	Social Awareness Program	$198,787	$98,559	-$80,224	∞	0.5
TTA 4 *TTA 6*	Emergency Protocols Institutional Training Program	$1,659,793	$3,767,319	$1,489,173	0	2.3
TTA 7	Rainwater harvesting	$1,714,977	$1,180,476	-$493,475	25	0.7
TTA 8	Infrastructure and Building Reinforcement	$61,820,734	$27,911,274	-$26,705,453	35	0.5
TTA 9	Retention ponds	$279,616	$47,027	-$180,117	∞	0.2
TTA 10	Filter Strips	$487,080	$356,132	-$119,458	25	0.7
TTA 11	Permeable pavements	$375,536,762	$38,897,785	-$240,055,769	∞	0.1
TTA 12	Beach Nourishment in Tobago	$23,688,332	$20,736,386	-$5,810,982	19	0.9
TTA 13	Mangrove Restoration in Trinidad	$744,188	$71,348,613	$40,273,146	5.1	95.9
TTA 14	Parametric Insurance Scheme	$62,850	N/A	N/A	N/A	N/A
TTA 15	Agriculture & Climate Change Research Unit	$4,455,439	$986,772	-$2,544,836	∞	0.2
TTA 16	Green Roofs	$1,055,220	$1,786,554	$213,421	10	1.7

Please note: The total costs and total benefits for TTA 4 and TTA 6 were calculated together. Also, TTA 14 does not have any measureable economic benefits, as it is considered that insurance programmes do not modify the overall damage caused by the extreme events. They are useful from a cost-efficiency perspective but not from a cost-benefit approach, because the economic damage is the same even if insurance programmes are not developed. The only difference is the way in which that economic damage is covered. Therefore, from a societal cost perspective the cost-benefit analysis does not change. However, from a private cost perspective of course it does make a difference. TTA 17 also does not have any economic benefits that can be calculated; the survey will provide information to both policy makers and practitioners, yet without knowing the results of the survey, it is impossible to determine the impact of this information in economic terms.

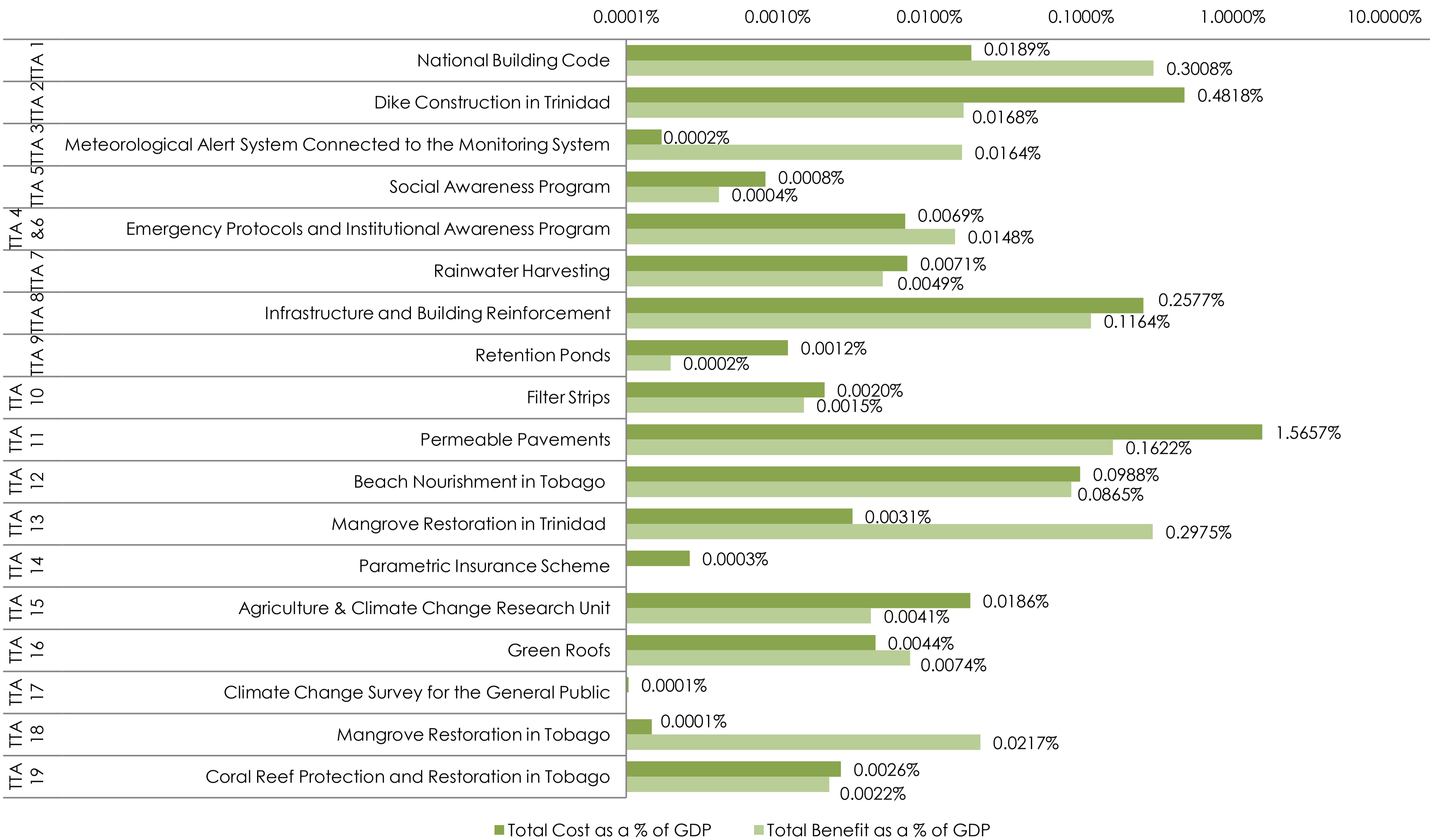
The table and graph below show the total costs and total benefits of each measure as a percentage of total GDP in Trinidad and Tobago:

Table 65: Total Costs and Total benefits as a Percentage of GDP.
Source: Prepared by the authors.

Action code	Title	Total cost	Total benefit	Net present value	Pay back (years)	Benefit-Cost Ratio
TTA 1	National Building Code	$4,529,327	$72,151,025	$43,923,883	1.9	15.9
TTA 2	Dike Construction in Trinidad	$115,554,303	$4,033,247	-$79,223,470	61.6	0.0
TTA 3	Meteorological Alert System Connected to the Monitoring System	$41,000	$3,935,834	$2,830,906	0.1	96.0
TTA 5	Social Awareness Program	$198,787	$98,240	-$83,151	∞	0.5
TTA 4 *TTA 6*	Emergency Protocols Institutional Training Program	$1,659,793	$3,545,712	$1,344,701	0.9	2.1
TTA 7	Rainwater Harvesting	$1,714,977	$1,180,476	-$500,418	24.9	0.7
TTA 8	Infrastructure and Building Reinforcement	$61,820,734	$27,911,274	-$27,646,239	35.4	0.5
TTA 9	Retention Ponds	$279,616	$47,027	-$187,075	∞	0.2
TTA 10	Filter Strips	$487,080	$356,132	-$121,338	24.9	0.7
TTA 11	Permeable Pavements	$375,536,762	$38,897,785	-$252,122,202	∞	0.1
TTA 12	Beach Nourishment in Tobago	$23,688,332	$20,736,386	-$5,522,748	19.4	0.9
TTA 13	Mangrove Restoration in Trinidad	$744,188	$71,348,613	$43,881,303	4.4	95.9
TTA 14	Parametric Insurance Scheme	$62,850	N/A	N/A	N/A	N/A
TTA 15	Agriculture & Climate Change Research Unit	$4,455,439	$986,772	-$2,661,472	∞	0.2
TTA 16	Green Roofs	$1,055,220	$1,786,554	$276,093	9.9	1.7
TTA 17	Climate Change Survey for the General Public	$24,794	N/A	N/A	N/A	N/A
TTA 18	Mangrove Restoration in Tobago	$35,325	$5,193,043	$3,402,443	4.2	147.0
TTA 19	Coral Reef Protection and Restoration in Tobago	$624,672	$523,245	-$89,772	∞	0.8

Graph 14: Total Costs and Total benefits as a Percentage of GDP

Source: Prepared by the authors



Please Note: This Graph is in Logarithmic Scale.

As can be seen by these measures, with the exception of permeable pavements (TTA 11) and Dike Construction in Trinidad (TTA 2) all of the measures have a total cost (not discounted) that is less than 0.3% of the GDP of Trinidad and Tobago in 2012. In terms of total benefit (not discounted), Mangrove Restoration in Trinidad (TTA 13) and National Building Code (TTA 1) have total benefits of about 0.3% of GDP. The average total cost as a percentage of GDP is 0.137% and the average total benefit as a percentage of GDP is 0.59%.

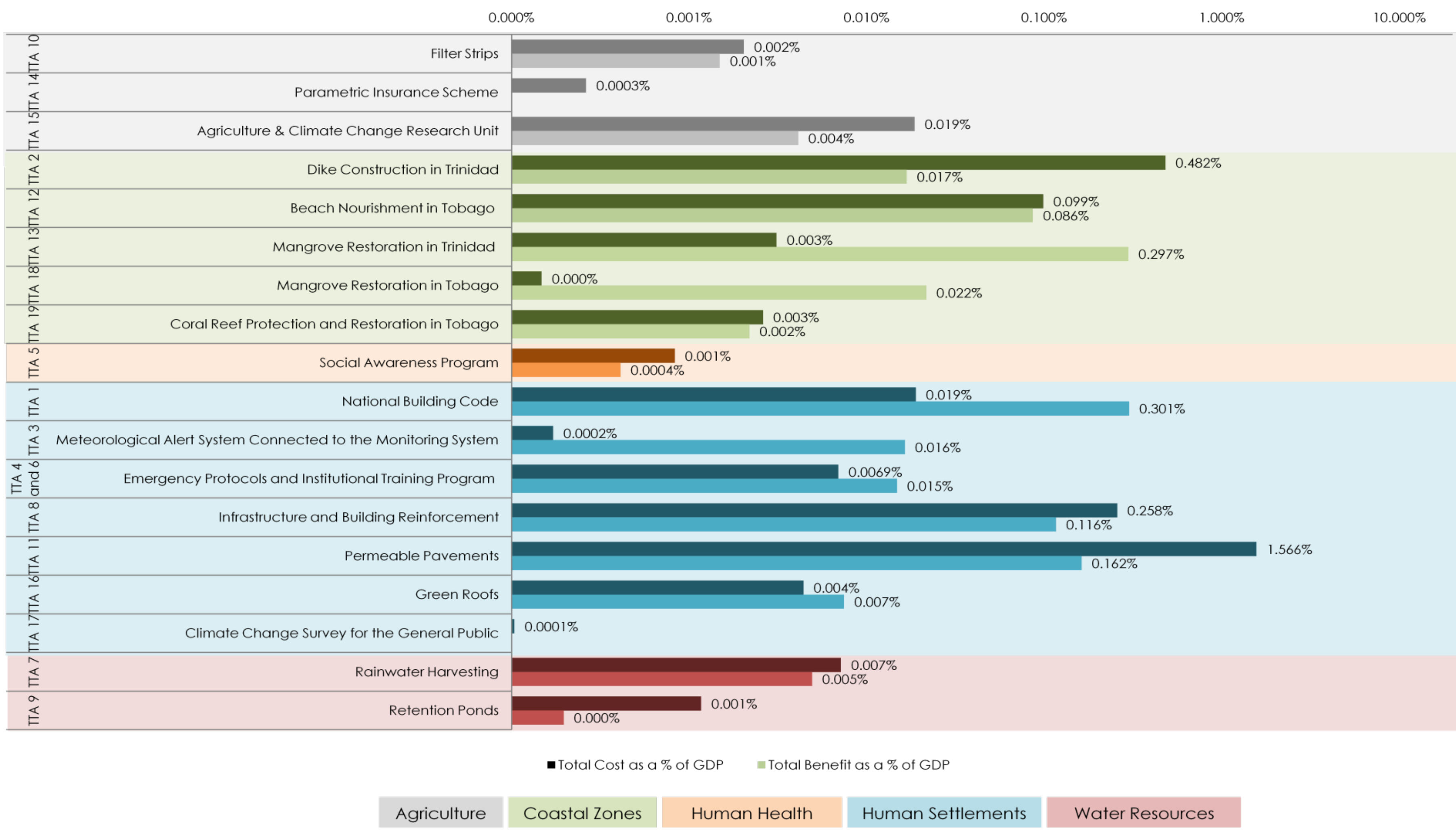
The following table and graph show the Cost Benefit Analysis organized by the sector which they correspond:

Table 66: Results of the Cost-Benefit Analysis of the actions, organized by sector.
Source: Prepared by the authors.

Action code	Title	Sector	Total cost	Total benefit	Net present value	Pay back (years)	Benefit-Cost Ratio
TTA 10	Filter Strips		$487,080	$356,132	-$121,338	24.9	0.7
TTA 14	Parametric Insurance Scheme	Agriculture	$62,850	N/A	N/A	N/A	N/A
TTA 15	Agriculture & Climate Change Research Unit		$4,455,439	$986,772	-$2,661,472	∞	0.2
TTA 2	Dike Construction in Trinidad		$115,554,303	$4,033,247	-$79,223,470	61.6	0.0
TTA 12	Beach Nourishment in Tobago		$23,688,332	$20,736,386	-$5,522,748	19.4	0.9
TTA 13	Mangrove Restoration in Trinidad	Coastal zones	$744,188	$71,348,613	$43,881,303	4.4	95.9
TTA 18	Mangrove Restoration in Tobago		$35,325	$5,193,043	$3,402,443	4.2	147.0
TTA 19	Coral Reef Protection and Restoration in Tobago		$624,672	$523,245	-$89,772	∞	0.8
TTA 5	Social Awareness Program	Human health	$198,787	$98,240	-$83,151	∞	0.5
TTA 1	National Building Code		$4,529,327	$72,151,025	$43,923,883	1.9	15.9
TTA 3	Meteorological Alert System Connected to the Monitoring System		$41,000	$3,935,834	$2,830,906	0.1	96.0
TTA 4	Emergency Protocols		$1,659,793	$3,545,712	$1,344,701	0.9	$2
TTA 6	Institutional Training Program	Human settlements					
TTA 8	Infrastructure and Building Reinforcement		$61,820,734	$27,911,274	-$27,646,239	35.4	0.5
TTA 11	Permeable Pavements		$375,536,762	$38,897,785	-$252,122,202	∞	0.1
TTA 16	Green Roofs		$1,055,220	$1,786,554	$276,093	9.9	1.7
TTA 17	Climate Change Survey for the General Public		$24,794	N/A	N/A	N/A	N/A
TTA 7	Rainwater Harvesting	Water resources	$1,714,977	$1,180,476	-$500,418	24.9	0.7
TTA 9	Retention Ponds		$279,616	$47,027	-$187,075	∞	0.2

Graph 15: Total Costs and Total benefits as a Percentage of GDP, organized by Sector

Source: Prepared by the authors.

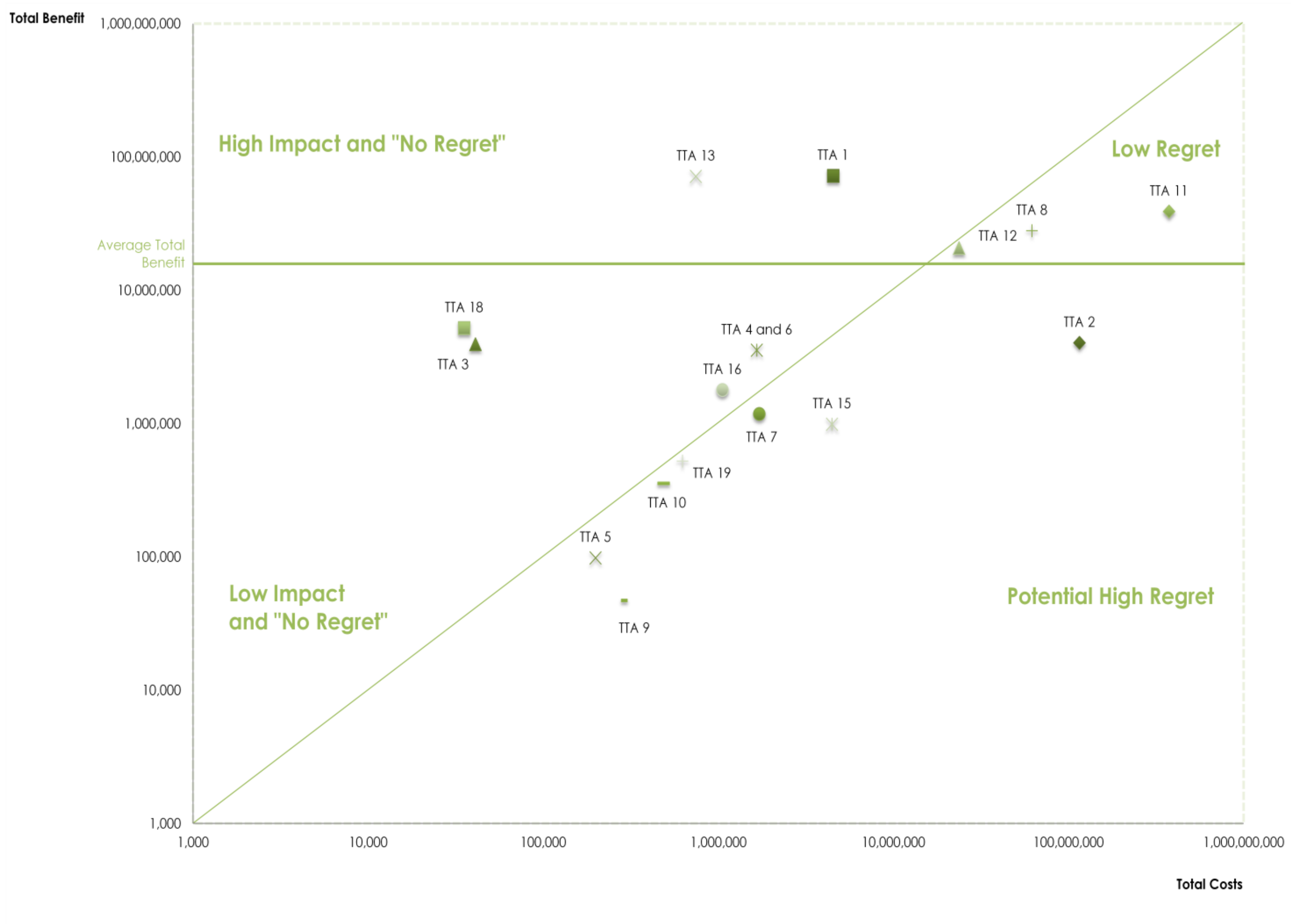


Please Note: This Graph is in Logarithmic Scale.

When organized by sector, the measures for Coastal Zones and the measures for Human Settlements have relatively high benefits. Coastal Zone measures average a benefit equivalent to 0.426% of GDP and Human Settlements measures average a benefit equivalent to 0.618% of GDP. That being said, these two groups of measures also have the largest costs. Coastal Zone measures average cost is equivalent to 0.586% of GDP and Human Settlements measures average cost is equivalent to 1.854% of GDP. The next groups of measures with the highest benefits are the agriculture (with an average benefit of 0.006% of GDP) and water resources (with an average total benefit of 0.005% of GDP). However, in terms of cost; the measures for water resources have an average cost equivalent to 0.008% of GDP, while the average costs of measures for agriculture is higher, at 0.021% of GDP. Lastly, the measure for the Human Health sector has both the smallest cost (0.001% of GDP) and smallest benefit (0.004% of GDP).

The table on the next page shows the results for each measure in terms of "No Regret":

Graph 16: No Regret Analysis
Source: Prepared by the Authors.



Please note: this graph is showing the present value of the total benefits and total costs. It is also in logarithmic scale.

From this analysis, the results show that:

- The National Building Code (TTA 1) and Mangrove Restoration in Trinidad (TTA 13) fall into the category of High Impact and "No Regret"
- Meteorological alert system connected to the Monitoring System (TTA 3); Emergency Protocols (TTA 4) and Institutional Training Program (TTA 6); Green Roofs (TTA 16); and Mangrove Restoration in Tobago (TTA 18) all fall into the category of Low Impact and "No Regret"
- Infrastructure & Building Reinforcement (TTA 8); Permeable Pavements (TTA 11); and Beach Nourishment in Tobago (TTA 12) fall into the category of Low Regret
- Dike Construction in Trinidad (TTA 2); Social Awareness Program (TTA 5); Rainwater Harvesting (TTA 7); Retention Ponds (TTA 9); Filter Strips (TTA 10); Agriculture & Climate Change Research Unit (TTA 15) and Coral Reef Protection and Restoration in Tobago (TTA 19) fall into the category of Potential High Regret.

The results of this Multi-Criteria Analysis exercise are shown in the table and graphs below. The measures have been given ratings based on:

- Importance: The importance that the measure has in regarding the ability to decrease the impacts of climate change.
- Urgency: The urgency with which the measure should be implemented in order to gain the maximum benefits from its implementation.
- No Regret: The level of "No Regret" this measure has. "No regret" strategies are those in which the project can be justified in economic terms, even without climate change, however its benefits increase even more with climate change.
- Secondary Effects: The level to which this measure would bring additional positive secondary effects to society.
- Mitigation Effects: The level to which, in addition to improving the adaptability of the country to Climate Change, the implementation of the measure also would help mitigate climate change by reducing emissions.

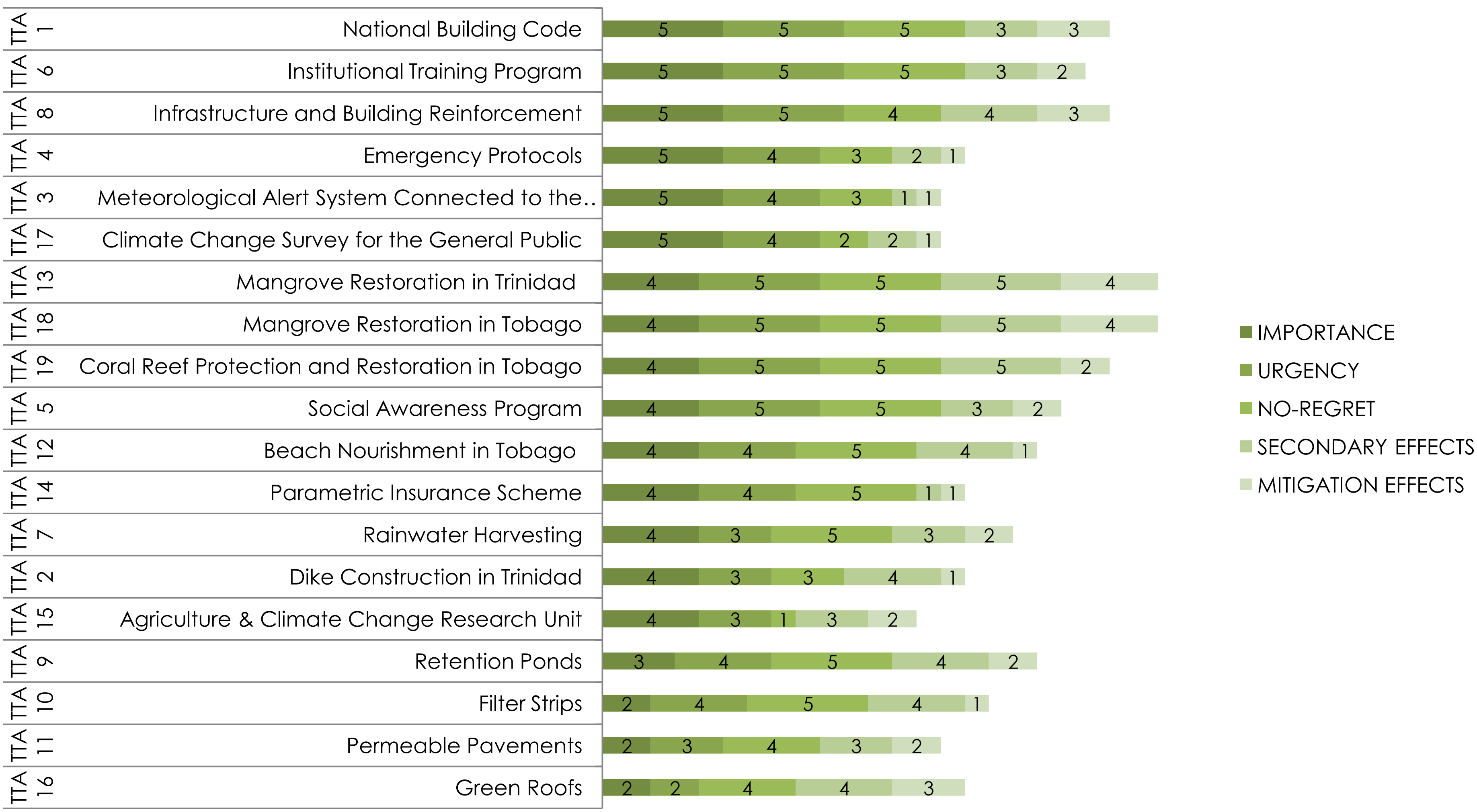
These scores have then been given a weighted score, with Importance having more weight (5) over urgency (4), No-Regret (3), Secondary Effects (2), and Mitigation Effects (1). Therefore, in the graphs below, those measures with the largest bar are not necessarily those with the highest priority. For example, although Mangrove Restoration has a rather high ranking in all aspects, it is not the highest in terms of priority since its weighted score was not the highest.

The measures are ordered within the table and graph below based on their score in Importance, then Urgency, then No-Regret, then Secondary Effects, and Lastly Mitigation Effects.

Table 67: Multi-criteria analysis of the actions.
Source: Prepared by the authors.

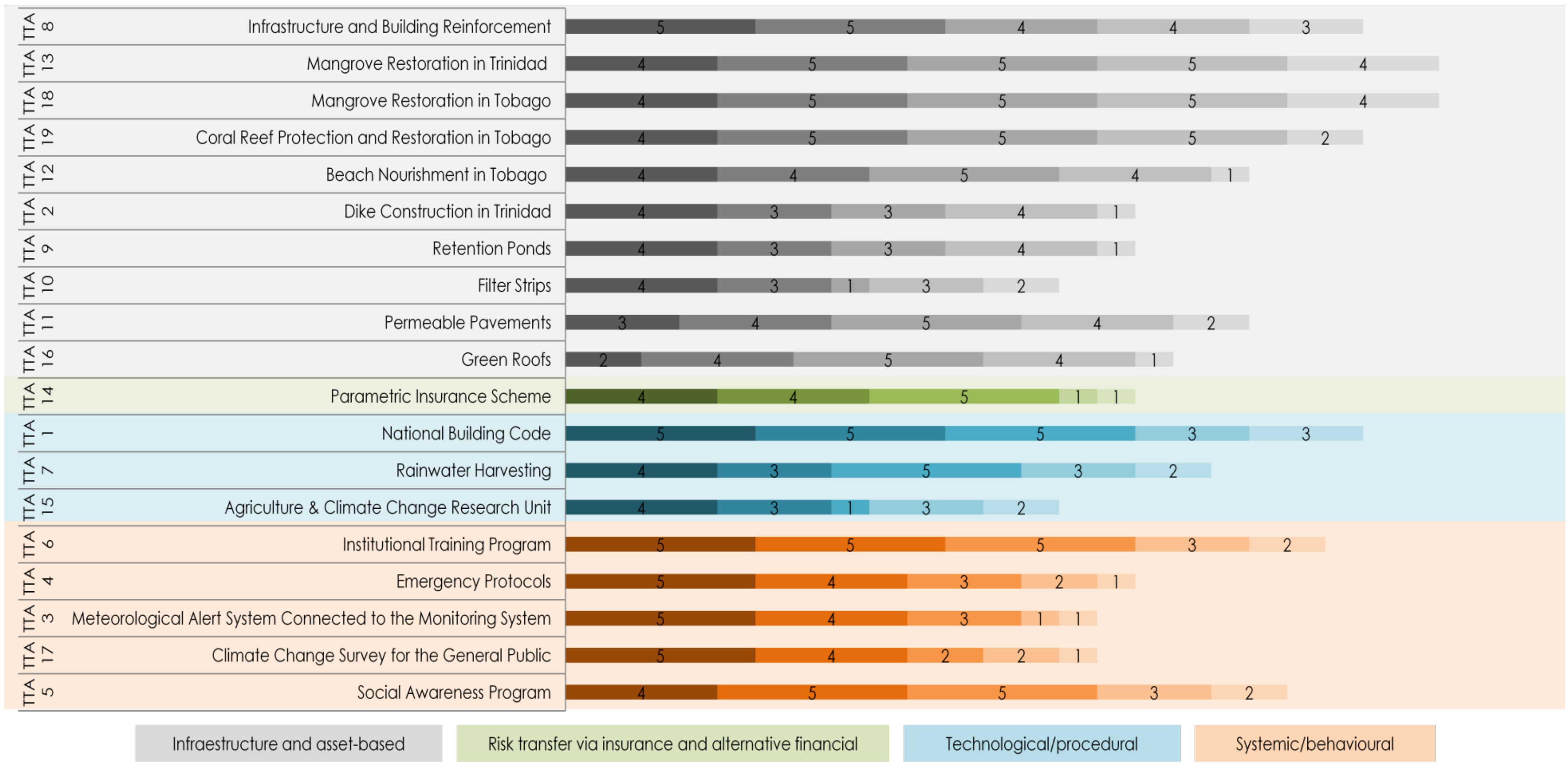
MEASURE PRIORITY	Nº	MEASURE	IMPORTANCE	URGENCY	NO-REGRET	SECONDARY EFFECTS	MITIGATION EFFECTS	WEIGHTED
1	*TTA 1*	National Building Code	5	5	5	3	3	69
2	*TTA 6*	Institutional Training Program	5	5	5	3	2	68
3	*TTA 8*	Infrastructure and Building Reinforcement	5	5	4	4	3	68
4	*TTA 4*	Emergency Protocols	5	4	3	2	1	55
5	*TTA 3*	Meteorological Alert System Connected to the Monitoring System	5	4	3	1	1	53
6	*TTA 17*	Climate Change Survey for the General Public	5	4	2	2	1	52
7	*TTA 13*	Mangrove Restoration in Trinidad	4	5	5	5	4	69
8	*TTA 18*	Mangrove Restoration in Tobago	4	5	5	5	4	69
9	*TTA 19*	Coral Reef Protection and Restoration in Tobago	4	5	5	5	2	67
10	*TTA 5*	Social Awareness Program	4	5	5	3	2	63
11	*TTA 12*	Beach Nourishment in Tobago	4	4	5	4	1	60
12	*TTA 14*	Parametric Insurance Scheme	4	4	5	1	1	54
13	*TTA 7*	Rainwater Harvesting	4	3	5	3	2	55
14	*TTA 2*	Dike Construction in Trinidad	4	3	3	4	1	50
15	*TTA 15*	Agriculture & Climate Change Research Unit	4	3	1	3	2	43
16	*TTA 9*	Retention Ponds	3	4	5	4	2	56
17	*TTA 10*	Filter Strips	2	4	5	4	1	50
18	*TTA 11*	Permeable Pavements	2	3	4	3	2	42
19	*TTA 16*	Green Roofs	2	2	4	4	3	41

Graph 17: Multi-criteria analysis of the actions.
Source: Prepared by the authors.



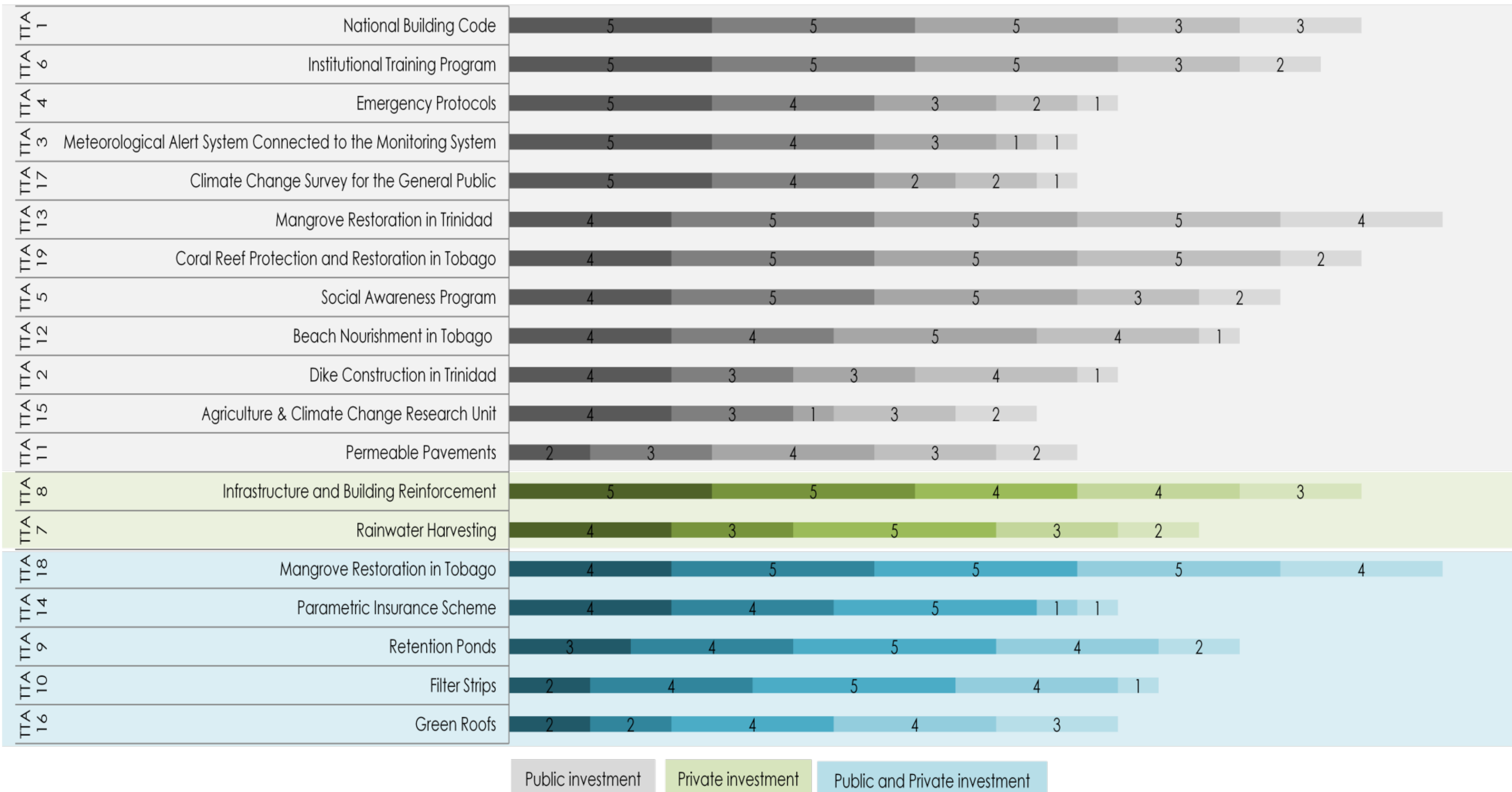
The multi-criteria analysis has also been graphed by type of measure, type of investment, and sector. These graphs are shown on the following pages:

Graph 18: Multi-criteria analysis of the actions, categorized by type of measure.
Source: Prepared by the authors.



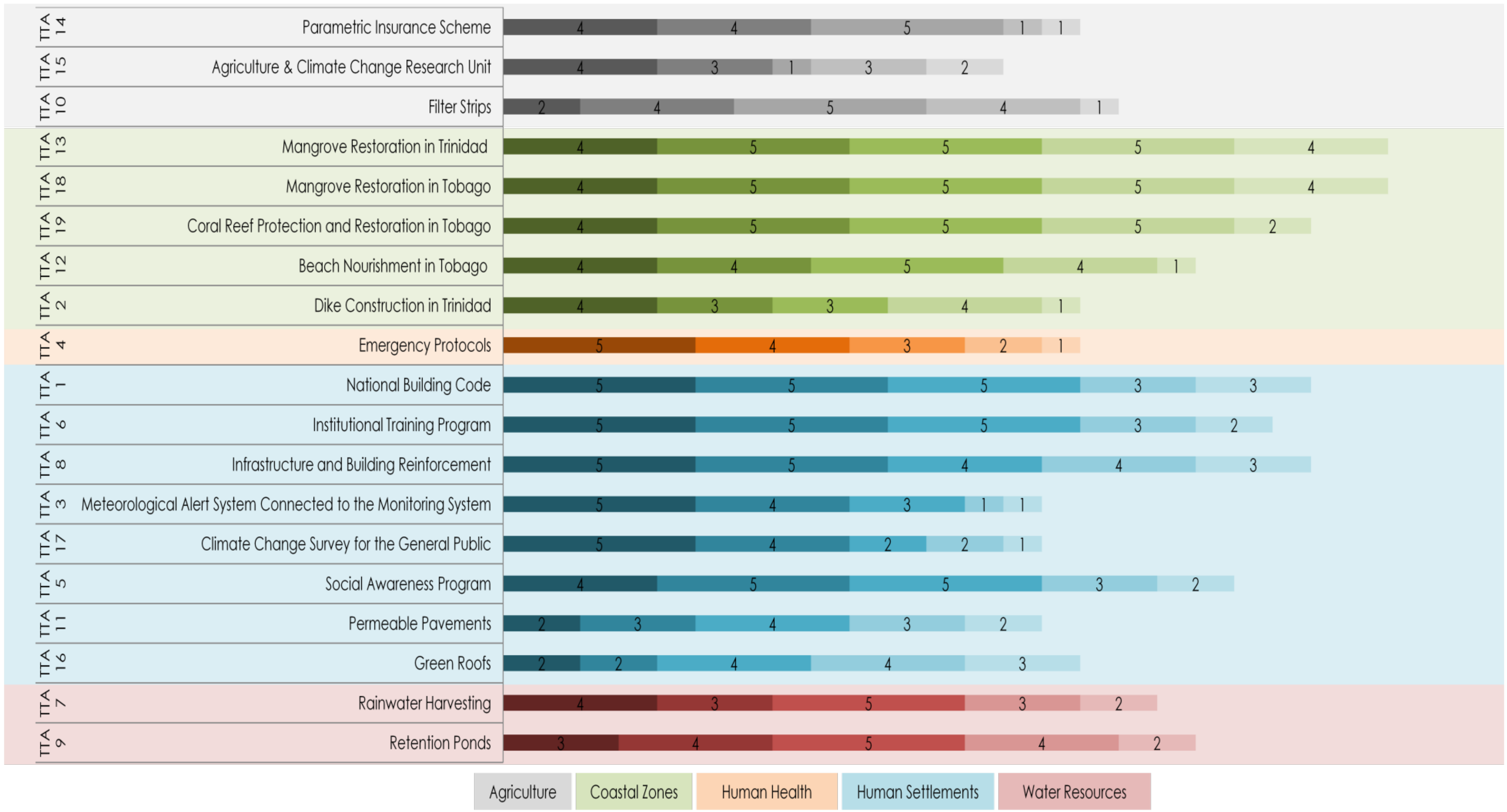
The scores in each bar in order from left to right: Importance, Urgency, No-Regret, Secondary Effects, and Mitigation Effects.

Graph 19: Multi-criteria analysis of the actions, categorized by type of investment.
Source: Prepared by the authors.



The scores in each bar in order from left to right: Importance, Urgency, No-Regret, Secondary Effects, and Mitigation Effects.

Graph 20: Multi-criteria analysis of the actions, categorized by sector.
Source: Prepared by the authors.



The scores in each bar in order from left to right: Importance, Urgency, No-Regret, Secondary Effects, and Mitigation Effects.

As can be seen in the graph showing the measure ordered by types of action, those involving systemic/behavioural responses and technological/procedural responses all have very high levels of importance. Those that are categorized as systemic/behavioural responses also all have very high level of urgency. This is often the case given that the earlier these types of measure are implemented, the larger impact they can have on reducing risks and possible damages.

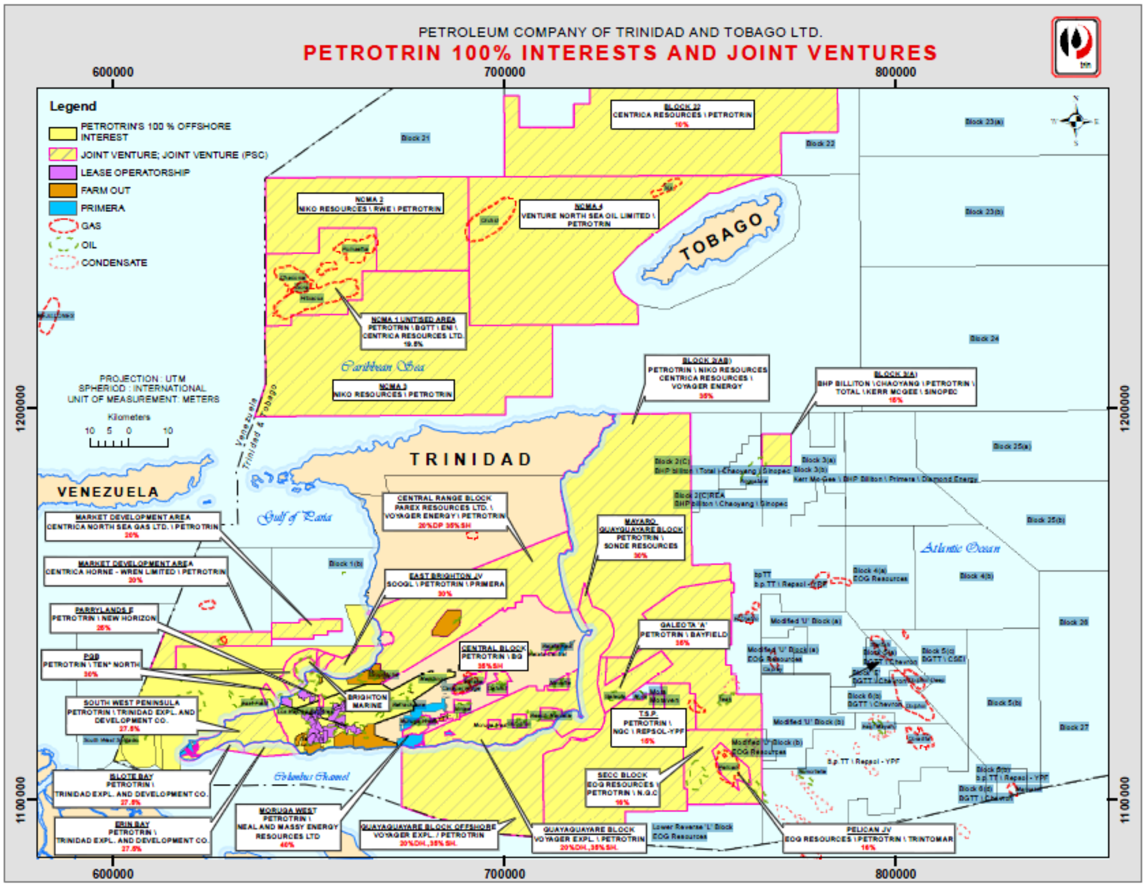
Additionally, as shown in the graph organized by types of investment, those involving private investment have relatively high un-weighted scores. Those measures involving public investment all have very high levels of importance and urgency, with the exception of permeable pavements (TTA 11). Those measures that involve both public and private investment are mostly of relatively less importance, with the exception of the mangrove Restoration in Tobago (TTA 18) and Parametric Insurance Scheme (TTA 14).

In the last graph, in which the measures are organized by sector, the clear sectors with the most priority are the Human Settlements Sector and coastal zones. Measures for Human Settlements all scored high in terms of importance and urgency with the exception of permeable pavements (TTA 11) and green roofs (TTA 16). In terms of Coastal Zones, Mangrove Restoration in both Trinidad and Tobago (TTA 13 and TTA 18) and Coral Reef Protection in Tobago (TTA 19) also have high scores in terms of importance, urgency, no-regret, and secondary effects. After Human Settlements and Coastal Zones, the sector with the most priority is Social Awareness. The last two sectors, Agriculture and Water Resources, have the measures with the lowest relative importance and urgency.

8. Pilot Experience

8.1. Description of the Pilot Case

Figure 85: Map showing Petrotrin´s Areas of Operations
Source: Petrotrin, Energy Map Feb 2013



For this analysis, the pilot case study has been focused on the Petroleum Corporation of Trinidad and Tobago (Petrotrin). This first approach to the Economics of Climate Change Adaptation methodology in a pilot site should not be regarded as a concluded document. On the contrary, it should be regarded as a developing work, because the information shown below needs to be discussed with Petrotrin and other relevant stakeholders in order to refine to proposal so as to make it suitable to their needs and possibilities.

Due to its importance in the economic activity in Trinidad and Tobago, Petrotrin was chosen to conduct the first pilot study of the Economics of Climate Adaptation methodology. It is an integrated oil and gas company which develops its activities in the exploration for, development of and production of hydrocarbons and the manufacturing and marketing of petroleum products. The company was incorporated in 1993 to consolidate the interests of the Trinidad and Tobago Oil Company (Trintoc) and the Trinidad and Tobago Petroleum Company (Trintopec), but its roots can be traced to the first years of the 20th century. In fact, they are tightly linked to the beginning of commercial oil production in Trinidad and Tobago, particularly to Well No. 3 at Guapo (Point Fortin), the first commercial oil discovery in Trinidad and Tobago, which was completed in December 1907.

Nowadays, Petrotrin plays a leading role in the development of the energy sector in Trinidad and Tobago, being the nation's largest crude oil producer. This is expressed in terms of production; the full capacity of the refinery is up to 168,000 barrels per day and average production is approximately 127,650 barrels per day.

Due to the location of its sites and activity, Petrotrin is susceptible to the same effects of climate change that Trinidad and Tobago will incur: increased likelihood of drought damages, flooding, sea level rise, and increased temperatures. Up until now, Petrotrin has shown a proactive activity in terms of climate change, having conducted several studies on the field. In fact, the company has already analyzed both the mitigation and adaptation sides of climate change.

In terms of climate change mitigation, the company has conducted:

- A Greenhouse Gas Inventory of the company, including the direct and indirect related to electricity consumption emissions.
- A report on evaluation of GHG emission reduction opportunities.

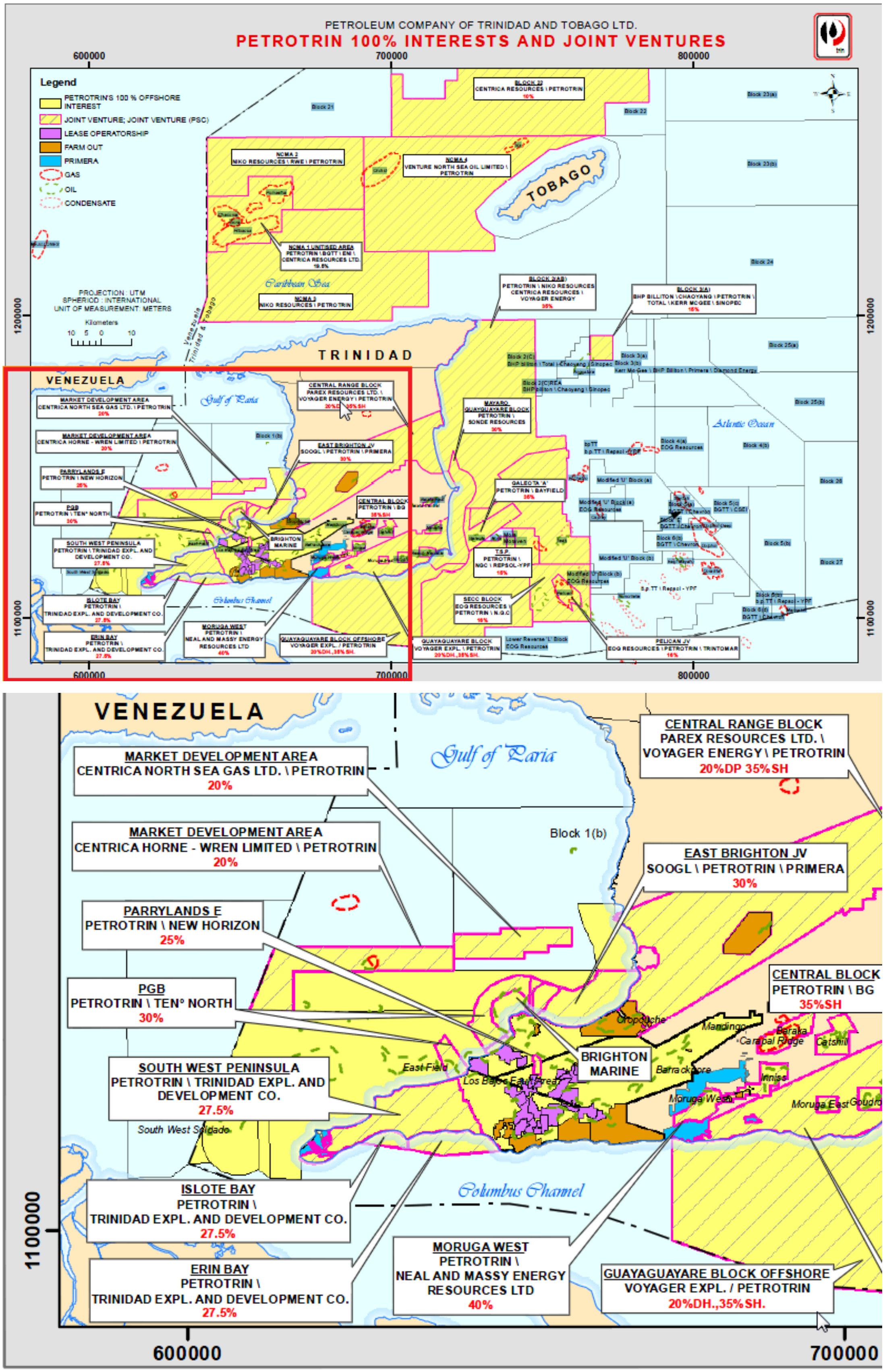
Their work related to climate change adaptation produced the following reports:

- A detailed vulnerability assessment survey and storm surge modelling of the west coast of Trinidad: Vessigny to Cap-de-ville quadrant.
- Vulnerability Assessment Survey for the Pointe-à-Pierre Foreshore Area.
- Vulnerability Assessment Study for Exploration and Production Development Works in the Oropuche Field.
- A Case Study of Adaptation to Sea Level Rise in the area looking at the Cost-Benefit Analysis of Climate Change Adaption and Mitigation Projects.

The work carried out by Petrotrin regarding climate change adaptation was one of the most relevant sources of information for the development of the Economics of Climate Change Adaptation methodology. In fact, the results obtained from the vulnerability assessments were key in selecting the Point Fortin area as the most suitable for the analysis.

Figure 86: Close up of the previous figure, showing a close up of the area surrounding of Pt. Fortin

Source: Petrotrin, Energy Map Feb 2013



In the First Interim Report of this project, the Point Fortin area was included among the most vulnerable areas to climate change in Trinidad and Tobago, based on economic and social aspects. In addition, the vulnerability assessment carried out by Petrotrin produced highly-worrying results. Based on the results, climate change would have important effects on the area, particularly in terms of land loss due to inundation, erosion and storm surge. Therefore, the Point Fortin area was selected for the pilot case based on its classification in terms of vulnerable areas to climate change in Trinidad and Tobago, shown in the First Interim Report, and the results of the vulnerability assessment conducted for the company.

For this pilot study, the information related to vulnerability and hazard explained in sections 3 and 4 was taken into consideration, along with the other past studies done for the company. With this information, an analysis of the possible actions which could be developed was carried out and a list of climate change adaptation actions most suitable for the area was developed. It should be noted that the geographical location of the pilot case just includes the industrial area owned by Petrotrin in Point Fortin and not any of the surrounding land which has no industrial use.

The list includes thirteen actions, which are classified depending on the type of action, the sector they focus on and the investment type. There are two different types of actions: technological/procedural optimisation responses and infrastructure and asset-based responses. All thirteen actions involve private investment, since Petrotrin would assume the costs of their implementation.

The table below describes how each of these measures is defined along these categories.

Table 68: Proposed actions for the pilot study.
Source: Prepared by the authors.

Action code	Title	Type of measure	Type of investment	Sector
PT 1	Climate Change Adaptation Tool	Technological/procedural optimisation responses	Private investment	Energy sector & industry
PF 1	Coastal Zone and Guaracara River Protection	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PF 2	Retention Ponds in Point Fortin	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PF 3	Construction of Swales and Berms in Point Fortin	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PF 4	Mangrove Protection in Point Fortin	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PF 5	Relocation of Infrastructure in Point Fortin	Infrastructure and asset-based responses	Private investment	Energy sector & industry

Action code	Title	Type of measure	Type of investment	Sector
PF 6	Infrastructure Elevation in Point Fortin	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PAP 1	Dike Construction in Pointe-à-Pierre	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PAP 2	Construction of Retention Ponds at Pointe-à-Pierre	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PAP 3	Sustainable Drainage Systems in Pointe-à-Pierre	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PAP 4	Mangrove Restoration in Pointe-à-Pierre	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PAP 5	Relocation of Infrastructure in Pointe-à-Pierre	Infrastructure and asset-based responses	Private investment	Energy sector & industry
PAP 6	Infrastructure Elevation in Pointe-à-Pierre	Infrastructure and asset-based responses	Private investment	Energy sector & industry

8.2. Description of the actions

Following the scheme used for the country-level actions, for every action, an assessment of its implementation and consequences was developed. Below, a detailed analysis of the actions is included. The analysis includes the objective of the action, an explanation of success cases in implementing this action in other countries, the preliminary considerations for the action and a detailed description of every action. Additionally, the description provides the implementation period and expected impacts of every action and the economic, technologic, social, institutional and legal capacity required for the implementation of every action. In the last part of every sheet, the results of the cost-benefit analysis are shown, including the benefit-cost ratios of the actions and the pay-back, as well as the total benefit and total cost of every measure.

It should be noted that PF 4 does not have any measureable economic benefits, because the climate adaptation tool, even if it can be very helpful for the company to have a better understanding of its present and future situation in terms of climate change adaptation, does not provide any economic benefits itself.

Due to the paucity of technical information, there is a certain lack of detailed analysis for some of the actions. It should be stated that this report includes a first assessment of adaptation measures that could be carried out the Point Fortin site of Petrotrin; however, before the implementation of any of these actions, a more detailed analysis should be developed and, as stated before, this pilot study needs to be validated by the company before it can be considered a definitive document.

As stated before, the sheets included below have the same format as those included previously in the country level assessment. Therefore, the information included in them is classified using the same methodology. As well as for the country-level sheets, the cost-benefit ratio shows the economic performance of the actions and when this value is higher than one, it means that the benefits of the action are higher than its costs.

8.2.1. *PT 1: Climate Change Adaptation Tool*

Objective

To provide Petrotrin with a tool that includes all the information regarding climate change adaptation already obtained as well as new information valuable for the future decision-making of the company.

Previous experiences and success cases

According to a report titled "Case Studies and Tools: A Systematic Review of the Literature on Business Adaptation to Climate Change" by the Network for Business Sustainability, Climate Change Adaptation Tools, which include scenario modelling and information gathering regarding potential risks, is considered a best practice in the area of climate change adaptation for businesses. While risk frameworks were the most widely used tool in the case studies mentioned in the report (in nine case studies), scenario tools were second (in five case studies). The report states, "scenario tools allow businesses to use projections of potential climate change scenarios to assess potential risk to their operations."

As an example, Anglian Water has been building its capacity in the areas of climate change adaptation through various efforts including "a program of raising awareness with staff, undertaking research to investigate what measures are required to protect critical infrastructure from future flooding events, and undertaking a project with the Tyndall Centre to understand the implications of sea level rise for coastal assets".

Another example is cited by BSR's report titled "Adapting to Climate Change: A Guide for the Energy and Utility Industry" in which they explain how EVN, an Austrian-based producer and transporter of electricity, has been working to better prepare for extreme weather events, disasters, and equipment malfunctions. They state that the company has "leveraged its geology branch, EVN Geoinfo GmbH, to analyze and integrate detailed data, such as floodwater studies, into its planning processes for site identification, environmental protection, and crisis management. The company has also packaged this into a commercial product for governments, the tourism industry, and environmental management bodies".

Preliminary Considerations

No preliminary considerations need to be looked at before the implementation of this action.

Description of the action

This action focuses on the development of a tailor-made adaptation software tool for Petrotrin. The tool will include all information obtained from the climate change projects already developed by Petrotrin: the vulnerability assessments of the West Coast, Oropuche Field and Pointe-à-Pierre. Furthermore, the tool would also contain the downscaled climate information for the areas in which Petrotrin carries out its operation and vulnerability assessments in climate change terms for all the operating areas of the company. The tool will also include climate change adaptation measures specifically designed for the different sites of the company.

Implementation period

2014-2016

Impact of the action

Having a wide knowledge of the consequences of climate change in its operations is a key factor for many companies worldwide. In the case of the oil sector, this information is particularly important due to the location of its operations; the consequences of climate change can negatively affect the results of the company in several ways. A tailor-made climate change adaptation tool would be highly beneficial for Petrotrin as it would include all the information already obtained by Petrotrin and have new information such as climate scenarios, vulnerability assessments for other areas, and actions to face the possible consequences - all in the same information source.

The use of climate change adaptation tools, as shown in the previous experiences, can be useful for companies to assess potential risks in their operations. This is particularly valuable for a company like Petrotrin, whose installations are located mainly in coastal areas and in a Small Island Developing State. Furthermore, the activities of an oil company imply important risks; knowing how climate change would affect those activities can help prevent dangerous situations.

Economic capacity

This measure has a low cost compared to the benefits the company could obtain from its development and use. As seen in the previous cases, private companies are currently paying more attention to climate change risks and the use of a climate change adaptation tool can help prevent dangerous situations which could be very costly for Trinidad and Tobago.

Technological capacity

Currently, adaptation tools are cutting-edge technology in the climate change area. However, they are becoming a more and more widespread tools. In fact, several companies are already making use of them and there are different companies and institutions that could collaborate with Petrotrin to develop a tailor-made climate change adaptation tool.

Social capacity

The application of this action would also have benefits in social terms, because enhanced climate change knowledge within Petrotrin could improve actions taken toward climate change derived hazards. Therefore, the implications of those hazards for the neighbouring population would also be reduced.

Institutional capacity

Trinidad and Tobago has a Climate Change Policy, in which vulnerability and risk assessment is considered. However, there are no definitive statements on the needs of companies to determine their vulnerability, so it would be necessary to develop the policy in more detail, including concrete actions. The Ministry of the Environment and Water Resources would be responsible for development of such a policy.

Legal capacity

Currently, in Trinidad and Tobago there is not a legal framework regarding climate change. Therefore, there are no regulations on the need for companies to carry out vulnerability assessments of their sites.

Cost-benefit ratio	**N/A**	**-**	**Total cost**	**117,500**	**$**
Pay-back	**N/A**	**Year(s)**	**Total benefit**	**N/A**	**$**

8.2.2. *PF 1: Coastal Zone and Guaracara River Protection*

Objective

To build barriers that can provide protection against 1.5 meter sea level rise in order to avoid floods in Point Fortin.

Previous experiences and success cases

Dikes are a widely used method worldwide for the prevention of flooding. In fact, in The Netherlands, the river flows have been managed by them for more than a thousand years. These structures have been used as a protective measure in several countries even before the hazards caused by climate change were taken into account, as proven by the already mentioned example of The Netherlands or the infrastructure in other flood prone areas like New Orleans (USA) or the Mekong River (Vietnam).

In The Netherlands, the flood prevention system is built with the objective of being able to face storms that would occur once in 10,000 years. To do so, the prevention systems are reinforced and supervised continuously to prevent damage - instead of working after the damage is done. In the flood prone regions, such as those mentioned above or others like the British Columbia in Canada, the efforts are currently devoted to adapting the existing systems to the predicted future conditions, taking into consideration the effects of climate change. The Economics of Adaptation to Climate Change developed by the World Bank for Vietnam also considers the reinforcement of the coastal and river defences as a key necessity of the adaptation strategy of the country.

Additionally, in Barbados, a Coastal Zone Management Unit was established to carry out and monitor the shoreline protection program, guided by the Coastal Zone Management Plan. The Unit looks at the impacts on coasts from commercial and housing development, drainage, ocean tides and currents, storm and hurricane probabilities, coral reef ecosystems and the rising sea level caused by global warming. It promotes engagement from all stakeholder groups involved in coastal management. Seawall construction, including rip raps, is one of its main infrastructure choices for intervention (Scruggs, G. and Bassett, T, 2013). These construction projects "involve either a riprap design of large rocks or a flat, concrete seawall that can create public space attractive to both tourists and residents, such as the Richard Haynes Boardwalk, partially funded by an IDB loan. Because these techniques can sometimes exacerbate erosion and require more expensive maintenance than natural interventions, their long-term efficacy is up for debate, but, in the short term, they protect the coastline…" (Scruggs, G. and Bassett, T, 2013).

The validity of these systems is proven when extreme events take place and the consequences of those events can be looked at. For instance, in New Orleans, the effects of tropical storm Katrina proved that the existing system was not valid in order to ensure the security of the city, and, subsequently, they are being modified in order to provide better results. This path of action is similar to that observed in The Netherlands, where after a devastating flood in 1953, the dike system was widely reinforced and became a country-level priority.

Preliminary Considerations

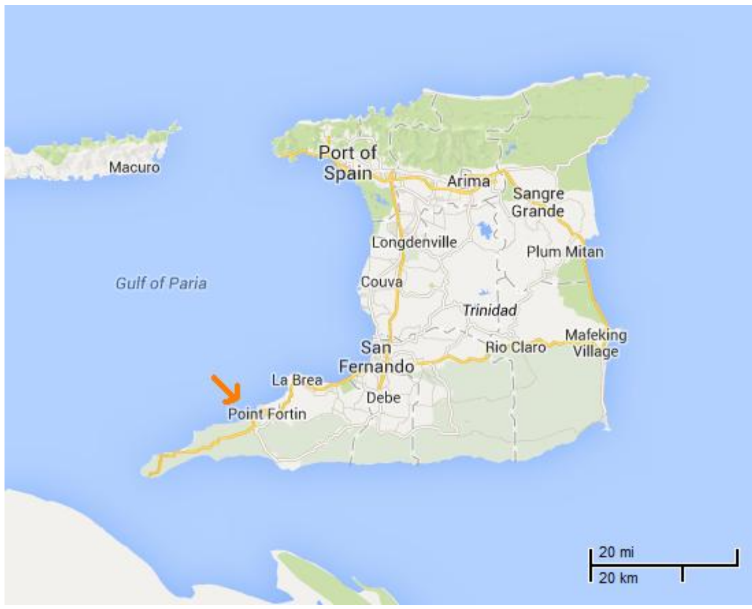
The area in which the barriers are proposed has been chosen for its population-density and industrial development. Therefore, it has a high level of vulnerability. However, before the implementation of the action, a more detailed assessment would need to be carried out to determine the needs for the area and the best construction solution for it.

Description of the action

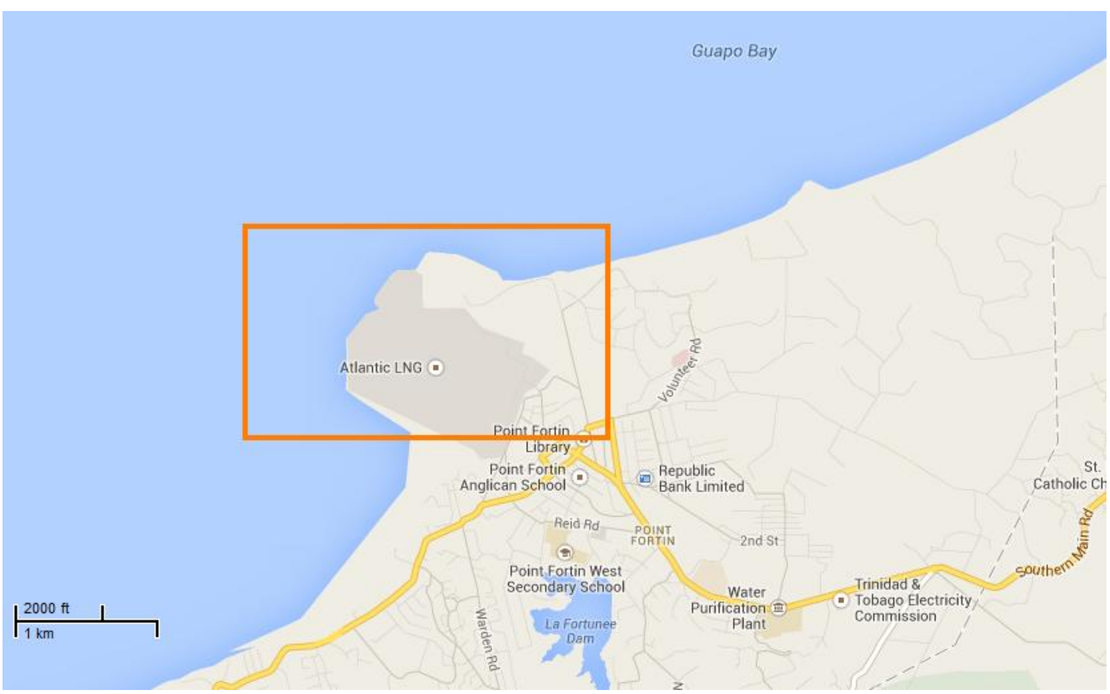
The measure consists in building barriers in coastal zones. Due to its cost-benefit ratio, the barrier type chosen is the riprap. This action includes the excavation of the dike root, transportation of the riprap, filling with gravel and revegetation of the area. The dike has a 5 meter width root, 2 meter deep, 1 meter on top and it is 3.7 meters high. The action would be located in the Point Fortin area, covering two strips of land. The perimeter of the first coastal zone is approximately 1.29 km and the perimeter of the second zone is approximately 366 m.

It is important to note that the larger dike sits on property owned by Atlantic LNG. This could pose legal problems given that Petrotrin does not own this land. However, it has still been included within this measure given that the vulnerability study done for the region (Singh. B. and A. El Fouladi, 2007) shows that a large portion of the inundation will enter from this part of the coast. Therefore, this dike will prove important in terms of reducing flooding for both Atlantic LNG and Petrotrin. It is advised that this construction be looked into as a joint venture between the two companies in order to protect the land owned by both companies.

The action would be developed progressively, with the construction of the infrastructure taking place over several years. In fact, under these conditions, the action would not be completed until 2030. However, some sections would be operative in 2020, which means that the benefits of the action, that is, the losses avoided by the improvement of the dikes, would be observed beginning 2020.



Source: Google Maps



Source: Google Maps, the orange box is representative of the following image, its scale is approximate

Implementation period

2014-2030

Impact of the action

As stated in the Vulnerability Assessment carried out for the West Coast area for Petrotrin, port facilities - Point Fortin in particular - will be very susceptible to climate-driven sea level rise and storm surges. Higher sea levels and storm surges will most likely decrease the effectiveness of breakwaters against wave forces and wharves. Loading docks and offshore platforms may have to be raised to avoid inundation.

The proposed barrier will protect the coastal zone, avoiding sea water from flooding the buildings and infrastructure close to the coast line. Additionally, this action will also help mitigate the effects of floods and erosion caused by the increased rainfall expected in the wet season in the Point Fortin area due to the climate change.

The proposed barrier would protect the coastal zone by avoiding the sea water from flooding the buildings and other infrastructure close to coast line. It would also provide protection to agricultural areas set near the sea line. As an indirect effect, the dike construction would also stimulate employment, especially in the building area. The negative aspects of the implementation of this action are mainly its disruption of the coastal dynamics, which may have adverse effects on ecosystems.

As stated previously, this is a widely implemented action in flood prone areas, having proved its usefulness in many cases. It is important to highlight that the impact of the action will not be truly observed until after the extreme events take place, when compared to the consequences of other similar events that happened previously.

Economic capacity

The investment amount for this adaptation measure is high in absolute terms, but compared to its benefits, it is definitely a more than reasonable investment. The sea level rise will happen; however, there is still plenty of time to prepare for that rise, which means that the investment can be distributed throughout the next 10-15 years. Taking into account the results of the vulnerability assessment carried out for Petrotrin in this area, this kind of activity could help greatly to reduce some of the effects of climate change in the area. Therefore, economically speaking, it is definitely an interesting measure; even if the costs are relatively high, the losses that could be avoided are also considerable.

It should be noted, regarding the benefits of the action, that until 2020 no benefits are obtained from this measure since there is not any completed rip-rap section until that year. Therefore, for this action, a wider time-frame would provide a better result in the cost-benefit analysis, because after all the construction work is over, the benefits would overcome the costs.

It should also be considered, in terms of economic capacity, the experience obtained from the implementation of this action in other countries. A key feature of this kind of action is that benefits are only observed if extreme events take place. Therefore, many times, due to the volume of the required investment, this type of infrastructures are observed as unnecessary. However, as it has been shown in previous experience, the development of this kind of infrastructures as a part of a long term coastal management plan provides more benefits than costs.

In terms of economic benefits calculated in this measure, the value of the land not lost from inundation, have been included. Benefits coming from the infrastructure in Point Fortin and its productive used for the company, have not been included due to a lack of specific information for the Point Fortin area.

Technological capacity

This technology was already developed in some of the coastal areas of Trinidad and Tobago; therefore, there is experience in the country in terms of constructing dikes. However, it would be interesting to consider, when analysing the implementation of the action in depth, the latest technologies implemented in countries that can be regarded as the path to follow, such as The Netherlands. These technologies might not be directly exportable, but would help define the best options for Trinidad and Tobago considering the latest advances in the development of coastal protection measures.

Social capacity

Even if it is regarded as the best example for the implementation of this technology, even in The Netherlands, the construction of dikes is many times regarded as a controversial issue. The visual effect in aesthetic terms of this kind of infrastructure is evident. Many times, the population does not cope well with the construction of dikes. However, if the effect in terms of disaster risk reduction and prevention of losses is well understood, the negative attitudes are usually lessened. For instance, in the Bulgarian municipality of Shabla, various structures were built to safeguard the coastline and ensure the livelihoods of the local communities. The measures proved effective to "hold the line", stopping the erosion problems of the area, and the increased safety has allowed other economic activities to develop e.g. eco-tourism.

The most negative effects found in Bulgaria are those connected with the aesthetics because the concrete walls and the stony dykes are not compatible with the normal natural landscapes in this area. However, a conscious decision was taken to compromise the natural landscapes in favour of the coastal protection facilities, reaching a compromise between the negative effects in terms of aesthetics and the positive effects in terms of disaster risk reduction. A similar approach could be used in terms of social capacity for Trinidad and Tobago.

Institutional capacity

Since this project would be carried out by Petrotrin, the institutional capacity would not affect the implementation of the measure.

Legal capacity

It is important to note that the larger dike sits on property owned by Atlantic LNG. This could pose legal problems given that Petrotrin does not own this land. However, it has still been included within this measure given that the vulnerability study done for the region (Singh. B. and A. El Fouladi, 2007) shows that a large portion of the inundation will enter from this part of the coast. Therefore, this dike will prove important in terms of reducing flooding for both Atlantic LNG and Petrotrin. It is advised that this construction be looked into as a joint venture between the two companies in order to protect the land owned by both companies.

The legal framework for the protection of the coastal areas of Trinidad and Tobago is poorly defined at the moment. Thus, it would be necessary to develop, as stated before, a Coastal Zone Development Plan, with well defined actions, which would then need to be implemented. If necessary, the development of a strict legal framework may be considered to ensure that the objectives are fulfilled.

Additionally, when considering the development of the action, in the planning and construction phases, the effects of the action should be considered regarding the legal framework established by the following laws: the Environmental Management Act; the Certificate of Environmental Clearance Rules; the Town and Country Planning Act; and the Public Health Ordinance and the Marine Areas (Preservation and Enhancement) Act. This action implies the construction of infrastructure, which may have negative effects on the environment and, therefore, the laws of Trinidad and Tobago need to be respected when designing and developing the action.

Cost-benefit ratio	**0.1**	**-**	**Total cost**	**7,267,721**	**$**
Pay-back	**∞**	**Year(s)**	**Total benefit**	**370,635**	**$**

8.2.3. *PF 2: Retention Ponds in Point Fortin*

Objective

To build water retention reservoirs that can harvest rainwater for industrial use. These would follow best practices, meaning reservoirs lined with impermeable lining and with water inflow and outflow infrastructure installed, to ensure that the maximum quantities of water can be harvested in the latter part of the dry-season, and then distributed to users after conservation and during dry seasons, to augment supply for local uses. The management of these would be tied to use of seasonal forecasts, with stricter use regimes imposed when more severe drought conditions are forecast as likely.

Previous experiences and success cases

Retention Pond technology increases water supply for industrial purposes in areas with chronic water shortages. In terms of this technology's functionality, according to a report done by Organization of America States, Paraguay has used this technology extensively; areas of low topography used for rainwater storage are known as tajamares. They use distribution canals that take water from the storage area to its point of use.

In addition, according to a report from UN Habitat, in 1993 the Frankfurt Airport constructed a rainwater harvesting system within the newly constructed terminal. The water collected is used for flushing toilets, watering plants, and cleaning the air conditioning system. The system helps save approximately 100,000 m^3 of water per year.

The Technical University of Darmstadt in Germany also has a rainwater harvesting system which provides water for flushing toilets and provides water to laboratories of the university for cooling and cleaning purposes. The water is cleaned prior to use. Estimates state that the system saves 80,000 m^3 of drinking water per year.

In Sumida City, Tokyo, a rainwater harvesting system was installed in a wrestling area in 1982, which the city states provides half of the building's water needs and significant economic savings. Since then, hundreds of buildings in Tokyo have introduced rainwater harvesting systems.

Preliminary Considerations

Due to the spatial and temporal availability of the water across the two islands, localised imbalances occur, resulting in water shortages being experienced by the population. The ability to supply all the competing demands for water is further affected by bottlenecks in the water supply infrastructure.

Description of the action

The key initial measure involves building 2 pilot ponds to catch rainwater. The ponds would have dimensions that are determined by site characteristics. Typically, they are of approximately 10 m in length and width (or 14m diameter, if circular) with a depth of at least 2 m, making them suitable for most locations even when the land availability may be scarce. Therefore, the volume of the proposed ponds would be of approximately 1,875 m^3, with a surface area of 625 m^2.

Implementation period

2014-2030

Impact of the action

Each pond can hold 1,875 m^3 of rainwater, meaning 1,875,000 water litres - 3,750,000 litres in total. Harvesting rainwater could calculate to thousands of dollars in savings every year, especially for industrial uses due to the large water demand by industrial processes. Ponds also increase the resilience to flooding, which is why they would be distributed among areas where the rainfall is especially intense and where flooding could increase damages.

Economic capacity

The action would imply a financial investment to build the ponds. However, benefits would be obtained, as shown in the previous experiences and success cases, from the damage avoided in flooding and from the use of the harvested water instead of water from other sources such as desalination.

Technological capacity

This technology has already been implemented in several industrial sites. There are many previous experiences from which information on the best practices to implement it could be obtained.

Social capacity

There are no relevant social implications due to the characteristics of this action, considering that it is going to be implemented on private land owned by Petrotrin. In general, it would be beneficial for given that it would make a better use of water, which is a very valuable resource. Additionally, it would reduce flooding risks.

Institutional capacity

In terms of an institutional framework, Trinidad and Tobago has a National Integrated Water Resources Management Policy, which establishes the principles of water management in the country. However, it does not include particular actions in terms of the management of water supply in the country.

Legal capacity

When it comes to water management in Trinidad and Tobago, the major legislative instruments are the Water and Sewerage Act (1980 Revised); the Waterworks and Water Conservation Act (1980 Revised); the Environmental Management Act (2000 Revised); and the Public Health Act (1950). There is however a need for a new legislative framework to create a new paradigm of integrated water resource management.

Cost-benefit ratio	**0.5**	**-**	**Total cost**	**269,900**	**$**
Pay-back	**24.1**	**Year(s)**	**Total benefit**	**145,574**	**$**

8.2.4. *PF 3: Construction of Swales and Berms in Point Fortin*

Objective

To build swales and berms in order to reduce the risk of floods due to excess of rainfall and storm surge in the Petrotrin owned area in Point Fortin.

Previous experiences and success cases

According to information from the Purdue University Engineering Department on sand filters, the benefits of sand filters include the fact that they "cost less to construct in rural areas than centralized treatment systems; they are energy-efficient; they have relatively low maintenance requirements but should be serviced by trained technicians; they can provide high quality effluent; [they] may enable development in difficult sites; they can remedy an existing malfunctioning system; and [they] can be a good option for homes in environmentally sensitive areas".

Also, the report titled "Costs and Benefits of Sustainable Drainage Systems" done by the Committee on Climate Change and Royal Haskoning, concluded that "SUDS have the potential to contribute to the reduction or prevention of surface water flood risk in a variety of situations, and in many cases will be cost-effective".

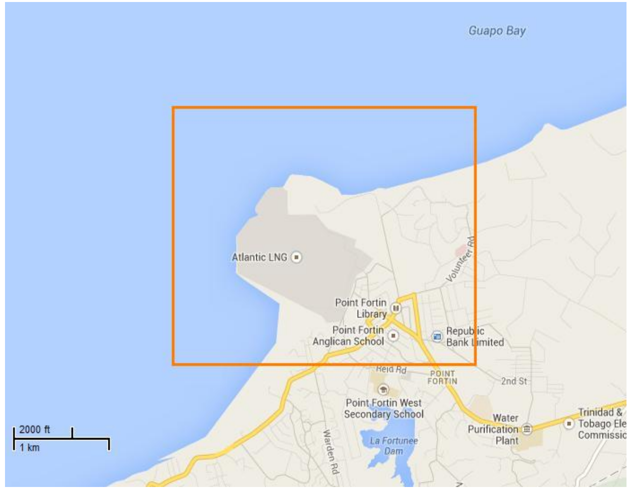
Lastly, according to a study done in Lamb Drove specifically designed to understand the benefits of SUDS measures, the program has reported significant benefits. In the study, the specific SUDS implemented included water butts, permeable paving, a green roof, swales, filter strips, detention and wetland basins and a retention pond. Although not all of these SUDS are presented in this measure. The general conclusions and benefits can be considered relevant to this measure, given that this measure also looks at context specific SUDS mechanisms for Petrotrin, and the study shares a mechanism with this measure, namely Swales. Also, PF 2 looks at installing two retention ponds, which is also part of the study. The report states that "overall both the capital and the maintenance costs associated with Lamb Drove are lower when compared to costs associated with conventional pipe drainage systems". Additionally, in terms of surface water flows, Lamb Drove showed significantly reduced peak flows when compared to the control site in the study. The estimated cost savings due to SUDS was approximately £11,000, which was estimated at about 10% saving compared to the control site.

Preliminary Considerations

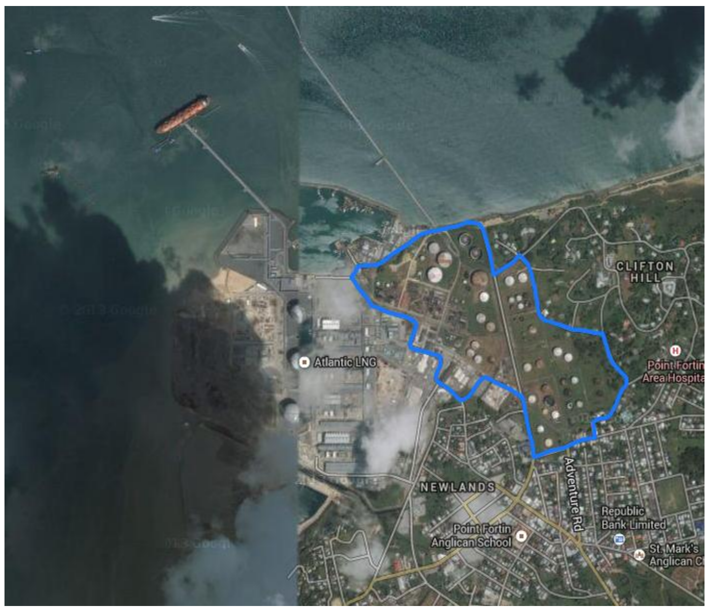
For the proper function of the drainage system, a technical assessment of the characteristics of the area and a map of the water cycle are needed in order to establish the most suitable locations for the systems and to define their capacities in detail.

Description of the action

The action includes building 8 dry swales (10m x 1m=10m2 each one) in the tank area and putting berms around the tanks still in use. The dry swales will be spread around the most vulnerable areas of the tank area.



Source: Google Maps, the orange box is representative of the following image, its scale is approximate



In addition, berms will be constructed around the tanks that are most vulnerable to flooding.

Source: Google Maps, the orange box is representative of the following image, its scale is approximate

Implementation period
2014-2030
Impact of the action
This group of drainage systems would help reduce the risk of floods caused by heavy rainfall and storm surge. As shown in the previous experiences, sustainable drainage systems can be very effective in reducing surface water flood risk, making them cost-effective in many cases. Furthermore, the impact of this action can be better understood if it is considered as a whole with PF 1 and PF 2, because the actions form a system that enhances the safety of Petrotrin's Point Fortin area regarding flood risk, being the dikes are helpful in storm surge and sea level rise and the ponds and swales and berms are useful for those purposes and at reducing superficial water flooding when intense rain fall occurs.
Economic capacity
Even if this system requires a certain investment in both construction and maintenance of the swales and berms, the previous experiences show that those systems are many times cost-effective in terms of reducing or preventing surface water flood risks. Particularly, this conclusion was reached in the Lamb Drove study as well as in the study done by the Committee of Climate Change and Royal Haskoning. In terms of economic benefits calculated in this measure, the value of the land not lost from inundation, have been included. Benefits coming from the infrastructure in Point Fortin and its productive used for the company, have not been included due to a lack of specific information for the Point Fortin area.
Technological capacity
This technology is used in other countries, as detailed in the previous cases. In fact, it is widely used in areas where conventional drainage solutions are not the best option. Therefore, when implementing this technology in Point Fortin, information and knowledge could be obtained from previous success cases in other countries.
Social capacity
There are no relevant social implications due to the characteristics of this action, considering that it is going to be implemented on private land owned by Petrotrin. In general, it would be beneficial for society because it would reduce the risk of flooding.
Institutional capacity

In terms of an institutional framework, Trinidad and Tobago has a National Integrated Water Resources Management Policy, which establishes the principles of water management in the country. However, it does not include particular actions in terms of the management of water supply in the country.

Legal capacity

When it comes to water management in Trinidad and Tobago, the major legislative instruments are the Water and Sewerage Act (1980 Revised); the Waterworks and Water Conservation Act (1980 Revised); the Environmental Management Act (2000 Revised); and the Public Health Act (1950). There is however a need for a new legislative framework to create a new paradigm of integrated water resource management.

Cost-benefit ratio	**1.1**	**-**	**Total cost**	**126,194**	**$**
Pay-back	**15.4**	**Year(s)**	**Total benefit**	**134,871**	**$**

8.2.5. *PF 4: Mangrove Protection in Point Fortin*

Objective

Planting and maintaining mangrove forests that are able to attenuate wind and swell waves in order to protect the dike proposed to build in Point Fortin (for further information on the dike construction action, please see action PF1).

Previous experiences and success cases

Mangroves provide significant benefits to society including increased biodiversity, coastal protection from cyclones, and increased uptake of carbon, amongst others. In a report by Prof. K. Kathiresan titled, "3.5. Importance of Mangrove Ecosystem", Kathiresan summarized the benefits reported by several different studies and projects worldwide. The report notes the significant benefits that have been found due to mangrove restoration including increased supply of forestry products (firewood, charcoal, timber, honey etc.) and fishery products (fish, prawn, crab, mollusk etc.). Mangroves also provide seeds for aquaculture industries. The report cites an example in which "40,000 fishers get an annual yield of about 540 million seeds of Penaeus monodon for aquaculture, in the Sundarban mangroves of West Bengal".

Ecological services that have been found in mangrove projects have included "solar UV-B radiation, 'green house' effects, and fury of cyclones, floods, sea level rise, wave action and coastal erosion". As an example of carbon sequestration the report cites the Rhizophora forest, which is a 20-year old plantation of mangroves that stores 11.6 kg m-2 of carbon with C burial rate of 580 g m^{-2} yr^{-1}.

Mangroves have also proven to help with the trapping of sediments. A previous study done by the author is cited in the report in which it was estimated that "mangroves help in trapping the sediment up to 25 % at low tide as compared to high tide".

It is also important to note the significant coastal protection benefits offered by mangroves. In the report by Prof. K. Kathiresan, it states an example in which "the super-cyclone ... on the 29th October 1999 with a wind speed of 310 km hr^{-1} along the Orissa coast (India) and played havoc largely in the areas devoid of mangroves. On the contrary, practically no damage occurred in regions with luxuriant mangrove growth. Similarly, in the Mahanadi delta, where large scale deforestation and reclamation of mangrove land for other purposes have been undertaken, maximum losses of life and property have been reported from time to time during stormy weather".

Mangroves also help reduce coastal flooding and prevent coastal erosion. The higher the density of vegetation and the depth of the water, the higher the reduction of waves. The report by Kathiresan cites on example from Vietnam, in which "in the tall mangrove forests, the rate of wave reduction per 100 m is as large as 20%". Kathiresan also cites work that proves that mangroves act as "live sea walls" which have proven to be more economically beneficial than artificial concrete sea walls for coastal protection, in some cases.

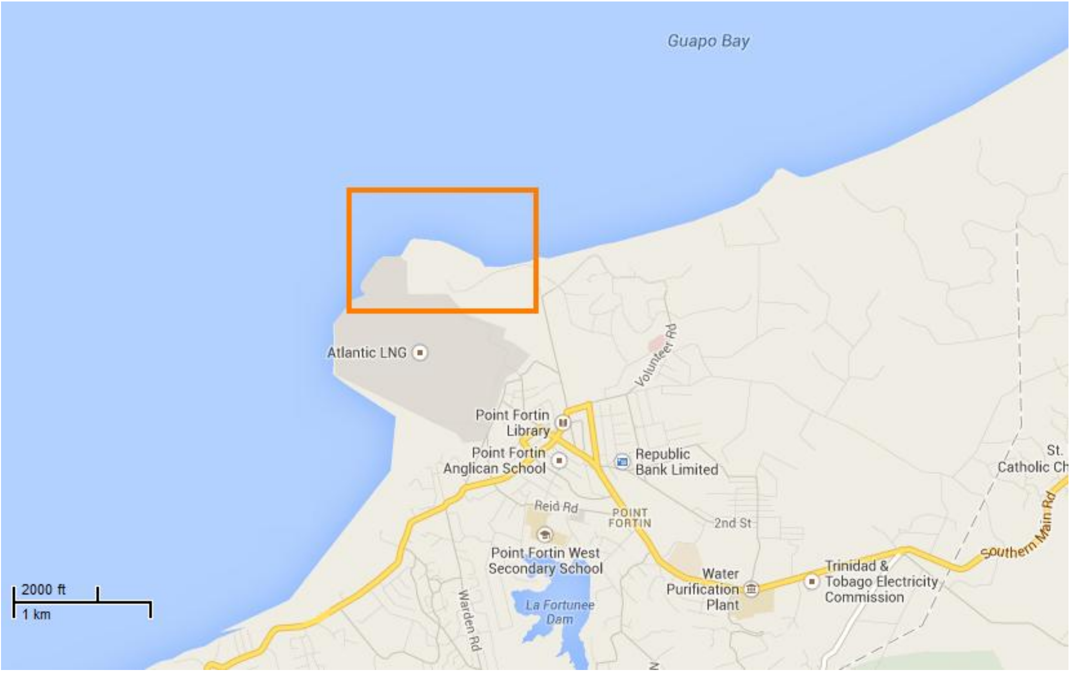
Preliminary Considerations

For the mangrove restoration to work, it is necessary to ensure that there is no water pollution and that the ecosystem is able to restore itself. Therefore, the selected areas need to be analysed first in order to find out whether the restoration is viable or not. Otherwise, the mangrove restoration would not be viable.

Description of the action

The action implies the regeneration a 100 meter width, 400 meter long mangrove. This would cover one of the strips of the dike proposed in PF 1. The mangrove forest would reduce the erosion effect produced by the waves and therefore the maintenance costs of the dike.

The technique proposed is hydrologic restoration, rather than planting. Hydrologic Restoration consists of connecting impounded mangroves to normal tidal influence, that is, instead of planting mangroves, the efforts would be focusing on restoring the previous state of the coastal areas, restoring the tidal schemes previous to the human influence. That way, if the environmental conditions are adequate, mangroves are restored without the need of planting, but rather just by the natural diffusion process which takes place due to the coastal tides. The development of the action would focus at first on achieving natural restoration. If this is not possible, mangroves would be planted. In the case that planting needs to occur, additional costs may have to be assumed, which are not considered in the economic analysis of this measure.



Source: Google Maps, the orange box is representative of the following image, its scale is approximate

Implementation period

2014-2023

Impact of the action

The mangrove forest would provide protection to the dike proposed in PF 1. Therefore, the annual maintenance cost of the dike would be reduced. Furthermore, mangroves are also highly beneficial because they can provide forestry and fishery products, which can be exploited commercially, if desired.

Additionally, mangroves enhance the sustainability of the area by protecting the coast from solar UV-B radiation, 'green house' effects, and the fury of cyclones, floods, sea level rise, wave action and coastal erosion. Mangrove swamps act as traps for sediments, and sinks for nutrients. The root systems of the plants keep the substrate firm, and thus contribute to a lasting stability of the coast.

As shown in the success cases section, mangrove restoration is a beneficial action in economic terms and provides many advantages for the environment, not only those derived from the prevention of the damage caused by the climate change hazards, but also options for the development of the local communities in terms of firewood, charcoal or timber procurement, improvement of fisheries, and so on.

Economic capacity

The implementation of this action in other countries shows that its benefits are much higher than the costs of mangrove restoration. The investment is low for this action because the mangrove restoration is selected instead of mangrove planting. This option should only be considered when the restoration is not viable; however, it is not very recommendable due to the difficulty to obtain good growth rates and its higher cost.

In terms of economic benefits calculated in this measure, the value of the land not lost from inundation, have been included. Benefits coming from the infrastructure in Point Fortin and its productive used for the company, have not been included due to a lack of specific information for the Point Fortin area.

Technological capacity

In Trinidad and Tobago, particularly in Petrotrin, efforts regarding the restoration of the mangroves are already being carried out. Therefore, it is not an unknown matter in the country. Additionally, the lessons learnt from the mangrove restoration projects carried out in other countries should be analysed and adapted to the characteristics of the selected coastal areas.

The success of this action depends on the capacity to carry out the hydrologic restoration technique. Therefore, if in a first assessment it is found that the conditions for the hydrologic restoration are not met, the use of other techniques should be analysed.

Social capacity

The restoration of the mangroves does not have any harmful effects in social terms; on the contrary, it can provide several benefits to the communities, because it would make the agricultural area more resilient to floods. For this reason, people who own these lands could be interested in cooperating in the restoration process. This activity would also improve the fishery and wood resources of the area and improve biodiversity, positively affecting the surrounding areas.

Institutional capacity

Institutional capacity is required in order to promote the development of the action within a national strategy on coastal areas protection. There is already a National Action Programme to Combat Land Degradation in Trinidad and Tobago 2006-2020, which should be considered. The action programme is defined in broad terms and it would be necessary to establish the adequacy of this action within the objectives set in the programme. In fact, in the programme, the need of a Coastal Zone Development Plan is stated, and it would be necessary to define that plan before this action can be carried out.

In a similar way, the National Biodiversity Strategy and Action Plan focuses on the conservation and sustainable use of the country's biodiversity, but it does not include a particular mention of the management of the country's mangroves.

There is also a National Policy and Programmes on Wetland Conservation in Trinidad and Tobago, which includes the management of some of the mangroves of the countries. It includes among its objectives the restoration of damaged but important wetlands, but no additional information on how the objective will be achieved is included.

Legal capacity

The legal framework for the protection of the coastal areas and wetlands of Trinidad and Tobago is poorly defined at the moment. Thus, it would be necessary to develop, as stated before, a Coastal Zone Development Plan, with well defined actions, which should need to be implemented. If necessary, the development of a strict legal framework may be needed in order to ensure that the objectives are fulfilled.

Mangrove Restoration in Tobago is slightly complicated in terms of legal capacity given that existing land use management policy dictates that "the local government such as the County Council has responsibilities up to the high water mark while land administration, rather than land management, is undertaken from the high water mark seawards to the extent of the EEZ by the Commissioner of State Lands under the Ministry of Planning and Development. Further, if beach facilities are constructed they are the responsibility of the Tourist Board under the Ministry of Enterprise Development, Foreign Affairs and Tourism; the construction and maintenance of coastal protection structures fall under the jurisdiction of the Ministry of Works and Transport; construction of fish landing facilities is the responsibility of the Fisheries Division of the Ministry of Agriculture Land and Marine Resources, and if the beach is fringed by mangroves or a site for turtle nesting the area is the responsibility of the Forestry Division in the Ministry of Public Utilities and the Environment. Additional jurisdictions involved may be the Ministry of Energy with regards to exploited petroleum and gas reserves" (Soomai, S., 2005). This interlinkage of authoritative figures will need to be looked into in order to determine the frameworks under which the measure falls.

Cost-benefit ratio	**10.7**	**-**	**Total cost**	**6,750**	**$**
Pay-back	**7.8**	**Year(s)**	**Total benefit**	**72,391**	**$**

8.2.6. *PF 5: Relocation of Infrastructure in Point Fortin*

Objective

To relocate specific infrastructure due to the risk of inundation in the future.

Previous experiences and success cases

The relocation of vulnerable infrastructure is a widely accepted and mentioned adaptation option (IPCC

TAR WG2, 2001, IPCC AR4 WG2, 2007). In a document analyzing the Economics of Adaptation to Climate change in Samoa by the World Bank (2010), they state that "large investments in relocating coastal infrastructure should only be implemented if and when the reduction in the expected value of storm damage exceeds the annualized costs". According to the US EPA (2013), Entergy Corporation, an energy company with business in the Gulf Coast, has been doing just that. They have been working on a climate risk assessment in order to understand the potential costs of continuing to operate business-as-usual in the Gulf Coast. After Hurricane Katrina, the company partnered with America's Wetlands Foundation and commissioned a study titled "Building a Resilient Energy Gulf Coast" in order to assess the impacts of climate change on the area. From their analysis, the company made strategic decisions to relocate "important business centres inland to areas less likely to be affected by future storms". Other infrastructure has been armoured to increase resistance to storms.

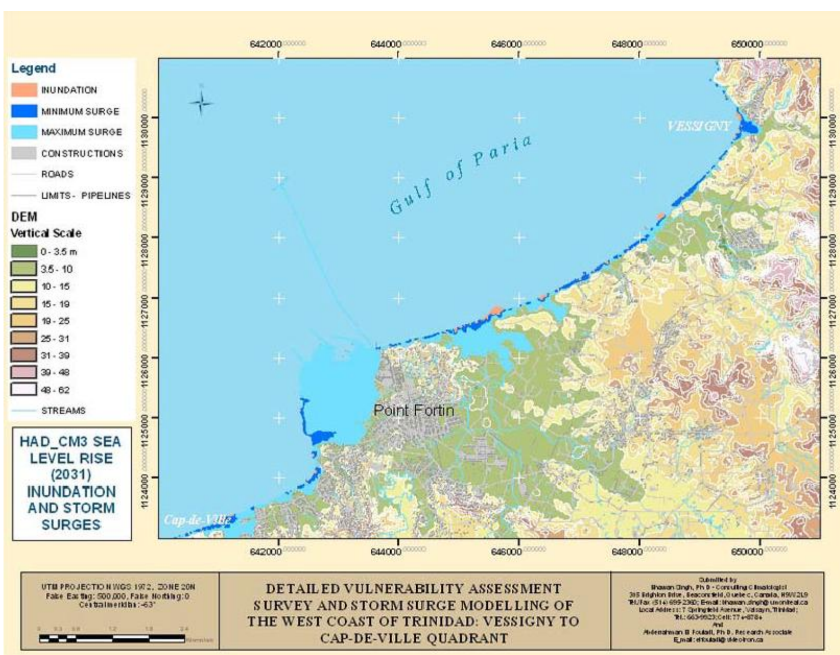
Preliminary Considerations

Before implementing this measure, Petrotrin will need to look at the overall future of Point Fortin, taking into account the possible risks due to climate change. As seen in the images below, from the projections of inundation, storm surge, and erosion made from the region, it is likely that by 2031, the port and terminalling stations will be inundated in a business as usual scenario. Therefore, the relocation of infrastructure in this area may not be economically beneficial for Petrotrin, given that the Petrotrin's main use for this area at the moment is for terminalling. Petrotrin should first look holistically at its adaptation plans for Point Fortin, and ensure the continued functionality of the port and terminalling stations first, before considering relocating other related infrastructure.

Once Petrotrin decides to move vulnerable infrastructure, they will need to decide on a new location for the infrastructure being relocated. The company should look strategically at all the possible options in terms of infrastructure relocation, construction, and elevation and decide what is best for the company's future plans. The study done on vulnerability, land inundation and erosion in the Point Fortin area, and other areas owned by the company, should be taken into consideration when making these decisions.

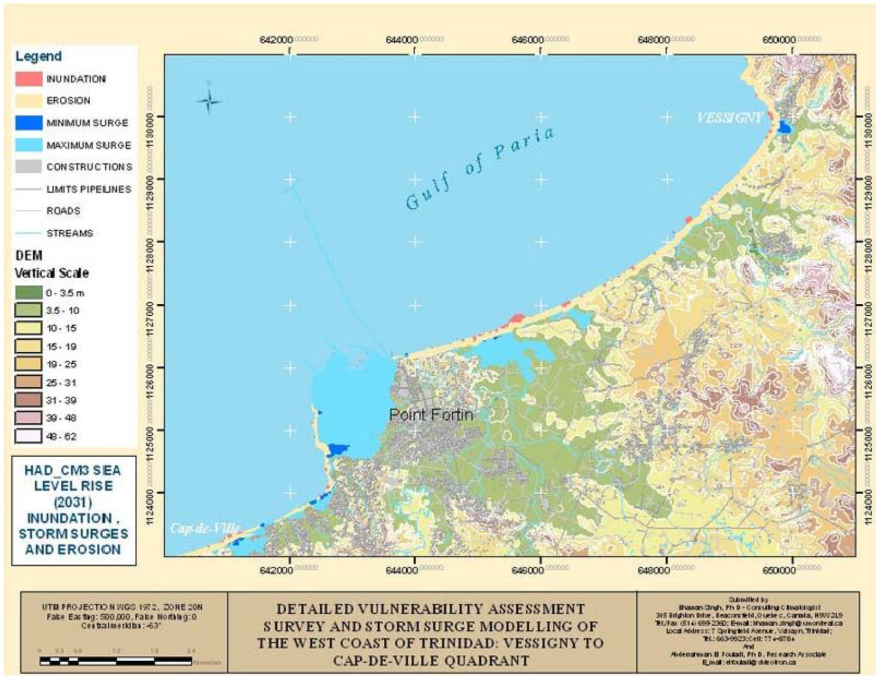
Description of the action

This action looks to relocate the tanks and their related infrastructure in the zone marked in blue in the map below. This infrastructure has been marked eligible for relocation due to the preliminary vulnerability studies done for Point Fortin (Singh. B. and A. El Fouladi, 2007). In this study, portions of Point Fortin are expected to be inundated by 2031, whereas other portions will still be intact:



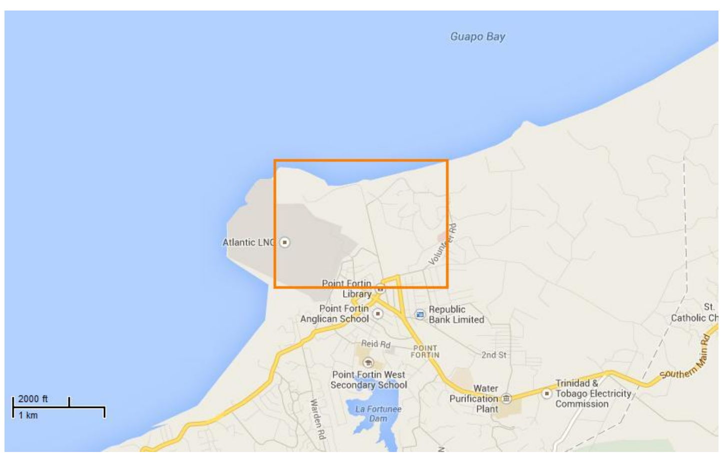
Inundation Of The Coastland Along The Gulf Of Paria On The West Coast Of Trinidad
Due To Sea Level Rise As Simulated By Hadcm3 And Flooding Due To Minimum And

Maximum Storm Surges, Coupled With The Dem, 2031 :Vessigny To Cap-De-Ville Quadrant (Singh. B. and A. El Fouladi, 2007)



Inundation And Erosion Of The Coastland Along The Gulf Of Paria On The West Coast Of Trinidad Due To Sea Level Rise As Simulated By Hadcm3 And Flooding Due To Minimum And Maximum Storm Surges, Coupled With The Dem, 2031 :Vessigny To Cap-De-Ville Quadrant (Singh. B. and A. El Fouladi, 2007)

Therefore, those areas that are expected to be completely inundated have been chosen for possible relocation.



Source: Google Maps, the orange box is representative of the following image, its scale is approximate

Relocation of this infrastructure includes strategic planning of where the infrastructure will be moved to, acquisition of the land (if necessary), zoning and permit requests (if necessary), engineering design and construction. In addition, the measure includes the removal of now obsolete infrastructure in Point Fortin and of any hazardous materials, which could pose environmental problems in the event of storm surge and flooding in the area in the future.

Implementation period

2014-2030

Impact of the action

According to the vulnerability assessments done for the area (Singh. B. and A. El Fouled, 2007), this area will likely experience severe problems of inundation and erosion by 2031. It is therefore recommended that Petrotrin begin to consider relocating this infrastructure to another location. This will help reduce the risks of infrastructure being damaged, and hence reduce the risk of possible environmental problems. These problems not only would impact the surrounding habitats and ecosystems, but could also cause severe reputational problems for Petrotrin.

Economic capacity

While this measure will incur substantial costs, given the high risk of inundation in the future, it is recommended that this infrastructure be removed from its current location and relocated to an area with less risk of inundation and erosion. The benefit of this measure is the fact that the new infrastructure being less vulnerable to risks from climate change. This measure therefore reduces the risk of storm surge damaging infrastructure and causing hazardous accidents. As with the construction of other major infrastructure, such as the dike mentioned in other measures, benefits from this project would go much further than what can be depicted in the time frame used in this study. Therefore, if the economic analysis were taken out further into the future, along the entire use life of this infrastructure, the economic results would likely be better.

It should be noted that by 2031, the projections of inundation in the area show that the port and terminalling areas will be inundated. Therefore, in a business as usual scenario, this area would not offer significant economic benefits to Petrotrin in terms of productive use -given that it is currently used primarily for terminally purposes. If the port and terminalling stations are not elevated to ensure their productivity in the future (see PF 6), then this newly relocated infrastructure may not provide much use to Petrotrin. Therefore, the economic benefits due to the productive value of the infrastructure are contingent on the fact that the port and terminalling stations are available in the future (see PF 6). Due to lack of information regarding the level of activity at the Port Fortin's terminalling station and port, the economic benefits related with productive use of the infrastructure have not been included in the analysis. This economic benefit, however, is likely the most important benefit from this activity.

In this measure, the economic costs have been estimated; however, several expected costs have not been included in the estimation due to lack of information. Firstly, given the lack of information regarding the physical infrastructure in the area and is use, an estimation of the number of tanks in use was taken from maps available. The volume of these tanks was estimated by calculating the base area of these tanks, and assuming their height was 17 meters, as the height of the tanks could not be extracted from the maps. The cost of building new tanks with the same total volume was estimated. Other infrastructure that was seen in the maps, but was not able to be identified by its use, such as buildings, and therefore was not included in this study. Additionally, the potential costs of land purchase for relocation, in the event that the company does not already own land on which this infrastructure can be moved to, has not been included in the cost estimation. The costs of removing the current infrastructure have also not been calculated due to the lack of information regarding the physical infrastructure and the status of the soil in this area.

Given the lack of specific information regarding infrastructure in the vulnerable area, about the infrastructures' current value (estimated useful life remaining of the assets) and about its current and future expected uses, it should be considered that this is a rough estimate could be improved if specific details were made available.

Technological capacity

This technology required for this measure is general construction, given that tanks will be dismantled in one area in constructed in another. Therefore, this measure does not require any technological capacity that is not available in Trinidad and Tobago, nor available to Petrotrin.

Social capacity

In terms of social concern for this action, if the area decided on for the new infrastructure includes the displacement of local communities or severe environmental risks, this could provoke social discontent with the project. There are times when local communities protest the construction of this type of infrastructure near their communities. Stakeholder meetings and engagement in order to ensure that the local community is part of the action and that they understand the impacts that it may have on their community are recommended. In addition, if the existing tanks and infrastructure is properly dismantled, this could help improve any negative opinions from the community.

Institutional capacity

Since this project would be carried out by Petrotrin, the institutional capacity would not affect the implementation of the measure.

Legal capacity

When considering the development of the action, in the planning and construction phases, the effects of the action should be considered regarding the legal framework established by the following laws: the Environmental Management Act; the Certificate of Environmental Clearance Rules; the Town and Country Planning Act; and the Public Health Ordinance and the Marine Areas (Preservation and Enhancement) Act. This action implies the construction of infrastructure, which may have negative effects on the environment and, therefore, the laws of Trinidad and Tobago need to be respected when designing and developing the action.

Cost-benefit ratio	**8.8**	**-**	**Total cost**	**2,317,739**	**$**
Pay-back	**0**	**Year(s)**	**Total benefit**	**20,375,901**	**$**

8.2.7. *PF 6: Infrastructure Elevation in Point Fortin*

Objective

To elevate a portion of the port, terminalling stations, tanks and their related infrastructure at Point Fortin, making it less susceptible to significant inundation in the long term.

Previous experiences and success cases

There is significant discussion around the need to adapt infrastructure, specifically in the oil industry, to the expected effects of climate change in the future. The IPCC Working Group II: Impacts, Adaptation and Vulnerability, of the Third Assessment Report (IPCC TAR WG2, 2001), it states that "port facilities are another type of infrastructure that will be affected by climate change and sea-level rise. Higher sea level probably will decrease the effectiveness of breakwaters against wave forces, and wharves may have to be raised to avoid inundation. When such effects are anticipated, countermeasures can be implemented to maintain function and stability. Therefore, the real impacts will occur as an additional expenditure to reinforce the infrastructure. The total expenditure to keep the present level of functions and stability for about 1,000 Japanese ports is estimated to be US$110 billion for a 1-m sea-level rise..." They cite a study done by Maria de Lourdes Olivo (1997), which estimated the potential economic impacts of a sea-level rise of 0.5 m on the coast of Venezuela. In this study, Olivo estimates the costs of raising infrastructure in the areas of Costa oriental del Lago de Maracaibo (6,589 million USD), Costa Oriental de Falcón (897 million USD), Cabo Codera-Parque Nacional Laguna de Tacarigua (2,986 million USD), Barcelona-Puerto La Cruz-Guanta (4,206 million USD), and Juan Griego en La Isla de Margarita (2,98.5 million USD).

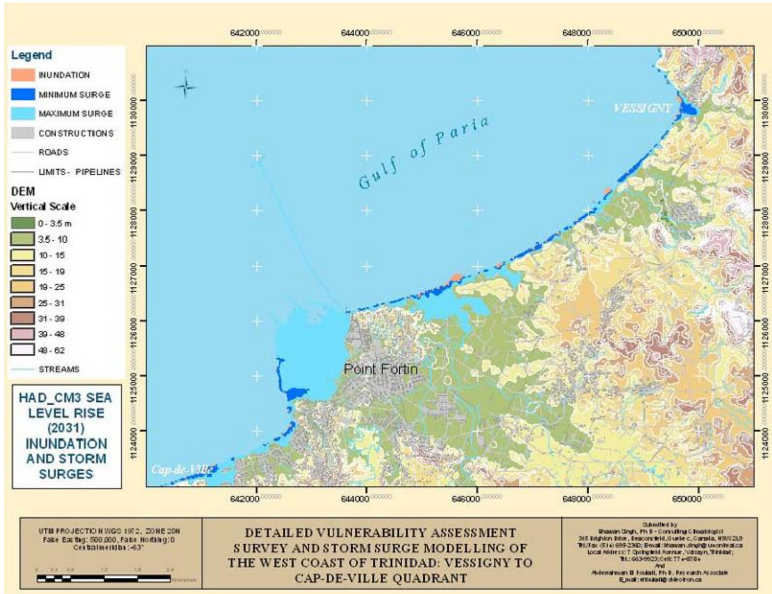
In a report done for the City of Cape Town Environmental Resource Department (LaquaR Consultants CC, 2008), raising infrastructure was one of the adaptation measure considered for the city. The report states that "Cape Town docks, for example, would prove difficult to relocate, but could be raised or dredged in order to protect against sea-surges and inundation. Similarly raising the level of roads at Paardon Eiland could reduce the chance of these roads being over-topped by the sea. Problems with raising infrastructure, apart from the cost, include knowing exactly how high the infrastructure needs to be in order to be considered safe (or deciding what is considered safe enough), and the required adjustments to adjacent infrastructure".

Preliminary Considerations

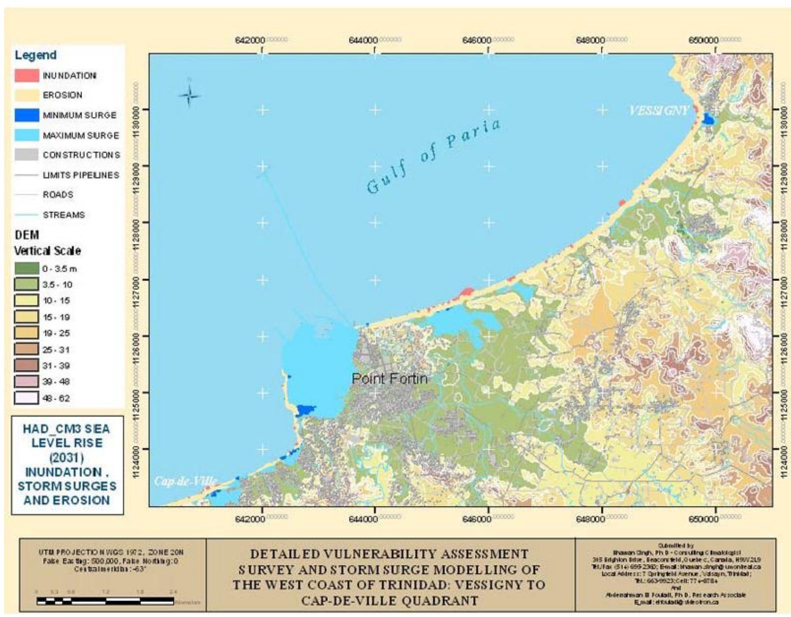
Before considering the elevating infrastructure, the company should look strategically at all the possible options in terms of infrastructure relocation, construction, and elevation and decide what is best for the company's future plans. The studies done on vulnerability, land inundation and erosion that have been done for Point Fortin, and other areas owned by the company, should be taken into consideration when making these decisions.

Description of the action

In the preliminary vulnerability studies done for Point Fortin (Singh. B. and A. El Fouladi, 2007), portions of Point Fortin are expected to be inundated by 2031, whereas other portions will still be intact:



Inundation Of The Coastland Along The Gulf Of Paria On The West Coast Of Trinidad Due To Sea Level Rise As Simulated By Hadcm3 And Flooding Due To Minimum And Maximum Storm Surges, Coupled With The Dem, 2031 :Vessigny To Cap-De-Ville Quadrant (Singh. B. and A. El Fouladi, 2007)



Inundation And Erosion Of The Coastland Along The Gulf Of Paria On The West Coast Of Trinidad Due To Sea Level Rise As Simulated By Hadcm3 And Flooding Due To Minimum And Maximum Storm Surges, Coupled With The Dem, 2031 :Vessigny To Cap-De-Ville Quadrant (Singh. B. and A. El Fouladi, 2007)

Therefore, the port and terminalling stations, which are the most productive portions of Point Fortin for Petrotrin (Petrotrin, 2013) will have to be elevated in order to continue to be able to use them in the future.

In addition, the land area that is not expected to be completely inundated has been chosen for possible elevation. This action involves elevating all of the infrastructure related with the tanks shown in the blue region above, including pipes, electrical equipment, etc. It does not include elevating the tanks themselves. It is marked in blue in the map below:

Source: Google Maps, the orange box is representative of the following image, its scale is approximate

Implementation period

2014-2030

Impact of the action

As stated in the Vulnerability Assessment carried out for the West Coast area for Petrotrin, port facilities - Point Fortin in particular - will be very susceptible to climate-driven sea level rise and storm surges. Higher sea levels and storm surges will most likely decrease the effectiveness of breakwaters against wave forces and wharves.

According to the assessment, the port and terminalling areas, which are considered strategic for Petrotrin, will have to be elevated in order to continue to use them. This could have enormous impacts for Petrotrin, given that the Point Fortin facilities "deliver the region's best strategically located terminalling services" (Petrotrin, 2013).

The area in blue designated in the maps above will not be completely inundated in 2071, and therefore will still be able to be used for industrial purposes. However, it is recommended that this infrastructure be elevated in order to ensure that it is protected from flooding. In this measure, the tanks will not be elevated, however all of the pipes and relate infrastructure will be elevated in order to protect it from flooding. Benefits from this measure will include preserving the infrastructure and land for valuable industrial purposes and making maintenance of these pipes easier and less costly.

Economic capacity

In this measure, the economic costs and benefits have not been estimated given the lack of specific information regarding infrastructure in the vulnerable area, about the infrastructures' current value (estimated useful life remaining of the assets) and about its current and future expected uses. Without specific information, it is hard to estimate the costs of the elevation of this infrastructure. Given that Point Fortin is one of Petrotrin's best terminalling services, this could be a beneficial measure to undertake. However, due to lack of information regarding the level of activity at the Port Fortin terminalling station and port, these economic benefits have not been included in the analysis.

Technological capacity

This would likely be one of the first attempts to elevate this type of infrastructure in Trinidad and Tobago, given that this type of adaptation measure is relatively new. However, it is not a type of construction in which qualified engineers are able to design. It would be recommended to look for similar projects in other countries, in order to determine best practices, or possible lessons that could be transferred to this project.

Social capacity

This action does not imply any social concerns. In fact, measures undertaken in order to reduce the environmental risks of the oil industry are generally welcomed by the general public.

Institutional capacity

Since this project would be carried out by Petrotrin, the institutional capacity would not affect the implementation of the measure.

Legal capacity

The legal framework for the protection of the coastal areas of Trinidad and Tobago is poorly defined at the moment. Thus, it would be necessary to develop, as stated before, a Coastal Zone Development Plan, with well defined actions, which would then need to be implemented. If necessary, the development of a strict legal framework may be considered to ensure that the objectives are fulfilled.

Additionally, when considering the development of the action, in the planning and construction phases, the effects of the action should be considered regarding the legal framework established by the following laws: the Environmental Management Act; the Certificate of Environmental Clearance Rules; the Town and Country Planning Act; and the Public Health Ordinance and the Marine Areas (Preservation and Enhancement) Act. This action implies the elevation of coastal infrastructure, which may have negative effects on the environment and, therefore, the laws of Trinidad and Tobago need to be respected when designing and developing the action.

Cost-benefit ratio	**N/A**	**-**	**Total cost**	**N/A**	**$**
Pay-back	**N/A**	**Year(s)**	**Total benefit**	**N/A**	**$**

8.2.8. PAP 1: Dike Construction in Pointe-à-Pierre

Objective

To build barriers that can provide protection against 1.5 meter sea level rise in order to avoid floods in Pointe-à-Pierre.

Previous experiences and success cases

Dikes are a widely used method worldwide for the prevention of flooding. In fact, in The Netherlands, the river flows have been managed by more than a thousand years. These structures have been used as a protective measure in several countries even before the hazards caused by climate change were taken into account, as proven by the already mentioned example of The Netherlands or the infrastructure in other flood prone areas like New Orleans (USA) or the Mekong River (Vietnam).

In The Netherlands, the flood prevention system is built with the objective of being able to face storms that would occur only once in 10,000 years. To do so, the prevention systems are reinforced and supervised continuously to prevent damage instead of working after the damage is done. In the flood prone regions, such as the already mentioned areas or others like the British Columbia in Canada, currently the efforts are devoted into adapting the existing systems to the predicted future conditions, taking into consideration the effects of climate change. The Economics of Adaptation to Climate Change developed by the World Bank for Vietnam also considers the reinforcement of the coastal and river defences as a key necessity of the adaptation strategy of the country.

Additionally, in Barbados, a Coastal Zone Management Unit was established to carry out and monitor the shoreline protection program, guided by the Coastal Zone Management Plan. The Unit looks at the impacts on coasts from commercial and housing development, drainage, ocean tides and currents, storm and hurricane probabilities, coral reef ecosystems and the rising sea level caused by global warming. It promotes engagement from all stakeholder groups involved in coastal management. Seawall construction, including rip raps, is one of its main infrastructure choices for intervention (Scruggs, G. and Bassett, T, 2013). "These construction projects involve either a riprap design of large rocks or a flat, concrete seawall that can create public space attractive to both tourists and residents, such as the Richard Haynes Boardwalk, partially funded by an IDB loan. Because these techniques can sometimes exacerbate erosion and require more expensive maintenance than natural interventions, their long-term efficacy is up for debate, but, in the short term, they protect the coastline…" (Scruggs, G. and Bassett, T, 2013).

The validity of those systems is proved when extreme events take place in terms of the consequences of those events. For instance, in New Orleans, the effects of tropical storm Katrina proved that the existing system was not valid to ensure the security of the city, and, subsequently, they are being modification to provide better results. This path of action is similar to that observed in The Netherlands, where after a devastating flood in 1953, the dike system was widely reinforced and became a country-level priority.

Preliminary Considerations

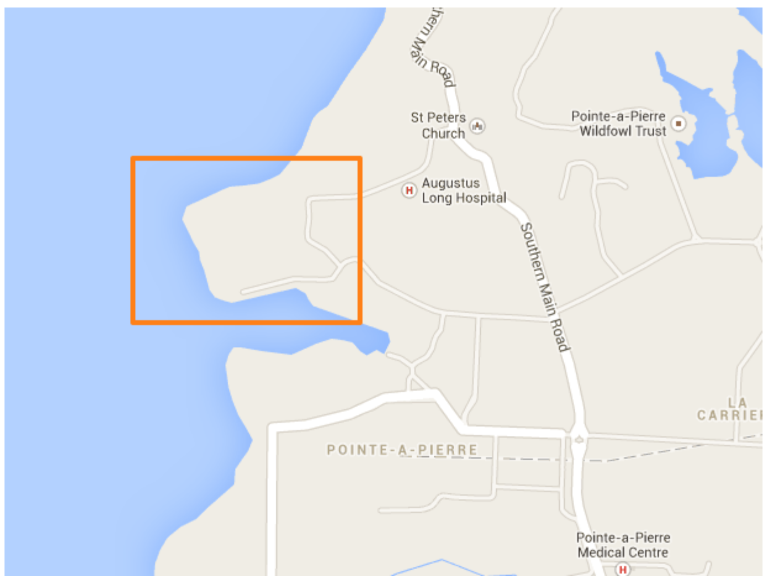
The area in which the barriers are proposed has been chosen for the surrounding strategic industrial infrastructure. Therefore, it has a higher level of vulnerability. However, before the implementation of the action, a more detailed assessment would need to be carried out to determine the needs for the area and the best construction solution for it.

Description of the action

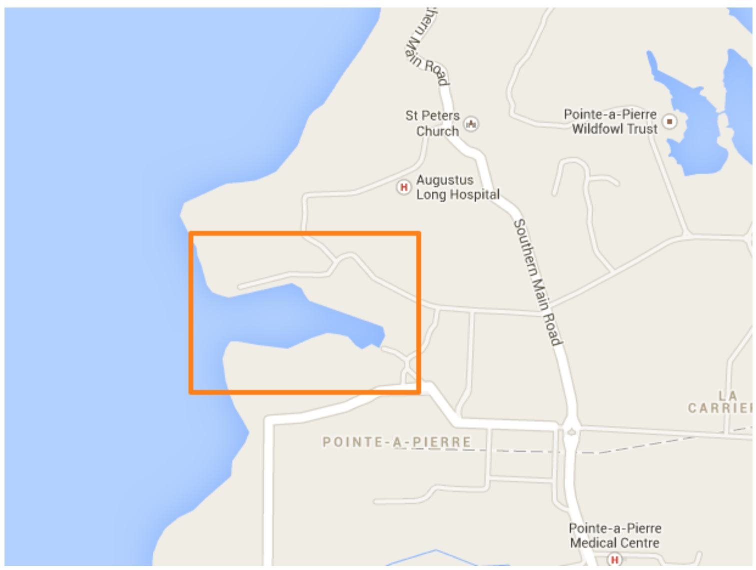
The measure consists in building barriers in coastal zones around Pointe-à-Pierre. Due to its cost-benefit ratio, the barrier type chosen is the riprap. This action includes the excavation of the dike root, transportation of the riprap, filling with gravel and revegetation of the area. The dike has a 5 meters wide root, 2 meters deep, 1 meter on top and it is 3.7 meters high. Dikes would be built along the coast marked in yellow in the images below, totalling 1.12 km.

The action would be developed progressively; the construction of the infrastructure would take place over ten years. The action would therefore not be completed until 2030. However, some sections would be operative in 2020, which means that the benefits of the action, that is, the losses avoided by the improvement of the dikes, would be observed already in 2020.

Source: Google Maps



Source: Google Maps, the orange box is representative of the following image, its scale is approximate



Source: Google Maps, the orange box is representative of the following image, its scale is approximate

Implementation period

2014-2030

Impact of the action

As stated in the Vulnerability Assessment done for Petrotrin for Pointe-à-Pierre, this area will be very susceptible to climate-driven sea level rise and storm surges. Higher sea levels and storm surges will most likely decrease the effectiveness of breakwaters against wave forces and wharves, loading docks and offshore platforms may have to be raised to avoid inundation.

The proposed barrier will protect the coastal zone, avoiding sea water flooding the buildings and infrastructure close to the coast line. Additionally, this action will also help mitigate the effects of floods and erosion caused by the increased rainfall expected in the wet season in the area due to the climate change.

The proposed barrier would protect the coastal zone avoiding the sea water flooding the areas close to coast line buildings and other infrastructure. As an indirect effect, the dike construction would also stimulate employment, especially in the building area. The negative aspects of the implementation of this action are mainly its disruption of the coastal dynamics, which may have adverse effects on the ecosystems.

As stated previously, this is a widely implemented action in flood prone areas, having proved its usefulness in many cases. It is important to highlight that the impact of the action will only be observed truly after the extreme events take place, when compared to the consequences of other similar events that happened previously.

Economic capacity

The investment amount for this adaptation measure is high in absolute terms, but compared to its benefits, it is definitely a more than reasonable investment. The sea level rise will happen; however, there is still plenty of time to prepare for that rise, which means that the investment can be distributed throughout the next 10-15 years. Taking into account the results of the vulnerability assessment carried out for Petrotrin in this area, this kind of activity could help greatly to reduce some of the effects of climate change in the area. Therefore, economically speaking, it is definitely an interesting measure; even if the costs are relatively high, the losses that could be avoided are also considerable.

It should be noted, regarding the benefits of the action, that until 2020 no benefits are obtained since there is not any completed rip-rap section until that year. Therefore, for this action, a wider time-frame would provide a better result in the cost-benefit analysis, because after all the construction work is over, the benefits would overcome the costs.

The value of the infrastructure in Pointe-à-Pierre was estimated by taking the value of the value of the refinery and marketing assets, declared in the financial statement of the company in 2012 and dividing this number by the number of acres in Pointe-à-Pierre. This calculation was performed given that Pointe-à-Pierre is the only refinery in the company, and therefore the assets declared by the company in the area of refinery and marketing should be close to the value of this land for the company. It should be mentioned however, that since the portion of "marketing" assets is unknown, this value has not been taken out of the asset value used in this calculation and therefore the estimation could be slightly over estimated.

It should also be considered, in terms of economic capacity, the experience obtained from the implementation of this action in other countries. A key feature of this kind of action is that benefits are only observed if extreme events take place. Therefore, many times, due to the volume of the required investment, this type of infrastructures are observed as unnecessary. However, as it has been shown in previous experience, the development of this kind of infrastructures as a part of a long term coastal management plan provides more benefits than the costs it requires.

Additionally, given the report done for Petrotrin on this area, Singh (2009) states that in 2071, "Facilities that are likely to be inundated and eroded include: the Propane Jetty, the Propane Depot, the Temporary Oil Catch, the Offshore Services Dock, the Simpson's Sump Oil Catch and drainage channel, the Oil Stock Main Pump and Filling Bay and the Tank Farm in the reclaimed land area". In fact, all tanks in the area, except three are expected to be inundated or eroded by 2071. Therefore, if this analysis were done taking into account long term climate change, it would likely have much higher benefits than costs.

Technological capacity

This technology was already developed in some of the coastal areas of Trinidad and Tobago; therefore, there is experience in the country in terms of constructing dikes. However, it would be interesting to consider, when analysing the implementation of the action in depth, the latest technologies implemented in countries that can be regarded as the path to follow, such as The Netherlands. The technologies might not be directly exportable, but would help define the best options for Trinidad and Tobago considering the latest advances in the development of coastal protection measures.

Social capacity

Even if it is regarded as the best example for the implementation of this technology, even in The Netherlands, the construction of dikes is many times regarded as a controversial issue. The visual effect in aesthetic terms of this kind of infrastructure is evident and many times, the population does not cope well with the construction of dikes. However, if the effect in terms of disaster risk reduction and prevention of losses is well understood, the negative attitudes are usually less. For instance, in the Bulgarian municipality of Shabla, various structures were built to safeguard the coastline and ensure the livelihoods of the local communities. The measures proved effective to "hold the line", stopping the erosion problems of the area, and the increased safety has allowed other economic activities to develop e.g. eco-tourism.

The most negative effects found in Bulgaria are those connected with the aesthetics because the concrete walls and the stony dykes are not compatible with the normal natural landscapes in this area. However, a conscious decision was taken to compromise the natural landscapes in favour of the coastal protection facilities, reaching a compromise between the negative effects in terms of aesthetics and the positive effects in terms of disaster risk reduction. A similar approach could be used in terms of social capacity for Trinidad and Tobago.

Institutional capacity

Since this project would be carried out by Petrotrin, the institutional capacity would not affect the implementation of the measure.

Legal capacity

The legal framework for the protection of the coastal areas of Trinidad and Tobago is poorly defined at the moment. Thus, it would be necessary to develop, as stated before, a Coastal Zone Development Plan, with well defined actions, which should need to be implemented, if necessary, developing a strict legal framework to ensure that the objectives are fulfilled.

Additionally, when considering the development of the action, in the planning and construction phases, the effects of the action should be considered regarding the legal framework established by the following laws: the Environmental Management Act; the Certificate of Environmental Clearance Rules; the Town and Country Planning Act; and the Public Health Ordinance and the Marine Areas (Preservation and Enhancement) Act. This action implies the construction of infrastructure, which may have negative effects on the environment and, therefore, the laws of Trinidad and Tobago need to be respected when designing and developing the action.

Cost-benefit ratio	**0.4**	**-**	**Total cost**	**4,961,914**	**$**
Pay-back	**27.8**	**Year(s)**	**Total benefit**	**1,869,243**	**$**

8.2.9. *PAP 2: Construction of Retention Ponds at Pointe-à-Pierre*

Objective

To build water retention reservoirs that can harvest rainwater for industrial use. These would follow best practices, meaning reservoirs lined with impermeable lining and with water inflow and outflow infrastructure installed, to ensure that the maximum quantities of water can be harvested in the latter part of the dry-season, and then distributed to users after conservation and during dry seasons, to augment supply for local uses. The management of these would be tied to use of seasonal forecasts, with stricter use regimes imposed when more severe drought conditions are forecast as likely.

Previous experiences and success cases

Retention Pond technology increases water supply for industrial purposes in areas with chronic water shortages. In terms of this technology's functionality, according to a report done by Organization of America States, Paraguay has used this technology extensively; areas of low topography used for rainwater storage are known as tajamares. They use distribution canals that take water from the storage area to its point of use.

In addition, according to a report from UN Habitat, in 1993 the Frankfurt Airport constructed a rainwater harvesting system within the newly constructed terminal. The water collected is used for flushing toilets, watering plants, and cleaning the air conditioning system. The system helps save approximately 100,000 m^3 of water per year.

The Technical University of Darmstadt in Germany also has a rainwater harvesting system which provides water for flushing toilets and provides water to laboratories of the university for cooling and cleaning purposes. The water is cleaned prior to use. Estimates state that the system saves 80,000 m^3 of drinking water per year.

In Sumida City, Tokyo, a rainwater harvesting system was installed in a wrestling area in 1982, which the city states provides half of the building's water needs and significant economic savings. Since then, hundreds of buildings in Tokyo have introduced rainwater harvesting systems.

Preliminary Considerations

Due to the spatial and temporal availability of the water across the two islands, localised imbalances occur, resulting in water shortages being experienced by the population. The ability to supply all the competing demands for water is further affected by bottlenecks in the water supply infrastructure.

Description of the action

The key initial measure involves building 2 ponds to catch rainwater. The ponds would have dimensions that are determined by site characteristics. Typically, they are of approximately 10 m in length and width (or 14m diameter, if circular) with a depth of at least 2 m, making them suitable for most locations even when the land availability may be scarce. Therefore, the volume of the proposed ponds would be of approximately 1,875 m^3, with a surface area of 625 m^2.

Implementation period

2014-2030

Impact of the action

Each pond can hold 1,875 m^3 of rainwater, meaning 1,875,000 water litres - 3,750,000 litres in total. Harvesting rainwater could calculate to thousands of dollars in savings every year, especially for industrial uses due to the large water demand by industrial processes. Ponds also increase the resilience to flooding, which is why they would be distributed among areas where the rainfall is especially intense and where flooding could increase damages.

Economic capacity

The action would imply a financial investment to build the ponds. However, benefits would be obtained, as shown in the previous experiences and success cases, from the damage avoided in flooding and from the use of the harvested water instead of water from other sources such as desalination.

The value of the infrastructure in Pointe-à-Pierre was estimated by taking the value of the value of the refinery and marketing assets, declared in the financial statement of the company in 2012 and dividing this number by the number of acres in Pointe-à-Pierre. This calculation was performed given that Pointe-à-Pierre is the only refinery in the company, and therefore the assets declared by the company in the area of refinery and marketing should be close to the value of this land for the company. It should be mentioned however, that since the portion of "marketing" assets is unknown, this value has not been taken out of the asset value used in this calculation and therefore the estimation could be slightly over estimated.

Technological capacity

This technology has already been implemented in several industrial sites. There are many previous experiences from which information on the best practices to implement it could be obtained.

Social capacity

There are no relevant social implications due to the characteristics of this action, considering that it is going to be implemented on private land owned by Petrotrin. In general, it would be beneficial for given that it would make a better use of water, which is a very valuable resource. Additionally, it would reduce flooding risks.

Institutional capacity

In terms of an institutional framework, Trinidad and Tobago has a National Integrated Water Resources Management Policy, which establishes the principles of water management in the country. However, it does not include particular actions in terms of the management of water supply in the country.

Legal capacity

When it comes to water management in Trinidad and Tobago, the major legislative instruments are the Water and Sewerage Act (1980 Revised); the Waterworks and Water Conservation Act (1980 Revised); the Environmental Management Act (2000 Revised); and the Public Health Act (1950). There is however a need for a new legislative framework to create a new paradigm of integrated water resource management.

Cost-benefit ratio	2.0	-	Total cost	269,900	$
Pay-back	9.3	Year(s)	Total benefit	537,769	$

8.2.10. PAP 3: Sustainable Drainage Systems in Pointe-à-Pierre

Objective

To build sustainable drainage systems (SUDS) in order to reduce the risk of floods due to excess of rainfall and storm surge in the Petrotrin owned area in Pointe-à-Pierre.

Previous experiences and success cases

According to information from the Purdue University Engineering Department on sand filters, the benefits of sand filters include the fact that they "cost less to construct in rural areas than centralized treatment systems; they are energy-efficient; they have relatively low maintenance requirements but should be serviced by trained technicians; they can provide high quality effluent; [they] may enable development in difficult sites; they can remedy an existing malfunctioning system; and [they] can be a good option for homes in environmentally sensitive areas".

Also, the report titled "Costs and Benefits of Sustainable Drainage Systems" done by the Committee on Climate Change and Royal Haskoning, concluded that "SUDS have the potential to contribute to the reduction or prevention of surface water flood risk in a variety of situations, and in many cases will be cost-effective".

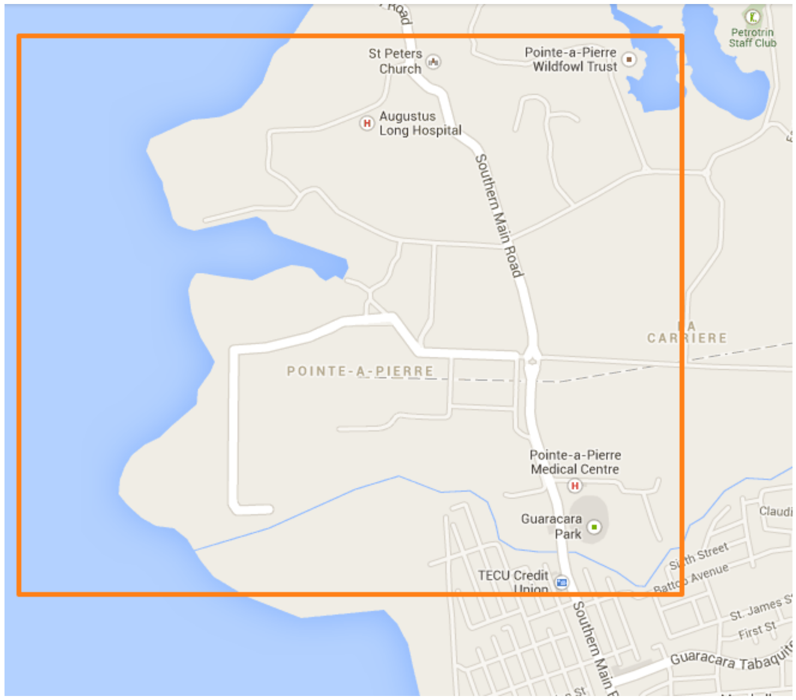
Lastly, according to a study done in Lamb Drove specifically designed to understand the benefits of SUDS measures, the program has reported significant benefits. In the study, the specific SUDS implemented included water butts, permeable paving, a green roof, swales, filter strips, detention and wetland basins and a retention pond. Although not all of these SUDS are presented in this measure. The general conclusions and benefits can be considered relevant to this measure, given that this measure also looks at context specific SUDS mechanisms for Petrotrin, and the study shares a mechanism with this measure, namely Swales. Also, PAP 2 looks at installing two retention ponds, which is also part of the study. The report states that "overall both the capital and the maintenance costs associated with Lamb Drove are lower when compared to costs associated with conventional pipe drainage systems". Additionally, in terms of surface water flows, Lamb Drove showed significantly reduced peak flows when compared to the control site in the study. The estimated cost savings due to SUDS was approximately £11,000, which was estimated at about 10% saving compared to the control site.

Preliminary Considerations

For the proper function of the drainage system, a technical assessment of the characteristics of the area and a map of the water cycle are needed in order to establish the most suitable locations for the systems and to define their capacities in detail.

Description of the action

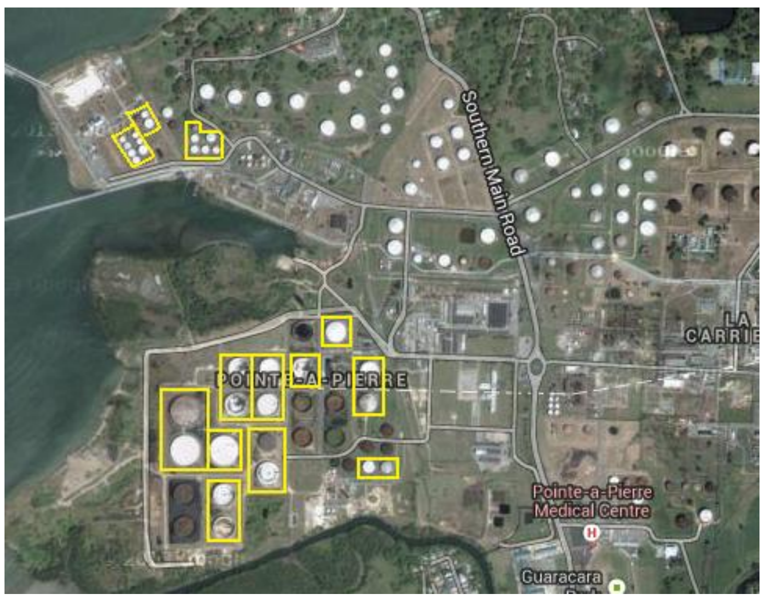
The action includes covering the perimeter of the tank area in yellow with sand filters (building 1,167.9 m^2); building 4 sand filters of 3 m^3 in strategically placed in the yellow area, likely on the southern end, near the riverbank; and building 8 swales (10m x 1m=10m2 each one) in the yellow tank area. It is also highly recommended to purchase an oil separator (6" diameter oil/water separator tanks with 4.000 gallons capacity) and combine it with the sand filter system in order to treat the surface water runoff of the refinery area. In the blue area, three additional swales will be constructed in strategic areas to improve drainage near the refinery.



Source: Google Maps, the orange box is representative of the following image, its scale is approximate

Berms will also be constructed around the tanks in order to prevent flooding. These berms will be constructed over a 6 year period.

Source: Google Maps, the orange box is representative of the following image, its scale is approximate



Implementation period

2014-2030

Impact of the action

This group of drainage systems would help reduce the risk of floods caused by heavy rainfall and storm surge. Additionally, these drainage systems also would help remove pollutants coming from rainfall and found in the air. Therefore these systems contribute to a cleaner environment. Additionally, if the water is not collected and subsequently discharged in the sea, the sea water will also have a lower pollutant concentration.

As shown in the previous experiences, sustainable drainage systems can be very effective in reducing surface water flood risk, making them cost-effective in many cases. Furthermore, the impact of this action can be better understood if it is considered as a whole with PAP 1 and PAP 2, because the actions form a system that enhances the safety of Petrotrin's Pointe-à-Pierre area regarding flood risk. The dikes are helpful in storm surge and sea level rise and the ponds and SUDS are useful for these purposes and at reducing superficial water flooding when intense rainfall occurs.

Economic capacity

Even if this system requires investment in both construction and maintenance of the SUDS, the previous experiences show that those systems are many times cost-effective in terms of reducing or preventing surface water flood risks. Particularly, this conclusion was reached in the Lamb Drove study as well as in the study done by the Committee of Climate Change and Royal Haskoning.

The value of the infrastructure in Pointe-à-Pierre was estimated by taking the value of the value of the refinery and marketing assets, declared in the financial statement of the company in 2012 and dividing this number by the number of acres in Pointe-à-Pierre. This calculation was performed given that Pointe-à-Pierre is the only refinery in the company, and therefore the assets declared by the company in the area of refinery and marketing should be close to the value of this land for the company. It should be mentioned however, that since the portion of "marketing" assets is unknown, this value has not been taken out of the asset value used in this calculation and therefore the estimation could be slightly over estimated.

Technological capacity

This technology is used in other countries, as detailed in the previous cases. In fact, it is widely used in areas where conventional drainage solutions are not the best option. Therefore, when implementing this technology in Pointe-à-Pierre, information and knowledge could be obtained from previous success cases in other countries.

Social capacity

There are no relevant social implications due to the characteristics of this action, considering that it is going to be implemented on private land owned by Petrotrin. In general, it would be beneficial for society because it would reduce the risk of flooding.

Institutional capacity

In terms of an institutional framework, Trinidad and Tobago has a National Integrated Water Resources Management Policy, which establishes the principles of water management in the country. However, it does not include particular actions in terms of the management of water supply in the country.

Legal capacity

When it comes to water management in Trinidad and Tobago, the major legislative instruments are the Water and Sewerage Act (1980 Revised); the Waterworks and Water Conservation Act (1980 Revised); the Environmental Management Act (2000 Revised); and the Public Health Act (1950). There is however a need for a new legislative framework to create a new paradigm of integrated water resource management.

Cost-benefit ratio	**10.0**	**-**	**Total cost**	**644,715**	**$**
Pay-back	**15.6**	**Year(s)**	**Total benefit**	**669,062**	**$**

8.2.11. *PAP 4: Mangrove Restoration in Pointe-à-Pierre*

Objective

Planting and maintaining mangrove forests that are able to attenuate wind and swell waves in order to protect the Pointe-à-Pierre installations.

Previous experiences and success cases

Mangroves provide significant benefits to society including increased biodiversity, coastal protection from cyclones, and increased uptake of carbon, amongst others. In a report by Prof. K. Kathiresan titled, "3.5.

Importance of Mangrove Ecosystem", Kathiresan summarized the benefits reported by several different studies and projects worldwide. The report notes the significant benefits that have been found due to mangrove restoration including increased supply of forestry products (firewood, charcoal, timber, honey etc.) and fishery products (fish, prawn, crab, mollusk etc.). Mangroves also provide seeds for aquaculture industries. The report cites an example in which "40,000 fishers get an annual yield of about 540 million seeds of Penaeus monodon for aquaculture, in the Sundarban mangroves of West Bengal".

Ecological services that have been found in mangrove projects have included "solar UV-B radiation, 'green house' effects, and fury of cyclones, floods, sea level rise, wave action and coastal erosion". As an example of carbon sequestration the report cites the Rhizophora forest, which is a 20-year old plantation of mangroves that stores 11.6 kg m-2 of carbon with C burial rate of 580 g m^{-2} yr^{-1}.

Mangroves have also proven to help with the trapping of sediments. A previous study done by the author is cited in the report in which it was estimated that "mangroves help in trapping the sediment up to 25 % at low tide as compared to high tide".

It is also important to note the significant coastal protection benefits offered by mangroves. In the report by Prof. K. Kathiresan, it states an example in which "the super-cyclone ... on the 29th October 1999 with a wind speed of 310 km hr^{-1} along the Orissa coast (India) and played havoc largely in the areas devoid of mangroves. On the contrary, practically no damage occurred in regions with luxuriant mangrove growth. Similarly, in the Mahanadi delta, where large scale deforestation and reclamation of mangrove land for other purposes have been undertaken, maximum losses of life and property have been reported from time to time during stormy weather".

Mangroves also help reduce coastal flooding and prevent coastal erosion. The higher the density of vegetation and the depth of the water, the higher the reduction of waves. The report by Kathiresan cites on example from Vietnam, in which "in the tall mangrove forests, the rate of wave reduction per 100 m is as large as 20%". Kathiresan also cites work that proves that mangroves act as "live sea walls" which have proven to be more economically beneficial than artificial concrete sea walls for coastal protection, in some cases.

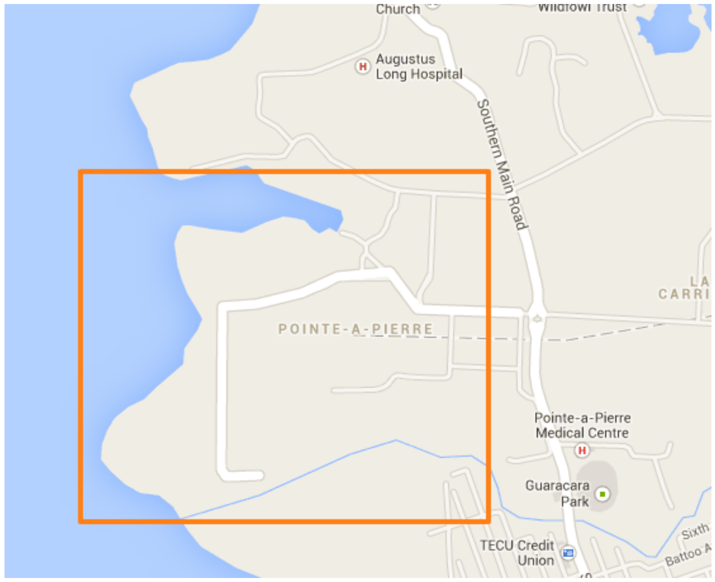
Preliminary Considerations

For the mangrove restoration to work, it is necessary to ensure that there is no water pollution and that the ecosystem is able to restore itself. Therefore, the selected areas need to be analysed first in order to find out whether the restoration is viable or not.

Description of the action

The action implies the regeneration a mangrove area totalling 1.499 sq km.

The technique proposed this is hydrologic restoration, rather than planting. Hydrologic Restoration consists of connecting impounded mangroves to normal tidal influence, that is, instead of planting mangroves, the efforts would be focusing on restoring the previous state of the coastal areas, restoring the tidal schemes previous to the human influence. That way, if the environmental conditions are adequate, mangroves are restored without the need of planting, but rather just by the natural diffusion process which takes place due to the coastal tides. The development of the action would focus at first on achieving natural restoration. If this is not possible, mangroves would be planted. In the case that planting needs to occur, additional costs may have to be assumed, which are not considered in the economic analysis of this measure.



Source: Google Maps, the orange box is representative of the following image, its scale is approximate

Implementation period

2014-2023

Impact of the action

Mangroves enhance the sustainability of the area by protecting the coast from solar UV-B radiation, 'green house' effects, and the fury of cyclones, floods, sea level rise, wave action and coastal erosion. Mangrove swamps act as traps for sediments, and sinks for nutrients. The root systems of the plants keep the substrate firm, and thus contribute to a lasting stability of the coast.

As shown in the success cases section, mangrove restoration is a beneficial action in economic terms and provides many advantages for the environment, not only those derived from the prevention of the damage caused by the climate change hazards, but also options for the development of the local communities in terms of firewood, charcoal or timber procurement, improvement of fisheries, and so on.

Economic capacity

The implementation of this action in other countries shows that its benefits are much higher than the costs of mangrove restoration. The investment is low for this action because the mangrove restoration is selected instead of mangrove planting. This option should only be considered when the restoration is not viable; however, it is not very recommendable due to the difficulty to obtain good growth rates and its higher cost.

Technological capacity

In Trinidad and Tobago, particularly in Petrotrin, efforts regarding the restoration of the mangroves are already being carried out. Therefore, it is not an unknown matter in the country. Additionally, the lessons learnt from the mangrove restoration projects carried out in other countries should be analysed and adapted to the characteristics of the selected coastal areas.

The success of this action depends on the capacity to carry out the hydrologic restoration technique. Therefore, if in a first assessment it is found that the conditions for the hydrologic restoration are not met, the use of other techniques should be analysed.

Social capacity

The restoration of the mangroves does not have any harmful effects in social terms; on the contrary, it can provide several benefits to the communities, because it would make the agricultural area more resilient to floods. For this reason, people who own these lands could be interested in cooperating in the restoration process. This activity would also improve the fishery and wood resources of the area and improve biodiversity, positively affecting the surrounding areas.

Institutional capacity

Institutional capacity is required in order to promote the development of the action within a national strategy on coastal areas protection. There is already a National Action Programme to Combat Land Degradation in Trinidad and Tobago 2006-2020, which should be considered. The action programme is defined in broad terms and it would be necessary to establish the adequacy of this action within the objectives set in the programme. In fact, in the programme, the need of a Coastal Zone Development Plan is stated, and it would be necessary to define that plan before this action can be carried out.

In a similar way, the National Biodiversity Strategy and Action Plan focuses on the conservation and sustainable use of the country's biodiversity, but it does not include a particular mention of the management of the country's mangroves.

There is also a National Policy and Programmes on Wetland Conservation in Trinidad and Tobago, which includes the management of some of the mangroves of the countries. It includes among its objectives the restoration of damaged but important wetlands, but no additional information on how the objective will be achieved is included.

Legal capacity

The legal framework for the protection of the coastal areas and wetlands of Trinidad and Tobago is poorly defined at the moment. Thus, it would be necessary to develop, as stated before, a Coastal Zone Development Plan, with well defined actions, which should need to be implemented. If necessary, the development of a strict legal framework may be needed in order to ensure that the objectives are fulfilled.

Mangrove Restoration in Tobago is slightly complicated in terms of legal capacity given that existing land use management policy dictates that "the local government such as the County Council has responsibilities up to the high water mark while land administration, rather than land management, is undertaken from the high water mark seawards to the extent of the EEZ by the Commissioner of State Lands under the Ministry of Planning and Development. Further, if beach facilities are constructed they are the responsibility of the Tourist Board under the Ministry of Enterprise Development, Foreign Affairs and Tourism; the construction and maintenance of coastal protection structures fall under the jurisdiction of the Ministry of Works and Transport; construction of fish landing facilities is the responsibility of the Fisheries Division of the Ministry of Agriculture Land and Marine Resources, and if the beach is fringed by mangroves or a site for turtle nesting the area is the responsibility of the Forestry Division in the Ministry of Public Utilities and the Environment. Additional jurisdictions involved may be the Ministry of Energy with regards to exploited petroleum and gas reserves" (Soomai, S., 2005). This interlinkage of authoritative figures will need to be looked into in order to determine the frameworks under which the measure falls.

Cost-benefit ratio	**10.7**	**-**	**Total cost**	**8,708**	**$**
Pay-back	**7.8**	**Year(s)**	**Total benefit**	**93,384**	**$**

8.2.12. *PAP 5: Relocation of Infrastructure in Pointe-à-Pierre*

Objective

To relocate specific infrastructure due to the risk of inundation in the future.

Previous experiences and success cases

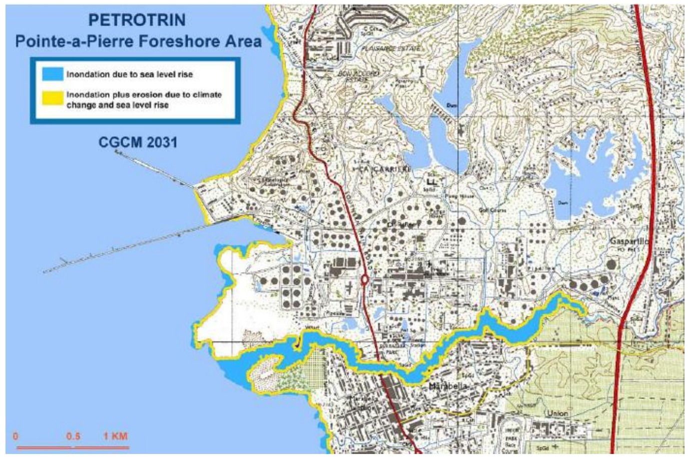
The relocation of vulnerable infrastructure is a widely accepted and mentioned adaptation option (IPCC TAR WG2, 2001, IPCC AR4 WG2, 2007). In a document analyzing the Economics of Adaptation to Climate change in Samoa by the World Bank (2010), they state that "large investments in relocating coastal infrastructure should only be implemented if and when the reduction in the expected value of storm damage exceeds the annualized costs". According to the US EPA (2013), Entergy Corporation, an energy company with business in the Gulf Coast, has been doing just that. They have been working on a climate risk assessment in order to understand the potential costs of continuing to operate business-as-usual in the Gulf Coast. After Hurricane Katrina, the company partnered with America's Wetlands Foundation and commissioned a study titled "Building a Resilient Energy Gulf Coast" in order to assess the impacts of climate change on the area. From their analysis, the company made strategic decisions to relocate "important business centres inland to areas less likely to be affected by future storms". Other infrastructure has been armoured to increase resistance to storms.

Preliminary Considerations

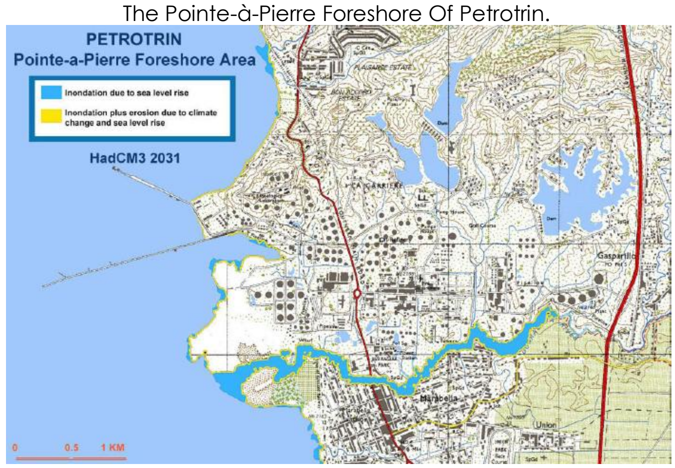
Before implementing this measure, Petrotrin will need to decide on a new location for the infrastructure being relocated. The company should look strategically at all the possible options in terms of infrastructure relocation, construction, and elevation and decide what is best for the company's future plans. The study done on vulnerability, land inundation and erosion that has been done for Pointe-à-Pierre, and other areas owned by the company, should be taken into consideration when making these decisions.

Description of the action

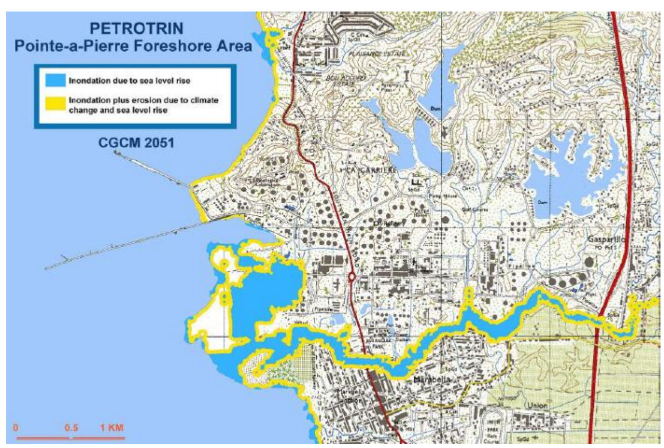
This action looks to relocate the tanks and their related infrastructure in the zone marked in blue in the map below. This infrastructure has been marked eligible for relocation due to the preliminary vulnerability studies done for Pointe-à-Pierre (Singh. B. and A. El Fouladi, 2006). In this study, portions of Pointe-à-Pierre are at risk of be inundated by 2051, whereas other portions will still be intact. As shown in the images below from the study, the southern portion of Pointe-à-Pierre is much more vulnerable than the northern portion.



Projected Topographic Map-Cgcm1_2031 Showing
Sea Level Rise Intrusions Due To Inundation And Erosion For
The Pointe-à-Pierre Foreshore Of Petrotrin.

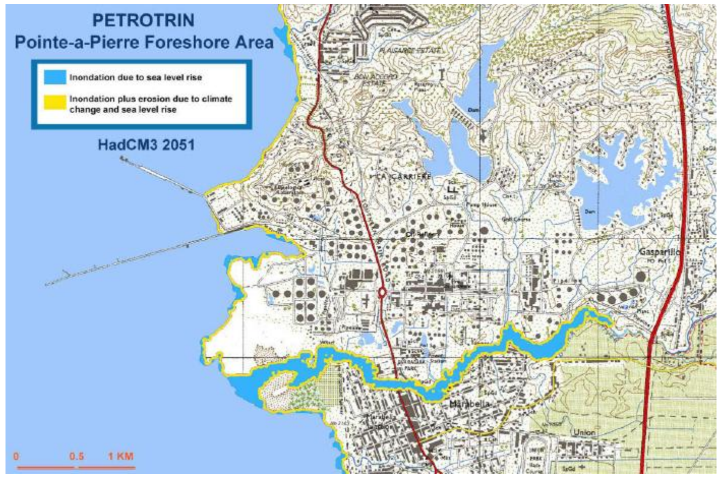


Projected Topographic Map-Hadcm3_2031 Showing
Sea Level Rise Intrusions Due To Inundation And Erosion For
The Pointe-à-Pierre Foreshore Area Of Petrotrin.

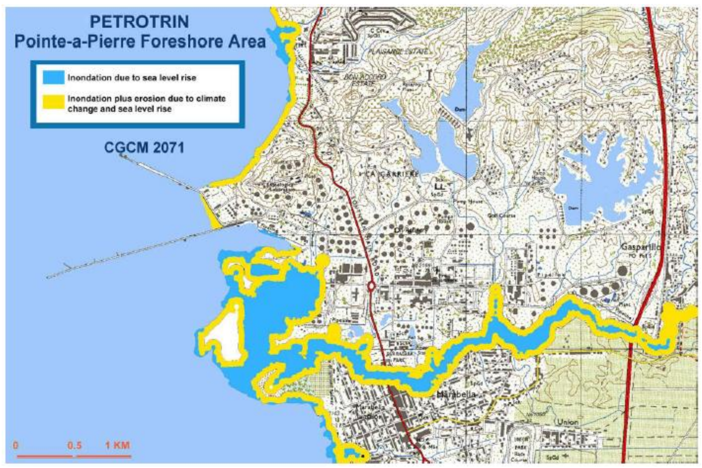


Projected Topographic Map-Cgcm1_2051 Showing Sea Level Rise Intrusions Due To Inundation And Erosion For The Pointe-à-Pierre Foreshore Of Petrotrin.

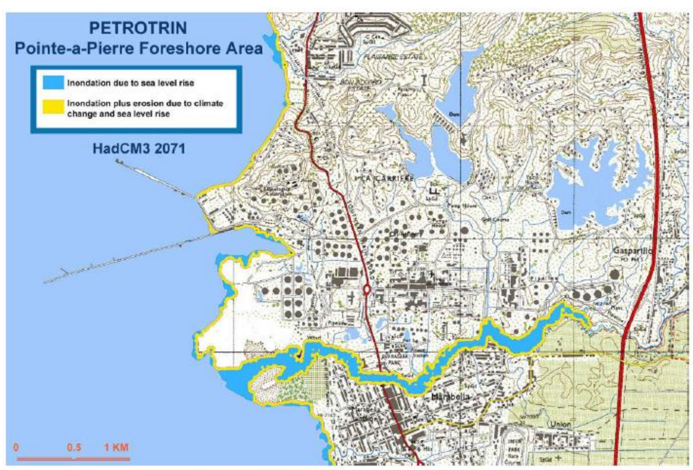
Therefore, those areas that are expected to be completely inundated have been chosen for possible relocation.



Projected Topographic Map-Hadcm3_2051 Showing
Sea Level Rise Intrusions Due To Inundation And Erosion For
The Pointe-à-Pierre Foreshore Area Of Petrotrin.

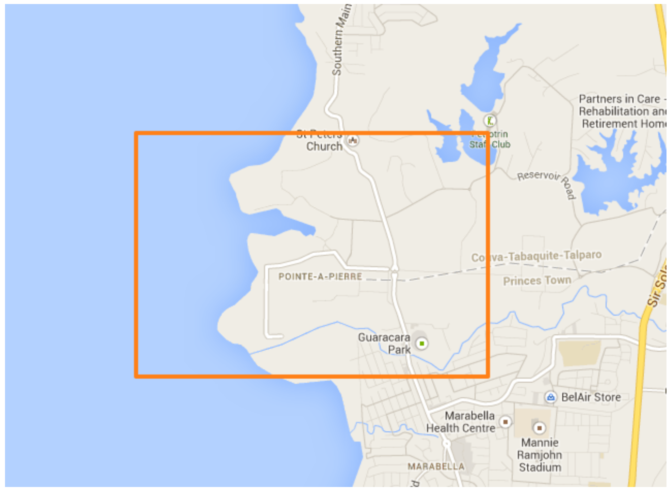


Projected Topographic Map-Cgcm1_2071 Showing Sea Level Rise Intrusions Due To Inundation And Erosion For The Pointe-à-Pierre Foreshore Of Petrotrin.



Projected Topographic Map-Hadcm3_2071 Showing
Sea Level Rise Intrusions Due To Inundation And Erosion For
The Pointe-à-Pierre Foreshore Area Of Petrotrin.

Therefore, those areas that are expected to be completely inundated have been chosen for possible relocation.



Source: Google Maps, the orange box is representative of the following image, its scale is approximate

Relocation of this infrastructure includes strategic planning of where the infrastructure will be moved to, acquisition of the land (if necessary), zoning and permit requests (if necessary), engineering design and construction. In addition, this action includes the removal of now obsolete infrastructure in Pointe-à-Pierre and of any hazardous materials, which could pose environmental problems in the event of storm surge and flooding in the future.

Implementation period

2014-2030

Impact of the action

According to the vulnerability assessments done for the area (Singh. B. and A. El Fouladi, 2006), this area will likely experience severe problems of flooding and erosion by 2051. It is therefore recommended that Petrotrin begin to consider relocating this infrastructure to another location. This will help reduce the risks of infrastructure being damaged, and hence causing possible environmental problems. These problems not only would impact the surrounding habitats and ecosystems, but could also cause severe reputational problems for Petrotrin.

Economic capacity

While this measure will incur substantial costs, given the high risk of inundation in the future, it is recommended that this infrastructure be removed from its current location and relocated to an area with less risk of inundation and erosion. Specifically, given the importance of the operations at Pointe-à-Pierre - since it is the only refinery on Trinidad and Tobago (Pertrotrin, 2013) - this measure could help protect important assets if done early.

In this measure, the economic costs have been estimated; however, several expected costs have not been included in the estimation due to lack of information. Firstly, given the lack of information regarding the physical infrastructure in the area and is use, an estimation of the number of tanks in use was taken from maps available. The volume of these tanks was estimated by calculating the base area of these tanks, and assuming their height was 17 meters, as the height of the tanks could not be extracted from the maps. The cost of building new tanks with the same total volume was estimated. Additionally, the potential costs of land purchase for relocation, in the event that the company does not already own land on which this infrastructure can be moved to, has not been included in the cost estimation. The costs of removing the current infrastructure have also not been calculated due to the lack of information regarding the physical infrastructure and the status of the soil in this area.

Given the lack of specific information regarding infrastructure in the vulnerable area, about the infrastructures' current value (estimated useful life remaining of the assets) and about its current and future expected uses, it should be considered that this is a rough estimate could be improved if specific details were made available.

Technological capacity

This technology required for this measure is general construction, given that tanks will be dismantled in one area in constructed in another. Therefore, this measure does not require any technological capacity that is not available in Trinidad and Tobago, nor available to Petrotrin.

Social capacity

In terms of social concern for this action, if the new area decided on for the new infrastructure included the displacement of local communities or severe environmental risks, this could provoke social discontent with the project. There are times when local communities protest the construction of this type of infrastructure near their communities. Stakeholder meetings and engagement in order to ensure that the local community is part of the action and understand the impacts that it may have on their community are recommended. If the existing tanks and infrastructure is properly dismantled, this could help improve any negative opinions from the community.

Institutional capacity

Since this project would be carried out by Petrotrin, the institutional capacity would not affect the implementation of the measure.

Legal capacity

When considering the development of the action, in the planning and construction phases, the effects of the action should be considered regarding the legal framework established by the following laws: the Environmental Management Act; the Certificate of Environmental Clearance Rules; the Town and Country Planning Act; and the Public Health Ordinance and the Marine Areas (Preservation and Enhancement) Act. This action implies the construction of infrastructure, which may have negative effects on the environment and, therefore, the laws of Trinidad and Tobago need to be respected when designing and developing the action.

Cost-benefit ratio	**8.3**	**-**	**Total cost**	**6,260,578**	**$**
Pay-back	**0**	**Year(s)**	**Total benefit**	**52,076,889**	**$**

8.2.13. PAP 6: Infrastructure Elevation in Pointe-à-Pierre

Objective

To elevate a portion of the tanks and related infrastructure at Pointe-à-Pierre, making it less susceptible to significant inundation in the long term.

Previous experiences and success cases

There is significant discussion around the need to adapt infrastructure, specifically in the oil industry, to the expected effects of climate change in the future. The IPCC Working Group II: Impacts, Adaptation and Vulnerability, of the Third Assessment Report (IPCC TAR WG2, 2001), it states that "port facilities are another type of infrastructure that will be affected by climate change and sea-level rise. Higher sea level probably will decrease the effectiveness of breakwaters against wave forces, and wharves may have to be raised to avoid inundation. When such effects are anticipated, countermeasures can be implemented to maintain function and stability. Therefore, the real impacts will occur as an additional expenditure to reinforce the infrastructure. The total expenditure to keep the present level of functions and stability for about 1,000 Japanese ports is estimated to be US$110 billion for a 1-m sea-level rise..." They cite a study done by Maria de Lourdes Olivo (1997), which estimated the potential economic impacts of a sea-level rise of 0.5 m on the coast of Venezuela. In this study, Olivo estimates the costs of raising infrastructure in the areas of Costa oriental del Lago de Maracaibo (6,589 million USD), Costa Oriental de Falcón (897 million USD), Cabo Codera-Parque Nacional Laguna de Tacarigua (2,986 million USD), Barcelona-Puerto La Cruz-Guanta (4,206 million USD), and Juan Griego en La Isla de Margarita (2,98.5 million USD).

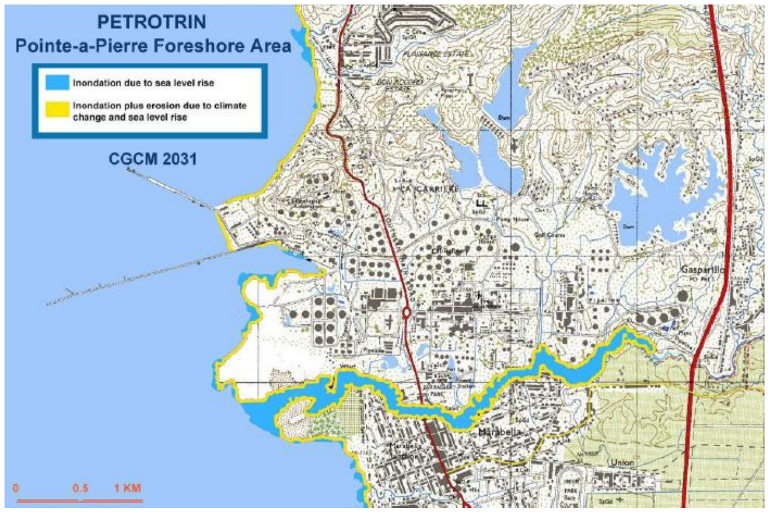
In a report done for the City of Cape Town Environmental Resource Department (LaquaR Consultants CC, 2008), raising infrastructure was one of the adaptation measure considered for the city. The report states that "Cape Town docks, for example, would prove difficult to relocate, but could be raised or dredged in order to protect against sea-surges and inundation. Similarly raising the level of roads at Paardon Eiland could reduce the chance of these roads being over-topped by the sea. Problems with raising infrastructure, apart from the cost, include knowing exactly how high the infrastructure needs to be in order to be considered safe (or deciding what is considered safe enough), and the required adjustments to adjacent infrastructure".

Preliminary Considerations

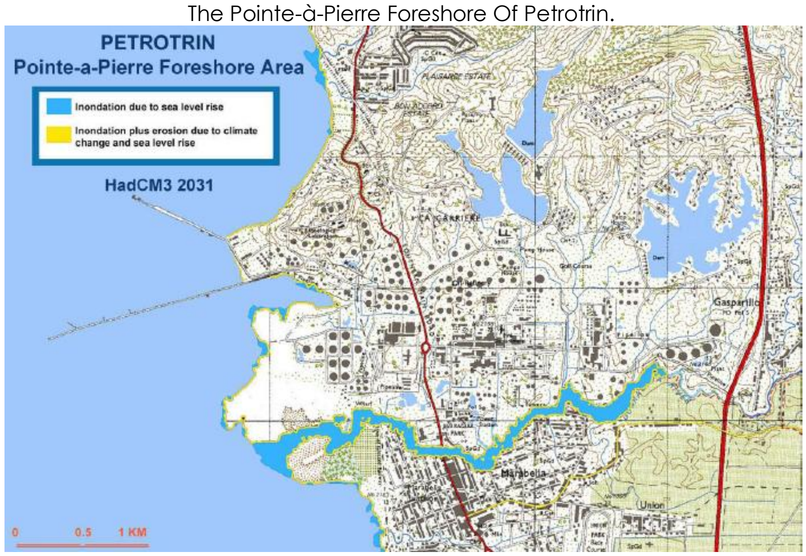
Before considering elevation of the infrastructure, the company should look strategically at all the possible options in terms of infrastructure relocation, construction, and elevation and decide what is best for the company's future plans. The studies done on vulnerability, land inundation and erosion that have been done for Pointe-à-Pierre, and other areas owned by the company, should be taken into consideration when making these decisions.

Description of the action

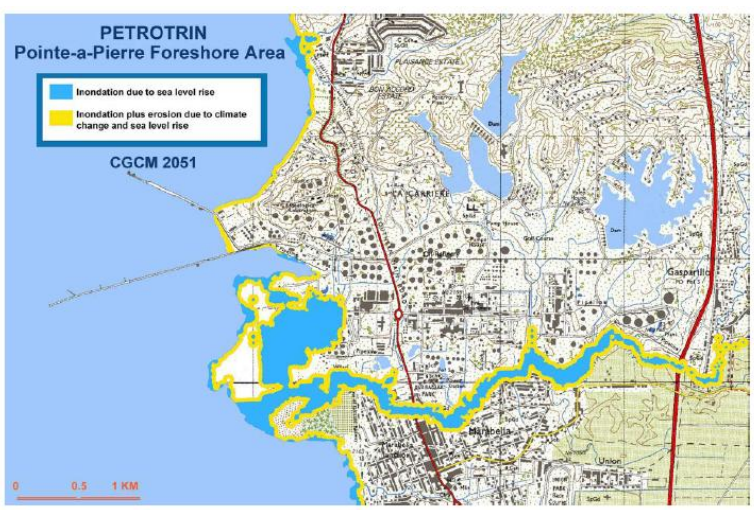
This action looks to elevate the tanks and their related infrastructure in the zone marked in blue in the map below. This infrastructure has been marked eligible for elevation due to the preliminary vulnerability studies done for Pointe-à-Pierre (Singh. B. and A. El Fouladi, 2006). In this study, portions of Pointe-à-Pierre are at risk of be inundated by 2051, whereas other portions will still be intact. By 2071, according to one of the simulations conducted (CGCM) it is highly likely that portions of Pointe-à-Pierre are inundated. As shown in the images below from the study, the southern portion of Pointe-à-Pierre is much more vulnerable than the northern portion.



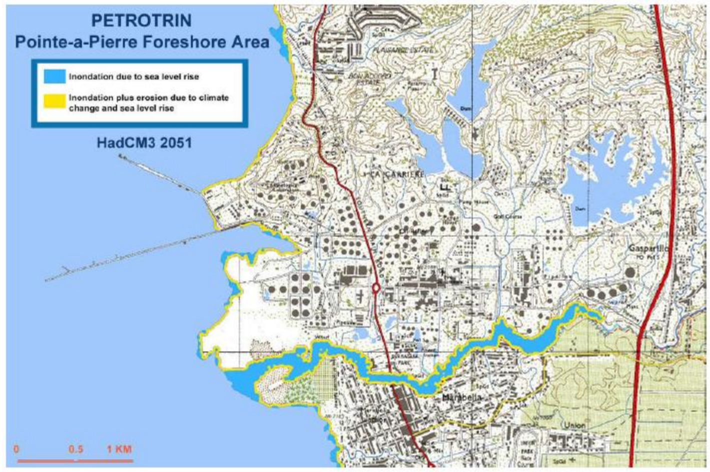
Projected Topographic Map-Cgcm1_2031 Showing
Sea Level Rise Intrusions Due To Inundation And Erosion For
The Pointe-à-Pierre Foreshore Of Petrotrin.



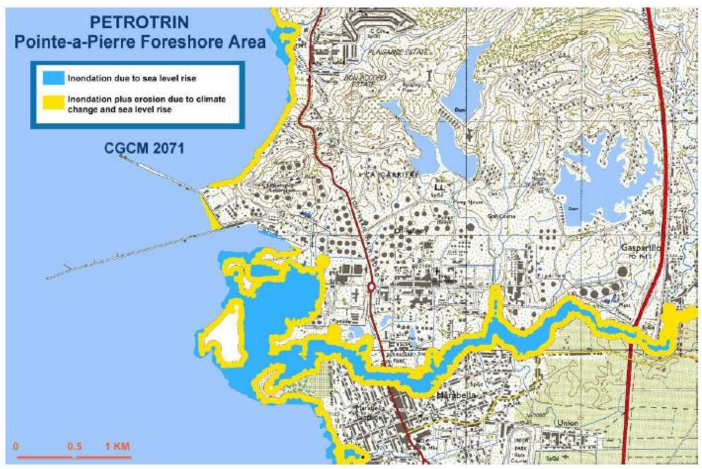
Projected Topographic Map-Hadcm3_2031 Showing
Sea Level Rise Intrusions Due To Inundation And Erosion For
The Pointe-à-Pierre Foreshore Area Of Petrotrin.



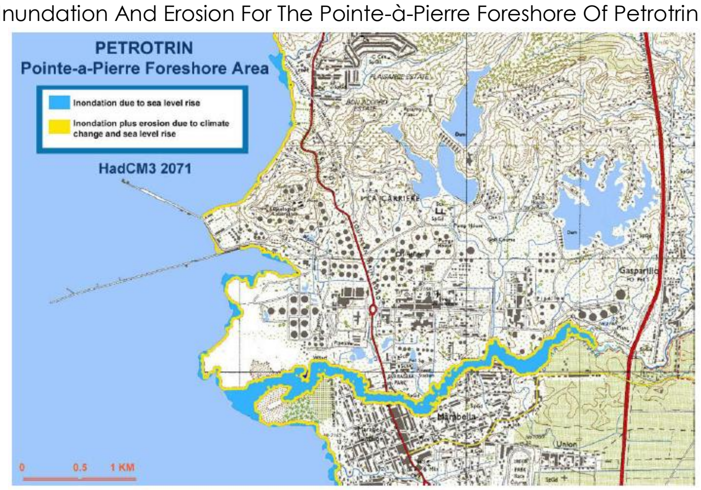
Projected Topographic Map-Cgcm1_2051 Showing Sea Level Rise Intrusions Due To Inundation And Erosion For The Pointe-à-Pierre Foreshore Of Petrotrin.



Projected Topographic Map-Hadcm3_2051 Showing
Sea Level Rise Intrusions Due To Inundation And Erosion For
The Pointe-à-Pierre Foreshore Area Of Petrotrin.

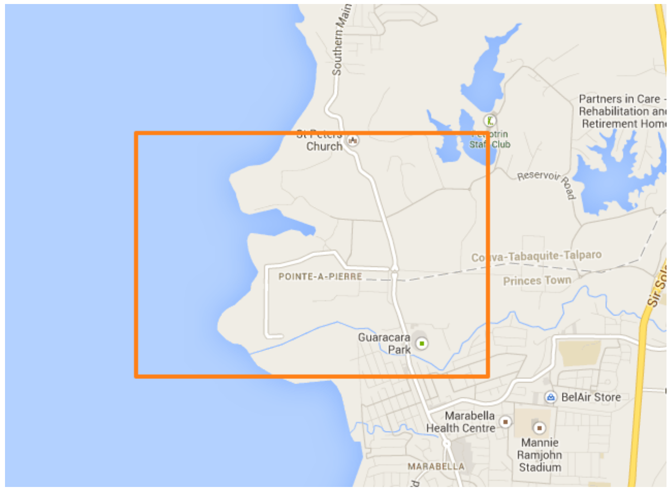


Projected Topographic Map-Cgcm1_2071 Showing Sea Level Rise Intrusions Due To Inundation And Erosion For The Pointe-à-Pierre Foreshore Of Petrotrin.

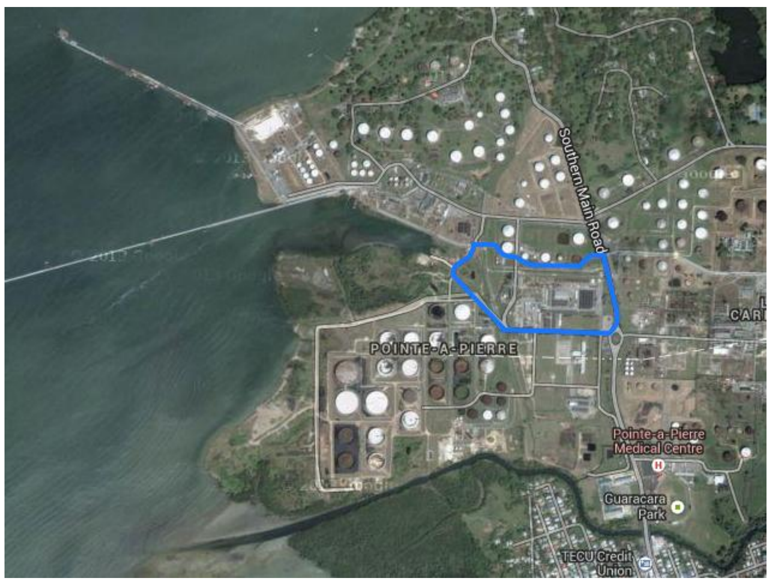


Projected Topographic Map-Hadcm3_2071 Showing
Sea Level Rise Intrusions Due To Inundation And Erosion For
The Pointe-à-Pierre Foreshore Area Of Petrotrin.

As can be seen in these images, the refinery located in the blue area shown in the map below, is close to the edge of inundated area in the CGCM simulations done above. Although projections even further into the long term were not conducted, this refinery is likely to be vulnerable to at least partial flooding and inundation, and therefore should be considered for elevation in the short term in order to complete this process before flooding occurs.



Source: Google Maps, the orange box is representative of the following image, its scale is approximate



This action involves elevating all of the infrastructure related with the refinery shown in the blue region above. This process would occur over the long term, as portions of the refinery need to be replaced or repaired.

Implementation period

2014-2030

Impact of the action

As stated in the Vulnerability Assessment carried out for the West Coast area for Petrotrin in the area, Pointe-à-Pierre will be very susceptible to climate-driven sea level rise and storm surges. Higher sea levels and storm surges will most likely decrease the effectiveness of breakwaters against wave forces and wharves.

According to the assessment, the area designated in this measure will not be inundated in 2071, and therefore will still be able to be used for industrial purposes. However, it is very close to the inundated area, and therefore is at risk for possible inundation further out into the future. Given that this refinery is highly valuable to Petrotrin, it recommended that this infrastructure be elevated in order to ensure that it is protected from flooding. Benefits from this measure would be preserving the infrastructure and land for valuable industrial purposes in the very long term.

Economic capacity

In this measure, the economic costs and benefits have not been estimated given the lack of specific information regarding infrastructure in the vulnerable area, about the infrastructures' current value (estimated useful life remaining of the assets) and about its current and future expected uses. Without specific information, it is hard to estimate the costs of the elevation of this infrastructure.

Technological capacity

This would likely be one of the first attempts to elevate this type of infrastructure in Trinidad and Tobago, given that this type of adaptation measure is relatively new. However, it is not a type of construction in which qualified engineers are able to design. It would be recommended to look for similar projects in other countries, in order to determine best practices, or possible lessons that could be transferred to this project.

Social capacity

This action does not imply any social concerns. In fact, measures undertaken in order to reduce the environmental risks of the oil industry are generally welcomed by the general public.

Institutional capacity

Since this project would be carried out by Petrotrin, the institutional capacity would not affect the implementation of the measure.

Legal capacity

Additionally, when considering the development of the action, in the planning and construction phases, the effects of the action should be considered regarding the legal framework established by the following laws: the Environmental Management Act; the Certificate of Environmental Clearance Rules; the Town and Country Planning Act; and the Public Health Ordinance and the Marine Areas (Preservation and Enhancement) Act. This action implies the construction of infrastructure, which may have negative effects on the environment and, therefore, the laws of Trinidad and Tobago need to be respected when designing and developing the action.

Cost-benefit ratio	**N/A**	**-**	**Total cost**	**N/A**	**$**
Pay-back	**N/A**	**Year(s)**	**Total benefit**	**N/A**	**$**

8.3. Analysis of the Results

The following table explains the Total Costs (not discounted), Total Benefits (not discounted), Net Present Value, the Payback period, and the Benefit-Cost Ratio for each adaptation measure defined within this pilot project:

Table 69: Results of the Cost-Benefit Analysis of the pilot project actions.
Source: Prepared by the authors.

Action code	Title	Total cost	Total benefit	Net present value	Pay back (years)	Benefit/Cost Ratio
PT 1	Climate Change Adaptation Tool	$117,500	N/A	N/A	N/A	N/A
PF 1	Coastal Zone and Guaracara River Protection	$7,267,721	$370,635	-$3,927,621	∞	0.1
PF 2	Retention Ponds in Point Fortin	$269,900	$145,574	-$173,446	24	0.5
PF 3	Construction of Swales and Berms in Point Fortin	$126,194	$134,871	-$52,703	15.4	1.1
PF 4	Mangrove Protection in Point Fortin	$6,750	$72,391	$26,285	7.8	10.7
PF 5	Relocation of Infrastructure in Point Fortin	$2,317,739	$20,375,901	$9,987,274	0	8.8
PF 6	Infrastructure Elevation in Point Fortin	N/A	N/A	N/A	N/A	N/A
PAP 1	Dike Construction in Pointe-à-Pierre	$4,961,914	$1,869,243	-$2,011,884	27.8	0.38
PAP 2	Construction of Retention Ponds at Pointe-à-Pierre	$269,900	$537,769	$37,866	9.3	2.0
PAP 3	Sustainable Drainage Systems in Pointe-à-Pierre	$644,715	$669,062	-$223,766	15.6	1.04
PAP 4	Mangrove Restoration in Pointe-à-Pierre	$8,708	$93,384	$33,907	7.8	10.7
PAP 5	Relocation of Infrastructure in Pointe-à-Pierre	$6,260,578	$52,076,889	$24,548,353	0	8.3
PAP 6	Infrastructure Elevation in Pointe-à-Pierre	N/A	N/A	N/A	N/A	N/A

Relocation of infrastructure in both Point Fortin and Pointe-à-Pierre both have significantly high positive Net Present Values, given the fact that the infrastructure built will provide the company benefits during their entire use life and remove the risks of inundation. For the actions restoring mangroves in both Point Fortin (PF 4) and Pointe-à-Pierre (PAP 4), the costs of the action are much lower than the potential benefits. The actions related to improving drainage in both Point Fortin (PF 2 and PF 3) and Pointe-à-Pierre (PAP 2 and 3) have Payback Periods of less than three years, making these measures interesting for consideration in terms of reducing the risk of inundation in both locations. Lastly, the measure related to building dikes in Point Fortin (PF 1) has rather high costs relative to its benefits. This is partly due to the fact that the benefits due to Petrotrin's use of the port area and terminalling stations were not able to be included in the study due to lack of specific information regarding the use of this port by the company. It should be mentioned that Point Fortin is considered and an important terminalling station for the company, and therefore if this benefit were able to be included, this measure's results would likely improve.

The table below shows the measures' total costs and total benefits as a percentage of the company's net Profit in 2012:

Table 70: Total Cost and Total Benefits of each measure as a percentage of Petrotrin's Net Profit in 2012

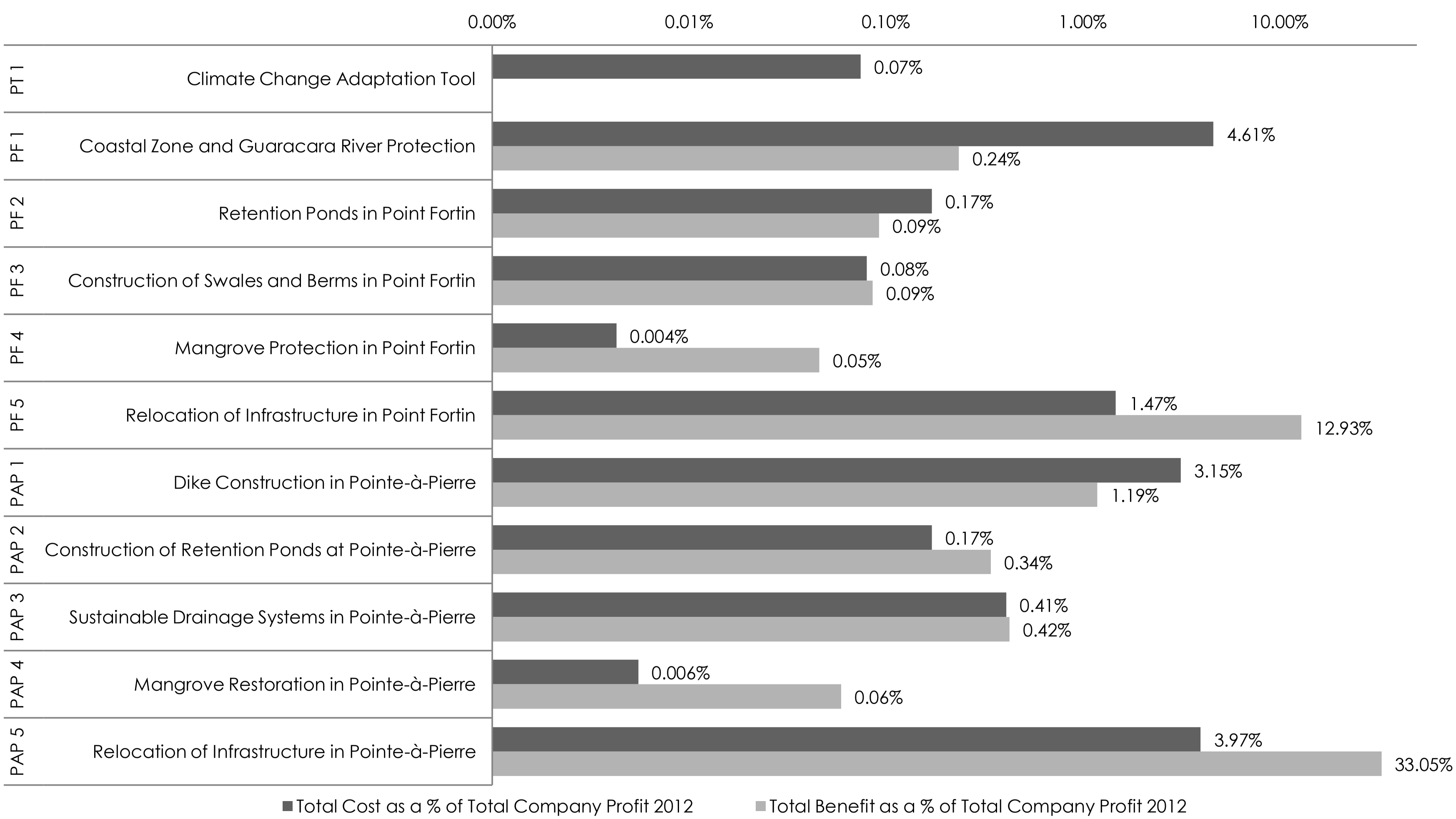
Source: Prepared by the authors.

Action code	Title	Total cost	Total benefit	Total Cost as a % of Total Company Profit 2012	Total Benefit as a % of Total Company Profit 2012
PT 1	Climate Change Adaptation Tool	$117,500	N/A	0.07%	0.00%
PF 1	Coastal Zone and Guaracara River Protection	$7,267,721	$370,635	4.61%	0.24%
PF 2	Retention Ponds in Point Fortin	$269,900	$145,574	0.17%	0.09%
PF 3	Construction of Swales and Berms in Point Fortin	$126,194	$134,871	0.08%	0.09%
PF 4	Mangrove Protection in Point Fortin	$6,750	$72,391	0.004%	0.05%
PF 5	Relocation of Infrastructure in Point Fortin	$2,317,739	$20,375,901	1.47%	12.93%
PAP 1	Dike Construction in Pointe-à-Pierre	$4,961,914	$1,869,243	3.15%	1.19%
PAP 2	Construction of Retention Ponds at Pointe-à-Pierre	$269,900	$537,769	0.17%	0.34%
PAP 3	Sustainable Drainage Systems in Pointe-à-Pierre	$644,715	$669,062	0.41%	0.42%
PAP 4	Mangrove Restoration in Pointe-à-Pierre	$8,708	$93,384	0.006%	0.06%
PAP 5	Relocation of Infrastructure in Pointe-à-Pierre	$6,260,578	$52,076,889	3.97%	33.05%

As can be seen from this analysis, the total costs of the larger infrastrucuture projects, including Coastal Zone and Guaracara River Protection (PF 1); Relocation of Infrastructure in Point Fortin (PF 5); Dike Construction in Pointe-à-Pierre (PAP 1); and Relocation of Infrastructure in Pointe-à-Pierre (PAP 5) have costs of more than 1% of net profits in 2012. PF 1, PAP 1, and PAP 5 are above 3% of net profit in 2012. On the other hand, the rest of the measures have costs that are below 0.5% of net profit in 2012. The measures regarding mangrove restoration in Point Fortin (PF 4) and Pointe-à-Pierre (PAP 4) have costs that are less that 0.01% of net profit in 2012.

The graph on the next page provides a visual of these results, showing a graph of each measures' total costs and total benefits as a percentage of the company's net profit in 2012.

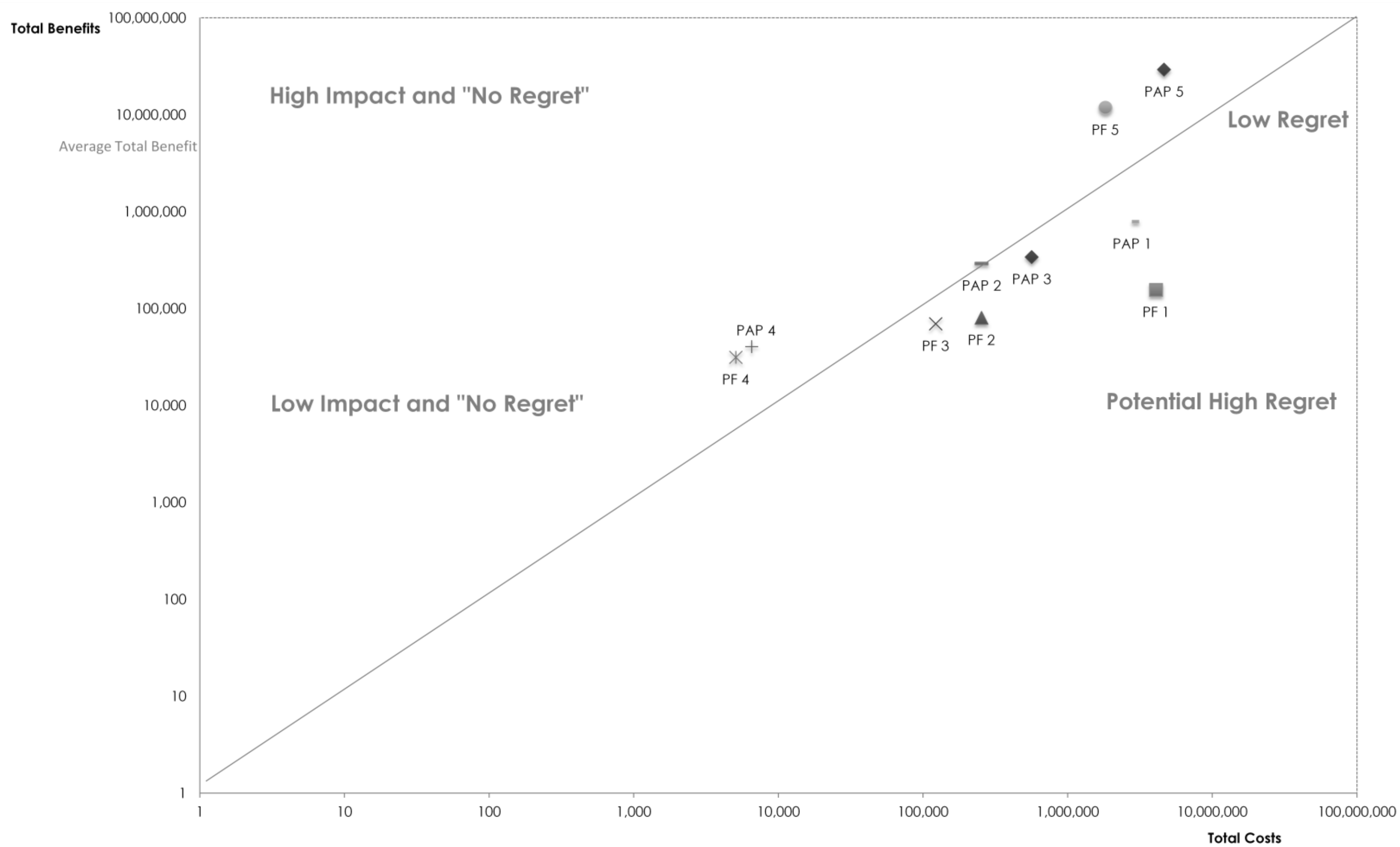
Graph 21: Total Cost and Total Benefits of each measure as a percentage of Petrotrin's Net Profit in 201
Source: Prepared by the autho



Please note, this graph is in logarithmic scale

The graph below shows what the analysis has determined for each analysis in terms of "No Regret". Please note that this graph is showing present value of the total benefits and total costs and both the x and y axes are represented in a logarithmic scale.

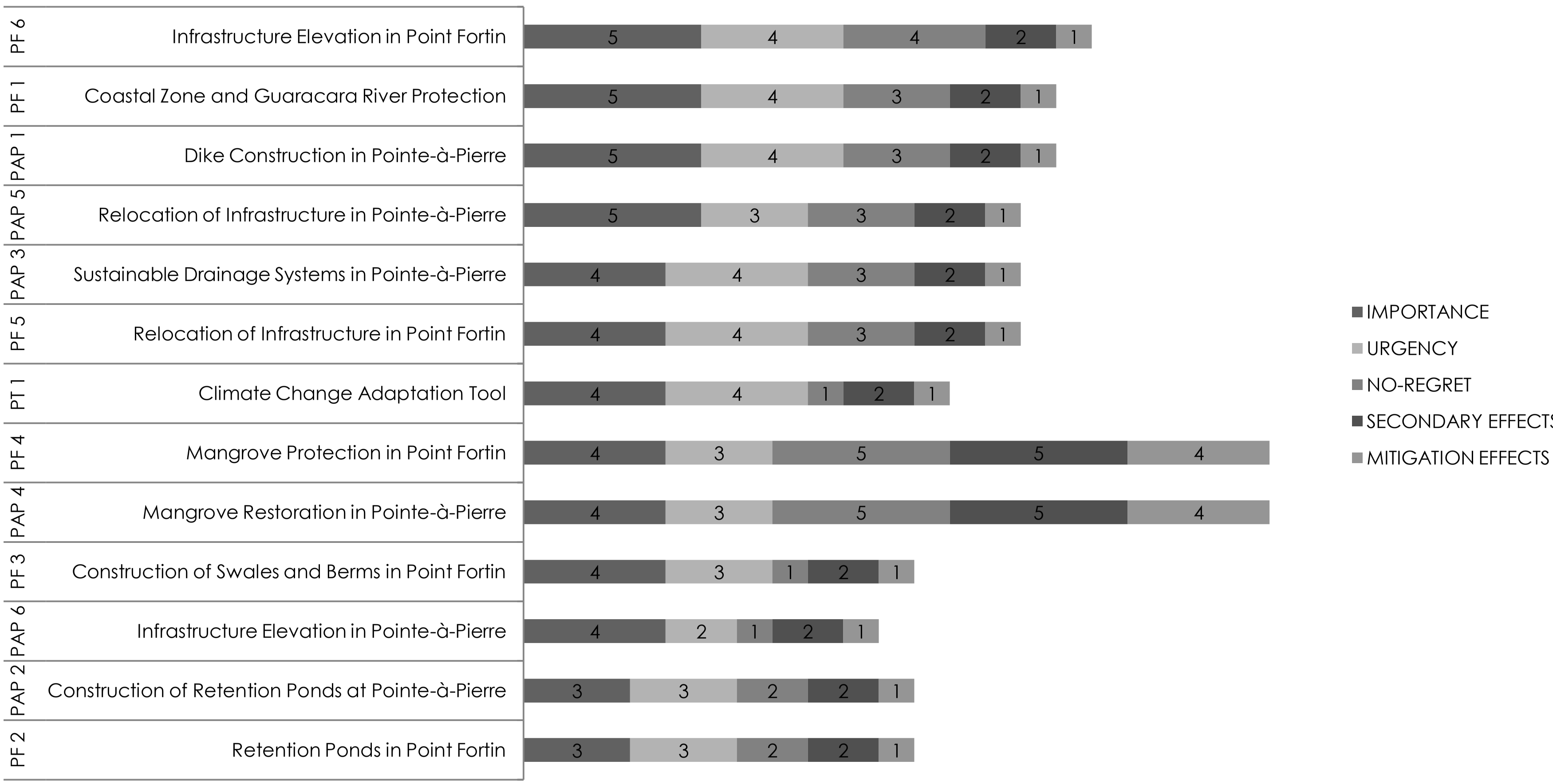
Graph 22: "No Regret" analysis of the pilot project actions.
Source: Prepared by the authors.



Both measures related to the relocation of infrastructure in Point Fortin (PF 5) and Pointe-à-Pierre (PAP 5) fall under the category of High Impact and "No Regret". As mentioned previously, this is due to the fact that the infrastructure built will provide the company benefits during their entire use life and remove the risks of inundation. The measures involving mangrove restoration in Point Fortin (PF 4) and Pointe-à-Pierre (PAP 4) are considered Low Impact and "No Regret" due to their high Benefit/Cost ratio. Retention Ponds in Pointe-à-Pierre is between Potential High Regret and Low Impact and "No Regret", as its costs are similar to its benefits. Lastly, the rest of the measures, fall under the category of Potential High Regret. The measures in Pointe-à-Pierre have slightly better results than those for Point Fortin. This is due partially to the fact that more of the benefits related to the productive value of Pointe-à-Pierre were able to be estimated and included in the analysis. However, this result also makes sense given that Pointe-à-Pierre has the country's only oil refinery, and is of relatively higher strategic importance for Petrotrin.

Similar to the country level actions, a Multi-Criteria Analysis was carried out as well for the actions of the pilot study. The results of this Multi-Criteria Analysis exercise are shown in the graphs below. The first of them shows the results of the general prioritization of the actions, that is, without any further categorization, the second graph, however, classifies the measures by its location, showing the differences between the actions in Point Fortin and Pointe-à-Pierre.

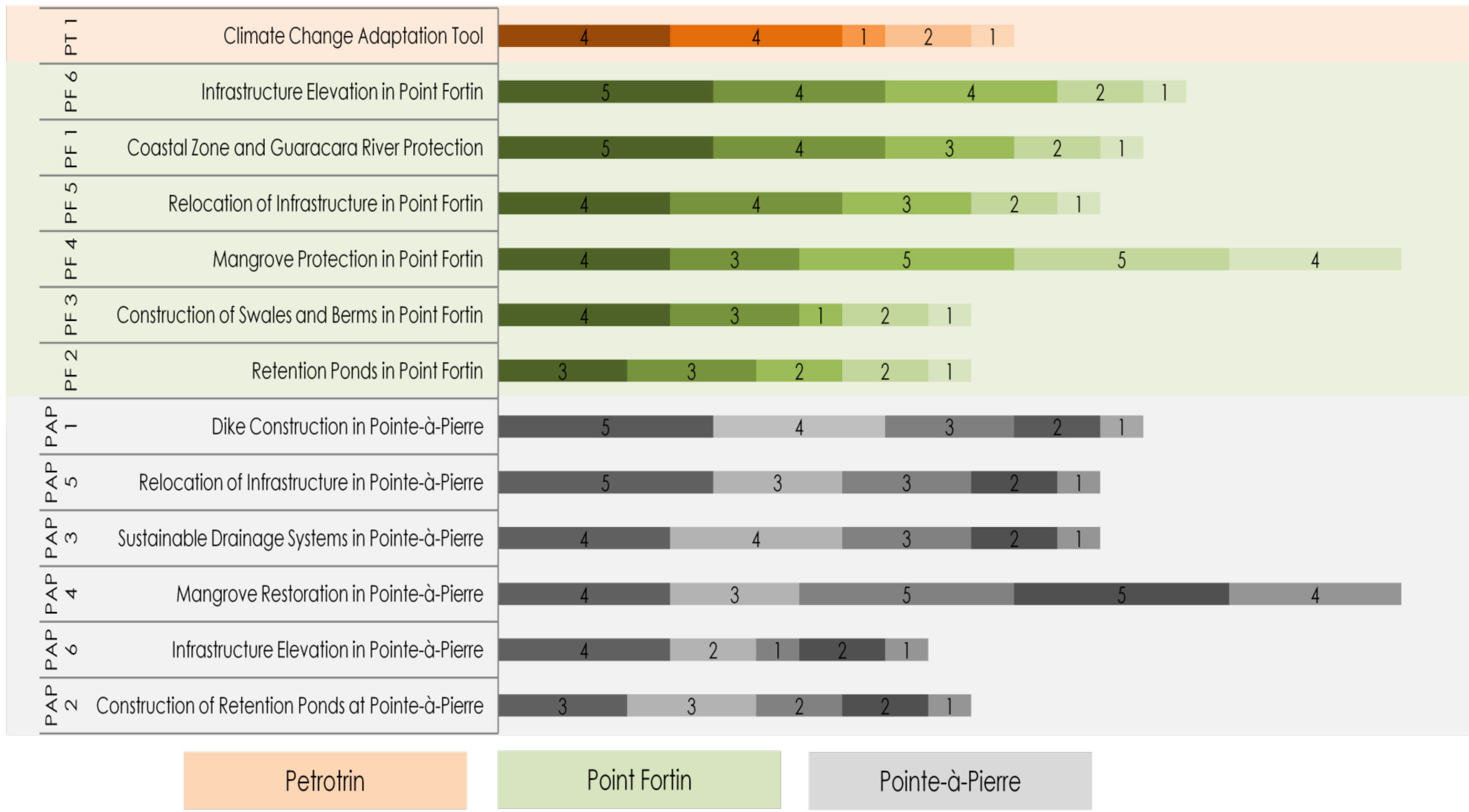
Graph 23: Multi-Criteria Analysis of the pilot project actions
Source: Prepared by the authors,



The scores in each bar in order from left to right: Importance, Urgency, No-Regret, Secondary Effects, and Mitigation Effects.

Graph 24: Multi-Criteria Analysis of the pilot project actions by type of action

Source: Prepared by the authors.



The scores in each bar in order from left to right: Importance, Urgency, No-Regret, Secondary Effects, and Mitigation Effe

As shown in the first graph, those actions focused on reinforcing the coastal areas in both Point Fortin and Pointe-à-Pierre are classified best in the Multi-Criteria Analysis. The elevation of the Port in Point Fortin is the classified as highest, by weighted score. This is due to the fact that the port and terminalling stations are strategic for Petrotrin. Second, the Relocation of Infrastructure and improvement of drainage systems in Pointe-à-Pierre also have high importance and urgency due to the significance of the infrastructure in Pointe-à-Pierre to Petrotrin. The climate change action adaptation tool obtains better results than mangrove restoration, mainly due to its urgency compared to that of the mangrove restoration.

When the actions are classified by type, actions in both Point Fortin and Pointe-à-Pierre are both relatively equal in terms of scoring, with actions in Point Fortin having slightly higher urgency. This is due to the fact that flooding in Point Fortin is expected to occur before 2031, whereas flooding in Pointe-à-Pierre - although affecting more infrastructure for the company - is not projected to occur until 2051.

When the actions are classified by type, actions in both Point Fortin and Pointe-à-Pierre are both relatively equal in terms of scoring, with actions in Point Fortin having slightly higher urgency. This is due to the fact that flooding in Point Fortin is expected to occur before 2031, whereas flooding in Pointe-à-Pierre - although affecting more infrastructure for the company - is not projected to occur until 2051.

As a conclusion, if the results of the different assessments conducted are analysed in conjunction, it can be seen that, for different reasons, all the actions proposed might be helpful and interesting from a climate change adaptation perspective. In terms of Mangrove Restoration in both Point Fortin (PF 4) and Pointe-à-Pierre (PAP 4), the results of the multi-criteria analysis related to importance and urgency are lower, but it has a good benefit-cost ratio and offers many positive secondary effects. Second, the climate change adaptation tool (PT 1) does not offer any economic benefits itself, but it would be very useful for the company to obtain a comprehensive view of its current and future situation in terms of climate change adaptation. Furthermore, it would include all the climate change adaptation information already developed by the company and would facilitate the development of complex adaptation assessments in the different sites in which the company is located - taking into account the vulnerability of those sites and any other relevant factors. It would therefore facilitate the decision-making by including the climate change factor in the assessments of the company.

Lastly, it is important for Petrotrin to look at the remaining measures holistically, and determine its best strategy for the company, and then for both Point Fortin and Pointe-à-Pierre. As can be seen by the projections done for both areas by Singh and El Fouladi (2006 for Pointe-à-Pierre and 2007 for the Point Fortin area), both locations are at risk of inundation and land erosion due to sea level rise and storm surge in the future. Both areas are also strategically important for the company, as Point Fortin facilities deliver the region's best strategically located terminalling services and Pointe-à-Pierre is home to the country's only oil refinery (Petrotrin, 2013). Therefore, both areas will likely need investments made in order to adapt to the risks of climate change and ensure their productive use in the future. Petrotrin will need to look strategically at the options and decide what is best for the company. As an example, they may decide to improve the drainage systems in both locations in the short term (PF 2 and 3, PAP 2 and 3), while working to acquire the financial investments required for larger projects such as Port and Infrastructure Elevation in Point Fortin (PF 6) and Dike Construction in Pointe-à-Pierre (PAP 1).

It is important to mention that these recommendations have been made based on the information currently available. It is recommended that before any of these measures are undertaken, a detailed analysis of their feasibility and impacts be done in order to decide whether or not to implement the measure. Additionally, it is recommended that Petrotrin complete a multi-criteria analysis similar to the one done in this study in order to include their knowledge and experience regarding their business practices into the results.

9. Conclusions

This report has shown the different hazards and vulnerability affecting Trinidad and Tobago due to climate change and has developed and analysed the costs and benefits of possible adaptation measures in order to reduce the negative impacts from climate change risks.

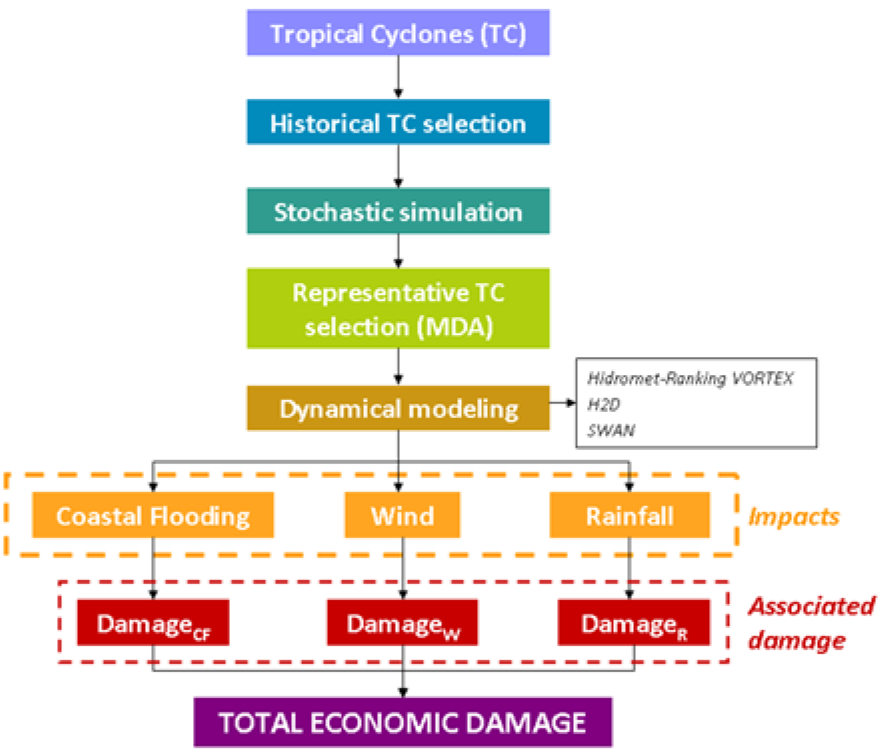
In section 3, a literature review and methodological review were undertaken in order to better understand the context of climate change vulnerability and adaptation potential in Trinidad and Tobago, and to understand which methodology would be best to use in terms of economic analysis given this context. The table below shows a summary of the potential effects of climate change in Trinidad and Tobago:

Table 71: Potential effects of climate change by sector in Trinidad and Tobago.
Source: Prepared by the authors.

Sector	Impact
Agriculture	▪ Warmer weather from high temperature will cause soil aridity, lead to proliferation of pests and diseases, and put pressure on water resources for water for irrigation purposes. ▪ Sea level rise will cause inundation and soil desalination. ▪ The combined impact is low agricultural yields, decrease in food production and higher food process.
Human Health	▪ Higher temperature will increase spread of vector diseases. ▪ Decrease in rainfall will affect potable water supply. ▪ Sea level rise will cause increases in water borne diseases.
Human settlements	▪ Increase in frequency and intensity of storm surge will cause more flooding and disrupt or destroy coastal settlements. ▪ Increase in frequency and intensity of storm surge and extreme rainfall will cause damages to infrastructure from flooding and erosion.
Coastal zones	▪ Sea level rise will lead to increased inundation, increased erosion, loss of wetlands, loss of ecosystems, and displacement of coastal communities. ▪ High temperature will result in loss of coral reefs and reduction in fish stock.
Water resources	▪ Increase in temperature will result in increased evapotranspiration and loss of available surface water. ▪ Decrease in precipitation will reduce groundwater and aquifer recharge. ▪ As an effect, available water resources will be reduced.
Energy sector	▪ Infrastructure, including field installations and offshore operations, are at risk of inundation from sea level rise, storm surges and erosion from extreme rainfall. ▪ Water shortages in the country may affect the needs of the industry in terms of energy generation. ▪ Infrastructure damages due to extreme weather events.

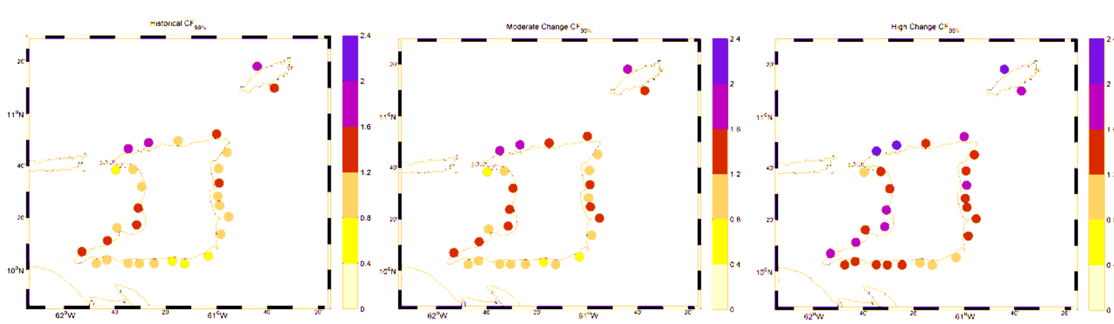
In sections 4 and 5, the historical damage distributions due to natural hazards were looked at, the hazards and vulnerability due to climate change within Trinidad and Tobago were analysed, and the economic implications of climate change within the country were studied. As a result, an assessment of the economic losses expected in the future due to the effects of climate change in Trinidad and Tobago was developed.

Figure 87: Methodology used in sections 3 through 5
Source: Prepared by the authors,



As shown in the figure below, the coastal flooding in Trinidad and Tobago will be more pronounced due to climate change in the future.

Figure 88: Coastal flooding (m) corresponding to the 99 percentile for Today's climate (left panel), moderate change scenario (central panel) and high change scenario (right panel).
Source: Prepared by the authors.



Similarly, the predicted effects of climate change in the country were assessed, obtaining, as a result, future scenarios in which hazards such as flooding, erosion or sea level rise will affect the country. Therefore, even if hurricanes do not pose such an important threat in Trinidad and Tobago as they do in other Caribbean countries, Trinidad and Tobago will be affected by climate change, and adaptation must be seriously considered.

In Sections 6 and 7, measures were identified in order to help reduce these expected damages, proposing different actions for the country. These actions have been selected taking into account the previously explained characteristics of the country, the economic fabric of Trinidad and Tobago and the necessities of its inhabitants. These measures were then analysed by using both a cost benefit analysis (Net Present Value, Payback Period, Cost-Benefit Analysis Ratio, "No Regret" analysis) and a multi-criteria analysis in order to understand and determine their feasibility.

From this analysis, the results show that:

- The National Building Code (TTA 1) and Mangrove Restoration in Trinidad (TTA 13) fall into the category of High Impact and "No Regret"
- Meteorological alert system connected to the Monitoring System (TTA 3); Emergency Protocols (TTA 4) and Institutional Training Program (TTA 6); Green Roofs (TTA 16); and Mangrove Restoration in Tobago (TTA 18) all fall into the category of Low Impact and "No Regret"
- Infrastructure & Building Reinforcement (TTA 8); Permeable Pavements (TTA 11); and Beach Nourishment in Tobago (TTA 12) fall into the category of Low Regret
- Dike Construction in Trinidad (TTA 2); Social Awareness Program (TTA 5); Rainwater Harvesting (TTA 7); Retention Ponds (TTA 9); Filter Strips (TTA 10); Agriculture & Climate Change Research Unit (TTA 15) and Coral Reef Protection and Restoration in Tobago (TTA 19) fall into the category of Potential High Regret.

Based on the Multi-criteria analysis, National Building Code (TTA 1), Institutional Training Program (TTA 6), Infrastructure & Building Reinforcement (TTA 8), Emergency Protocols (TTA 4), and Meteorological alert system connected to the Monitoring System (TTA 3) came in as the top five in terms of priority measures to implement.

In conclusion, after looking at all of the different facets of each measure and analyzing cost/benefit results mentioned in this study, the measures that are the most favourable and feasible for Trinidad and Tobago are the implementation of a National Building Code (TTA 1), Meteorological Alert System connected to the Monitoring System (TTA 3), Emergency Protocols (TTA 4), and Institutional Training Program (TTA 6), given that they were ranked the highest priority and they are all considered "No Regret" Measures. Additionally, Infrastructure & Building Reinforcement (TTA 8) is recommended due to its high ranking in the multicriteria analysis and that it is considered "Low Regret". Given the large benefits associated with mangroves, Mangrove Restoration in Trinidad (TTA 13) and Tobago (TTA 18) are also highly recommended for implementation. The Parametric Insurance Scheme (TTA 14) is also highly recommended, although it is not considered "No Regret", is as it will help reduce the financial risks felt by the Government, private companies and individuals in situations of Natural Hazard. Also, given the strong percentage of tourism related to the economic well-being of Tobago, it would be interesting to look into Beach Nourishment (TTA 12) and Coral Reef Protection and Restoration (TTA 19) as a possible ways to maintain the long term growth of tourism on the island.

In section 8, the pilot case for the Petroleum Company of Trinidad and Tobago was developed and the economic costs and benefits analysed. As a result, both measures related to the relocation of infrastructure in Point Fortin (PF 5) and Pointe-à-Pierre (PAP 5) fall under the category of High Impact and "No Regret". This is due to the fact that the infrastructure built will provide the company benefits during their entire use life and remove the risks of inundation. The measures involving mangrove restoration in Point Fortin (PF 4) and Pointe-à-Pierre (PAP 4) are considered Low Impact and "No Regret" due to their high Benefit/Cost ratio. Retention Ponds in Pointe-à-Pierre is between Potential High Regret and Low Impact and "No Regret", as its costs are similar to its benefits. Lastly, the rest of the measures, fall under the category of Potential High Regret. The measures in Pointe-à-Pierre have slightly better results than those for Point Fortin. This is due partially to the fact that more of the benefits related to the productive value of Pointe-à-Pierre were able to be estimated and included in the analysis. However, this result also makes sense given that Pointe-à-Pierre has the country's only oil refinery, and is of relatively higher strategic importance for Petrotrin.

When scored based on importance, urgency, "no regret", secondary effects, and mitigation potential, those actions focused on reinforcing the coastal areas in both Point Fortin and Pointe-à-Pierre are classified best in the Multi-Criteria Analysis. Actions in both Point Fortin and Pointe-à-Pierre are both relatively equal in terms of multicriteria analysis, with actions in Point Fortin having slightly higher urgency. This is due to the fact that flooding in Point Fortin is expected to occur before 2031, whereas flooding in Pointe-à-Pierre - although affecting more infrastructure for the company - is not projected to occur until 2051.

All the actions proposed might be helpful and interesting from a climate change adaptation perspective. In terms of Mangrove Restoration in both Point Fortin (PF 4) and Pointe-à-Pierre (PAP 4), the results of the multi-criteria analysis related to importance and urgency are lower, but it has a good benefit-cost ratio and offers many positive secondary effects. Second, the climate change adaptation tool does not offer any economic benefits itself, but it would be very useful for the company to obtain a comprehensive view of its current and future situation in terms of climate change adaptation. Furthermore, it would include all the climate change adaptation information already developed by the company and would facilitate the development of complex adaptation assessments in the different sites in which the company is located - taking into account the vulnerability of those sites and any other relevant factors. It would therefore facilitate the decision-making by including the climate change factor in the assessments of the company.

Lastly, it is important for Petrotrin to look at the remaining measures holistically, and determine its best strategy for the company, and then for both Point Fortin and Pointe-à-Pierre. As can be seen by the projections done for both areas by Singh and El Fouladi (2006 for Pointe-à-Pierre and 2007 for the Point Fortin area), both locations are at risk of inundation and land erosion due to sea level rise and storm surge in the future. Both areas are also strategically important for the company, as Point Fortin facilities deliver the region's best strategically located terminalling services and Pointe-à-Pierre is home to the country's only oil refinery (Petrotrin, 2013). Therefore, both areas will likely need investments made in order to adapt to the risks of climate change and ensure their productive use in the future. Petrotrin will need to look strategically at the options and decide what is best for the company. As an example, they may decide to improve the drainage systems in both locations in the short term (PF 2 and 3, PAP 2 and 3), while working to acquire the financial investments required for larger projects such as Port and Infrastructure Elevation in Point Fortin (PF 6) and Dike Construction in Pointe-à-Pierre (PAP 1).

It is important to note that while all of these measures are analyzed as individual measures, many of these measures would have increased impacts if they were implemented in conjunction with other proposed measures. As an example, many of the measures regarding coastal management, including the construction of dikes (TTA 2), the restoration of mangroves (TTA 13 and TTA 18) and the protection of coral reefs (TTA 19), will have improved results if jointly implemented. The same can be said for the social awareness campaign (TTA 5), emergency protocols (TTA 4), institutional training program (TTA 6), and meteorological alert system connected to the monitoring system (TTA 3). In the pilot case, all of the measures, with the exception of relocation and elevation of infrastructure, are designed to help reduce the risk of flooding and storm surge, and therefore could help improve the protection of the industrial area if jointly implemented. All of the measures detailed in this report should therefore be looked at holistically and strategically when deciding which activities to implement, ensuring that possible mutual and re-enforcing benefits are captured.

Additionally, the analysis provided in this report gives a rather detailed global picture of the possible climate adaptations actions available to Trinidad and Tobago given its unique hazards and vulnerabilities due to climate change. However, as mentioned previously, these recommendations have been made based on the information currently available. It is recommended that before the implementation of any of these actions, a more detailed analysis should be developed, retrieving as much available information as possible from relevant stakeholders, including the affected population, and government agencies.

Annex I: Explanation of short and long term timeframes in adaptation analysis

The IPCC 5th Assessment Reports use a standard format for scenario projections that include a current baseline average for the years 1986 - 2005 against which model projection averages are compared for time-slices for the time periods 2016-2035, 2046-2065 and 2081-2100. This is because with regard to climate, a single year is not appropriate to use as the baseline. Climate variability means that a single year may be unusually warm or cold or dry or wet and does not therefore make a useful reference point for measuring climate change. More common in climatological applications is the use of the average climate over a 20 or 30-year period to define the reference or baseline climate and smooth many of the year-to-year variations in climate.

The users consulted before arriving at the decision on time frames to be used, could be classified into two broad groups: "end users," that is policy- and decision makers who use scenario outputs and insights in various decision processes; and "intermediate users," who are researchers who use scenarios from another segment of the research community as inputs into their work.

The distinction between near- and long-term scenarios is important because the nature of policy-and decision making, the climate system responses, and capabilities of model projections all change with time scale. They are defined as follows:

- "near-term" scenarios cover the period to about 2035; and
- "Long-term" scenarios cover the period to 2100.

Major motivations for using near-term scenarios are to understand the effect of emissions on air quality, providing information on trends and extreme events, and providing high-resolution output for the Impact-Adaptation and Vulnerability (IAV) community. Near-term adaptation and mitigation analyses can be matched to conventional planning time scales, can explore opportunities and constraints given institutional and technological inertia, and can play an important role in integrating climate change considerations into other areas of management and policy. Key issues on this time scale include identifying immediate risks; developing corresponding adaptive capacity; reducing vulnerability; making efficient investments to cope with climate change; and implementing investments in low-emission technologies, energy conservation, and sink preservation and/or enhancement.

The longer term time-slice policy shifts the focus towards evaluating climate targets to avoid risks from climate change impacts, improving the understanding of risks of major geophysical and biogeochemical change and feedback effects, and adopting strategies for adaptation, mitigation, and development that are robust over the long term to remaining uncertainties. Scenarios of different rates and magnitudes of climate change provide a basis for assessing the risk of crossing identifiable thresholds in both physical change and impacts on biological and human systems.

Annex 2: Stochastic simulation of hurricane events

Several stochastic methods for hurricane risk assessment have been developed during the last decade. Emanuel et al. (2006) propose a coupled ocean-atmosphere hurricane model which is run along a large number of hurricane tracks in the Atlantic Ocean. Hall and Jewson (2007) present a statistical model of North Atlantic tropical cyclone tracks from genesis site, and use the means and variances of latitudinal and longitudinal displacements and model the remaining anomalies as autoregressive. Wang and Rosowsky (2012) suggest a methodology for characterizing the joint distribution of hurricane intensity (maximum wind speed) and size (radius of maximum winds).

However, the prediction of TCs trajectories in the ocean is a complex problem plagued with uncertainties. This problem is usually solved simulating the possible trajectories based on weighted vertical mean of the environmental flow in which they are embedded plus a drift effect due to Coriolis drag force (beta and advection model Marks (1992)), which are incorporated into Lagrangian trajectory models. However, both data and Lagrangian models are approximations of reality and when comparing trajectory data collected from existing track databases with respect to Lagrangian models results, they differ considerably. This work introduces a stochastic Lagrangian trajectory model that allows quantifying the uncertainties related to: i) weighted vertical mean of the environmental flow, and ii) the Lagrangian trajectory model. These uncertainties are accounted for within the model through random model parameters.

The quantification of these uncertainties consists on an estimation problem, where the parameters of the probability distribution functions of the random variables are estimated based on real historical tracks. Particularly, it is assumed that estimated parameters maximize the likelihood of our model to reproduce the trajectories from the tropical cyclone. Once the probability distribution parameters are estimated, they can be used to simulate different trajectories, obtaining location probability density functions at different times. The advantage of this method is that it allows: i) site and tropical cyclone specific calibration, and ii) comparing uncertainties related to different atmospheric reanalysis databases.

<u>Data requirements</u>

Hurricanes and tropical storms move with some weighted vertical mean of the environmental flow in which they are embedded, Holland (1983), plus a drift effect due to Coriolis drag force. For this reason, NCEP-NCAR database, which provides 4-times daily, daily and monthly values, is used for defining the historical atmospheric conditions from 1948/01/01 to present. Information is given on a 2.5 degree x 2.5 degree global grids (144x73), and contains wind speeds at 10 meters height and at 17 different pressure levels (mb): 1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10. Note that we only use information at levels 850, 500 and 250 mb.

Monthly Means of Sea Surface Temperature, NOAA Extended Reconstructed SST V3b. Information from 1854 to 2013 on a 2.0 degree x 2.0 degree global grids (180x89). The extended reconstructed sea surface temperature (ERSST) was constructed using the most recently available Comprehensive Ocean-Atmosphere Data Set (COADS). SST data and improved statistical methods that allow stable reconstruction using sparse data. Currently, ERSST version 2 (ERSST.v2) and version 3 (ERSST.v3) and ERSST.v3b are available from NCDC. ERSST.v3b is an improved extended reconstruction over version 2 but with no satellite data.

Stochastic model for track characterization and simulation

Hurricanes and tropical cyclones move due to the net result of several forces, i.e. some weighted vertical mean of the environmental flow in which they are embedded, plus a beta drift owing to the effect of vortex flow on the ambient potential vorticity distribution, plus ocean surface currents (Ekman drift, baroclinic motion, tidal and inertial currents). The latter factor might be considered also for characterizing propagation if ocean currents are available and in case this effect is negligible the model will capture this behaviour. This movement is governed by the transport equation in Lagrangian form, i.e.:

$$\frac{dx}{dt}=\sum_{i=1}^{n_l}a_iU_i\left(x,t\right)+dU_c\left(x,t\right)+U_\beta\left(x,t\right) \quad (1)$$

where $\mathbf{x}=\left(x,y\right)$ is the track positioning vector, $U_i;i=1,\ldots,n_l$ are vector flows at the pressure levels considered, U_c is the surface currents velocity vector (Ekman drift, baroclinic motion, tidal and inertial currents), and U_β represents the beta drift correction. Note that both positioning and velocities are time t dependent processes.

σ_y^β In this study, we assume that all components and coefficients $a_i; i = 1,\ldots,n_l$ and d are deterministic but the beta drift correction, which is normally distributed with mean parameters μ_x^β and μ_y^β and standard deviation parameters σ_x^β and σ_y^β, respectively.

Note that this work presents a general method to deal with the tropical cyclone track problem; however, the final model selected depends upon data availability for each particular case.

Numerical scheme

Equation given above governs the response and movement of the drifting object. The evolution of the location is obtained solving this ordinary differential equation (ODE) under the following assumptions:

- The initial location of the tropical cyclone is known (initial condition).
- Flows and currents information is given at regular time intervals.
- The selected numerical method to solve the ordinary differential equation is the first-order Euler method:

$$x_t = x_{t-1} + \Delta t \left[\sum_{i=1}^{n_l} a_i U_i(x_{t-1}) + dU_c(x_{t-1}) + U_\beta(x_{t-1}) \right]; t = 1,\ldots,n_t \tag{2}$$

where $\mathbf{x}_t$ is the track location at time t, $U_i(\mathbf{x}_t); i = 1,\ldots,n_l$, $U_c(\mathbf{x}_t)$ and $U_\beta(\mathbf{x}_t)$ are, respectively, the different flows, the surface current, and the beta drift correction velocities at the location of the track at time t. n_t is the number of time intervals considered.

Deterministic model parameters are the coefficients $a_i; i = 1,\ldots,n_l$ and d, while normal random model parameters are μ_x^β, μ_y^β, σ_x^β and σ_y^β. All these parameters are included within vector $\boldsymbol{\theta}$.

An advantage of the proposed procedure is that alternative distributions, such as log-normal, uniform, etc. could be used instead. Note also that these random model parameters also account, implicitly, for the uncertainties of the numerical scheme. However, alternative formulations including more complex parameterizations or numerical schemes are possible. In all cases, the adequacy of the model must be established based on the estimation results, which should follow the selected probability distribution hypothesis.

The Maximum Likelihood Estimation Method

The maximum likelihood method is based on maximizing the likelihood of an observed sample, and it can be used to derive point and interval parameter estimates.

In this particular case, the observed sample corresponds to the trajectories obtained from an historical cyclone. We assume that the deterministic and random probability distribution parameters are estimated so that, using Euler approach, the likelihood of the model to reproduce the given tropical cyclone trajectory is maximized.

Assuming that: i) the random model variables are independent, and ii) the location of the track $\mathbf{x}_t; t=0,\ldots,n_l$ at different times are given, then, the deterministic and the mean and standard deviation parameters $\boldsymbol{\theta} = \left(a_i; i=1,\ldots,n_l, d, \mu_x^\beta, \mu_y^\beta, \sigma_x^\beta, \sigma_y^\beta\right)^T$ can be estimated using the log-likelihood function by solving the following optimization problem:

$$\mathit{Maximize}_{\theta, p_{\beta,x}^t, p_{\beta,y}^t : \forall t} \sum_{t=1}^{n_t} \log\left[f_{\beta,x}\left(p_{\beta,x}^t;\theta\right) + f_{\beta,y}\left(p_{\beta,y}^t;\theta\right)\right] \qquad (3)$$

where $p_{\beta,x}^t$ and $p_{\beta,y}^t$ correspond to the actual horizontal and vertical components of random speed U_β at position $\mathbf{x}_t$ and time t, $f_{\beta,x}$ and $f_{\beta,y}$ are the probability density functions associated with the beta drift random components, and subject to the following constraints:

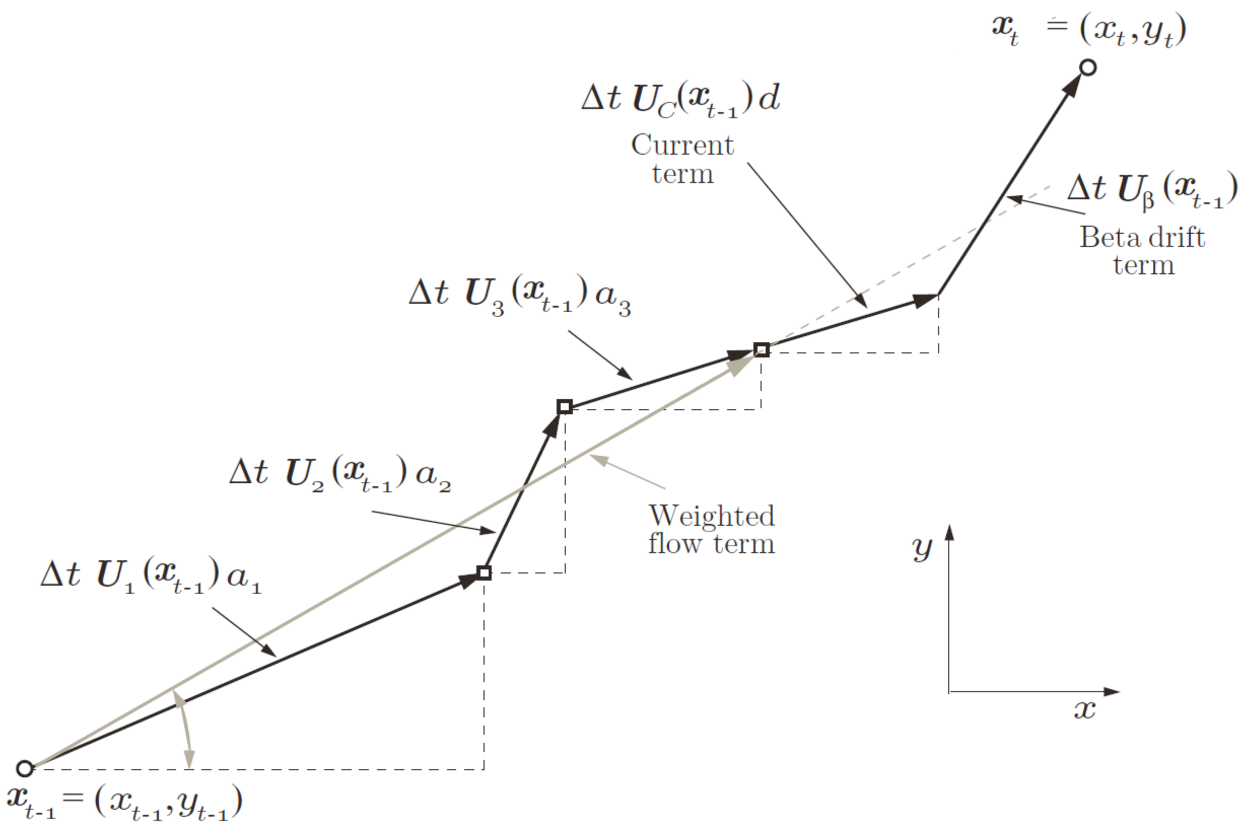
$$x_t - x_{t-1} = \Delta t\left[\sum_{i=1}^{n_l} a_i U_i\left(x_{t-1}\right) + dU_c\left(x_{t-1}\right) + U_\beta\left(x_{t-1}\right)\right]; t=1,\ldots,n_t \qquad (4)$$

Note that the previous optimization problem differs from the traditional maximum likelihood formulation because the actual values of the random variables are unknown and must be obtained from the trajectory equation. The optimal value from solving this problem, i.e. $\hat{\boldsymbol{\theta}}$, is the maximum likelihood estimate (MLE) of $\boldsymbol{\theta}$. In addition, the most likely values of the random variables ($\hat{p}_{\beta,x}^t$ and $\hat{p}_{\beta,y}^t; t=0,\ldots,n_t-1$) are also obtained. These values represent the actual random variable values, which allow reproducing the given trajectory with maximum probability. In the following figure, the graphical interpretation of the variables and constraints associated with the parameter estimation problem, related to the Euler method, is illustrated.

Observe that the maximization of the log-likelihood function can be done using any of the available solvers for nonlinear programming subject to constraints and bounds on variables, for instance, solver MINOS, Murtagh BA and Saunders MA (1998) under GAMS Brooke et al (1998) which allows for upper and lower bounds on parameters to be estimated and dealing with nonlinear equality constraints, and uses a reduced-gradient algorithm combined with the quasi-Newton algorithm, Murtagh BA and Saunders MA (1978), or the Trust Region Reflective Algorithm under Matlab, Coleman TF and Li Y (1994) and (1996), also capable of dealing with nonlinear equality constraints and upper and lower bounds through the function fmincon.

Figure: Graphical interpretation of the estimated values of the random variables and constraints, which allow reproducing the given tropical cyclone trajectory.

Source: Prepared by the authors.



In addition, the probability density functions may correspond to any kind of random variable distribution, such as normal, lognormal, uniform, exponential, etc. For this particular case, we assume normal random variables:

$$f_x(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad (5)$$

The main advantage of this method is that it allows the calculation of the probability distribution parameters based on observed data. This feature makes it appropriate for comparing different atmospheric reanalysis databases and/or current prediction technologies, i.e. the method provides a rationale criterion for comparing their performance. Note that the parameter estimation process has two different stages: i) time independent parameter estimation based on the maximum likelihood method, and ii) parameter estimation including time dependency through ARMA models. Thus, running the parameter estimation process with the same model, and different environmental data from different databases, would provide one optimal likelihood function, and different probability distribution parameters and ARMA residual estimates for each technology. This information may help deciding which technology is more accurate according to the following criteria:

- The higher the log-likelihood, the better the true uncertainty is accounted for within the model.
- The residuals of the ARMA models provide a way to estimate the magnitude of the uncertainty not explained by the model, thus, the lower the variance of residuals is, the better the model performance, and the better the predictive skills of the model are.

The parameter estimation method presented in the previous sub-section assumes temporal independence related to the random variables $p^t_{\beta,x}$ and $p^t_{\beta,y}$. We advocate this approach due to its simplicity and practical performance. However, the most likely values of the random variables, i.e. $\hat{p}^t_{\beta,x}$ and $\hat{p}^t_{\beta,y}; t = 0,\dots,n_t - 1$ may hide a temporal dependency structure which could be further explored after the parameter estimation process.

Autoregressive Moving Average Models (ARMA) are suitable for this task. However, these models require the marginal distribution associated with the stochastic process under study to be normally distributed, which may not be the case in our model. In order to preserve the original marginal distribution associated with each random model variable from our model (Y) while making use of the modelling capability of the ARMA models, a new stochastic process for each variable, Z, with a standard normal marginal distribution is defined through the following transformation, Liu PL and Der Kiureghian A (1986):

$$z = \Phi^{-1}\left[F_Y(z)\right] \tag{6}$$

Where $F_Y(\circ)$ the cumulative distribution function (CDF) of the marginal distribution is associated with the original stochastic process Y and $\Phi(\circ)$ is the cumulative distribution function of the standard normal random variable.

In this particular case, the stochastic temporal dependence of the random variables $p_{\beta,x}^{t}$ and $p_{\beta,y}^{t}$ is reproduced using transformation above and the following univariate Autoregressive Moving Average Models (ARMA) models:

$$z_t^{\beta,x} = \sum_{j=1}^{r\beta,x} \phi_j^{\beta,x} z_{t-1}^{\beta,x} + \varepsilon_t^{\beta,x} - \sum_{j=1}^{q\beta,x} \theta_{,}^{\beta,x} \varepsilon_{t-j}^{\beta,x}$$
$$z_t^{\beta,y} = \sum_{j=1}^{r\beta,y} \phi_j^{\beta,y} z_{t-1}^{\beta,y} + \varepsilon_t^{\beta,y} - \sum_{j=1}^{q\beta,y} \theta_{,}^{\beta,y} \varepsilon_{t-j}^{\beta,y} \quad (7)$$

One advantage of this kind of models is that well-known and computationally efficient univariate modelling procedures can be employed to estimate model parameters. Note also that residuals are uncorrelated, i.e. $E\left[\varepsilon_t^{\beta,x}\right]=0$ and $E\left[\varepsilon_t^{\beta,y}\right]=0$.

The standard protocol for model selection and parameter estimation can be found in, Box GEP, et al. (1994).

Hypothesis testing

The model proposed in this work has the advantage that it can be combined with any kind of probability density function, and it can be used to determine the best flow levels to be incorporated into the Lagrangian model. For this reason, once the parameter estimation processes are accomplished, it is very important to run different statistical hypothesis tests to check whether the selected distributions were appropriate or not. In this particular case we use the following tests:

Related to the marginal probability distribution function selected for the random model variables, a one-sample Kolmogorov-Smirnov test, Massey FJ (1951), is performed. This test compares for a given significance level α the transformed values $z_t^{\beta,x}$ and $z_t^{\beta,y}$, with respect to a standard normal distribution. The null hypothesis is that the samples follow a standard normal distribution.

Analogously to the previous case, we perform a one-sample Kolmogorov-Smirnov test for residuals from ARMA models divided by their standard deviation estimates. The null hypothesis is that they follow a standard normal distribution.

Related to the temporal dependence of the stochastic variables, the following tests and diagnostic plots are selected:

Sample autocorrelation and partial autocorrelation functions related to the transformed values $z_t^{\beta,x}$ and $z_t^{\beta,y}$. These plots help deciding the orders $r^{\beta,x}$, $r^{\beta,y}$, $q^{\beta,x}$ and $q^{\beta,y}$ of the ARMA processes.

Sample autocorrelation and partial autocorrelation functions related to the estimated residuals $\varepsilon_t^{\beta,x}$ and $\varepsilon_t^{\beta,y}$. Since the residuals are supposed to be uncorrelated, these values should be within the confidence bounds.

To further explore the residuals independence hypothesis, the Ljung-Box lack-of-fit hypothesis test, Brockwell PJ and Davis RA (1991), for model misidentification is applied. This test indicates the acceptance or not of the null hypothesis that the model fit is adequate (no serial correlation at the corresponding element of Lags).

Additional or alternative tests for those selected above could be applied. Note that in case any of those tests allow rejecting the null hypothesis with a given significance level, the probability distribution assumptions must be revisited before being acceptable for simulation purposes.

Monte Carlo track simulation technique

Once the relevant parameters of the model are estimated, it is possible to use the Monte Carlo method, Rubinstein BV (1981), in conjunction with the joint probability distribution function and the temporal dependency model presented in the previous subsections, to simulate multiple tropical cyclone tracks consistent with existing ocean and atmospheric conditions. This procedure provides a cloud of candidate locations for the TC track.

The procedure to generate those trajectories is described step by step.

- Input: Maximum likelihood estimated parameters $\hat{\boldsymbol{\theta}}$, the estimates of the ARMA models and the standard deviations of the corresponding residuals, the initial location of the tropical cyclone $\mathbf{x}_0$, the Euler time step Δt, the predicted or observed meteorological and ocean data, and finally, the number of trajectories n_s and time steps n_t to be simulated.
- Step 1: Initialization. Set the iteration counter to $\nu = 1$ and go to Step 2.

- Step 2: Error simulation. Sample the vectors $\hat{\boldsymbol{\varepsilon}}_t^{\beta,x}$ and $\hat{\boldsymbol{\varepsilon}}_t^{\beta,y}$ of dimensions $n_t \times 1$ composed by independent normal random errors with their corresponding standard deviations, respectively. Note that the tilde refers to synthetic sample values.
- Step 3: ARMA. Use those simulated errors in their corresponding ARMA models obtaining the vectors $\hat{\mathbf{z}}_t^{\beta,x}$ and $\hat{\mathbf{z}}_t^{\beta,y}$.
- Step 4: Inverse transformation. Get the simulated values of the random model variables, i.e. $\hat{\mathbf{p}}_{\beta,x}^t$ and $\hat{\mathbf{p}}_{\beta,y}^t$.
- Step 5: Trajectory generation. Reproduce the simulated trajectory through the Euler method. Update the iteration counter $\nu = \nu + 1$, if $\nu \le n_s$ go to Step 2 otherwise the trajectory simulation process concludes.

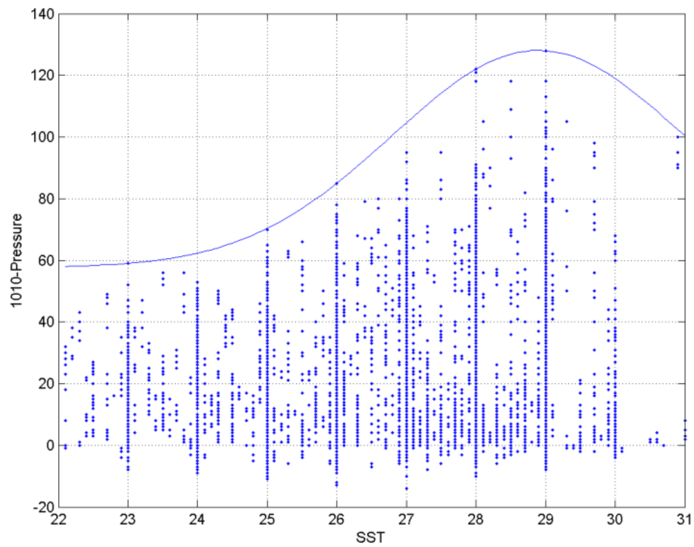
<u>Relationships between maximum wind speeds and minimum pressures, and limiting conditions associated with SST.</u>

So far, the method proposed for synthetic generation of additional tropical cyclones close to the area of interest, consist of characterization of all historical tracks and posterior simulation. This process provides alternative tracks for historical storms which are physically consistent with existing atmospheric conditions in terms of flows at different levels, and even with surface currents if they are available. Thus, we are able to clone all characteristics of past events but with different tracks, which in terms of possible effects in a specific area, it may constitute a completely different tropical cyclone.

However, besides atmospheric conditions, it is recognized in the literature that the storm characteristics related to maximum wind speeds and minimum pressures are dependent on sea surface temperatures (SST), and for this reason, we check that all sampled tracks hold a limiting condition in terms of the sea surface temperature at the track position. If we take the pressure associated with each historical cyclone track in mbar and its corresponding sea surface temperature (°C), and plot the pressure deficit ($MD_i =$ 1010-pressure) versus SST_i, the graph shown in figure below is obtained. Note that maximum deficits occur for sea surface temperatures between 22 and 31 degrees Celsius with a maximum in about 29 degrees.

Figure: Maximum deficits MD_i versus sea surface temperatures SST_i associated with tropical cyclones.

Source: Prepared by the authors.



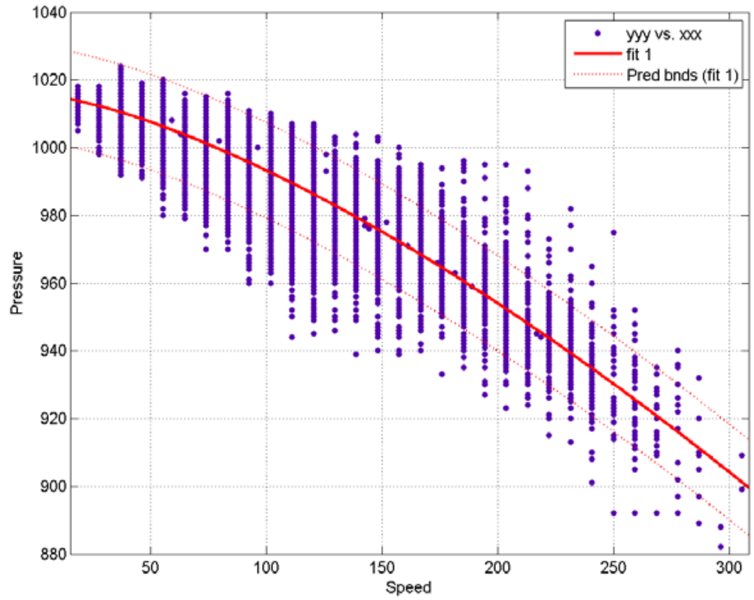
The blue line is associated with the parametric model given by expression:

$$MD(SST) = d + a\exp\left[-\frac{(SST-b)^2}{c}\right] \tag{8}$$

where $MD(SST)$ is the maximum deficit in terms of SST. This equation constitutes an upper envelope limiting the maximum deficit in terms of the sea surface temperature. Model parameters are obtained by minimizing the sum of maximum deficits for each SST data (SST_i) but imposing the additional conditions that the values $MD(SST_i)$ cannot be lower than MD_i. Optimal estimates of this parameters should be calculated ($\hat{a}$, $\hat{b}$, $\hat{c}$ and $\hat{d}$). In case any point from a synthetic track is above that envelope, we reduce the pressure to be in the limit condition given by the parametric model above. This makes synthetic tracks to be consistent also in terms of sea surface temperature.

Note that changing the pressure also affects the wind speed, in order to get wind speeds consistent with pressures; we use a regression model which related both magnitudes. Note in figure below that there a clear non linear relationship between pressure (mbar) and wind speed (km/h).

Figure: Relationship between pressures and wind speeds for tropical cyclones.
Source: Prepared by the authors.



The parametric model is given by expression:

$$P(V) = aV^b + c \quad (9)$$

where $P(V)$ is the pressure for a given wind speed. Optimal parameters are obtained using leasts squares, being the optimal values equal to: $\hat{a} = -0.02711$, $\hat{b} = 1.459$ and $\hat{c} = 1016$. This expression allows us: i) to modify the speed along the track according to its pressure for those cases where a change in pressure induced by SST occurs and ii) fill the pressure gaps from the tropical cyclone historical database if speeds are available. Note also that this expression allows us to correct wrong data from our dataset.

Annex 3: High-Resolution Coastal Flooding Risk

INTRODUCTION

The presentation on the project "Understanding the Economics of Climate Adaptation (ECA) in Trinidad and Tobago" led to the possibility of developing a high-resolution study of coastal flooding due to tropical storm events.

From a socioeconomic point of view the coastal boarder represents a crucial area for coastal states, especially islands, including the majority of the population, services, ports, refineries and a high percentage of economic activities. Globally, the coastal areas below 10 m height mean 2% of the continental areas but include around 10% of the worldwide population (McGranahan et al., 2007; Satterthwaite et al., 2009). On the other hand, the complexity of the processes taking place in coastal areas suggests different climate change impacts, being coastal flooding one of the most relevant impact to be expected.

Objectives

The main objective of this high-resolution study on coastal flooding is improving the spatial characterization of the factors of risk: coastal flooding impact, exposure and vulnerability. To achieve this goal several specific objectives are posed:

To establish a high-resolution spatial division of the coastal area and select the corresponding coastal receptor points.

- To statistically characterize the coastal flooding impact due to tropical storm events as a consequence of storm surge, waves and relative sea level rise at each receptor point. This characterization will provide an accurate spatial variability of coastal flooding due to tropical storms.
- To characterize the vulnerability information taking into account different factors such as population, and the existence of city, port or refinery (multivariate approach).
- To jointly address the exposure and vulnerability information/characterization based on expert judgment.

Improvements of the downscaled approach

The availability of high-resolution information on exposure and vulnerability, provided by the Institute of Marine Affairs of Trinidad and Tobago, has allowed a downscaled on the assessment of coastal flooding risk increasing the resolution from a regional to a local scale. The main differences and improvements carried on within this new approach are summarized below:

The regional scale has been downscaled into a local scale increasing the number of receptor points. The initial 29 receptor points (27 in Trinidad and 2 in Tobago) have been extended to 355 (229 in Trinidad and 126 in Tobago) with a spatial resolution of 2 km in Trinidad and 1 km in Tobago.

This new approach considers the coastal flooding (hazard), exposure and vulnerability information at each receptor point.

The exposure information (based on geomorphological characteristics) is considered as an independent factor of risk, while in the regional approach the exposure was included in the vulnerability information.

At the local scale the vulnerability is characterized by four factors: population and the existence of city, port or refinery at the location considered.

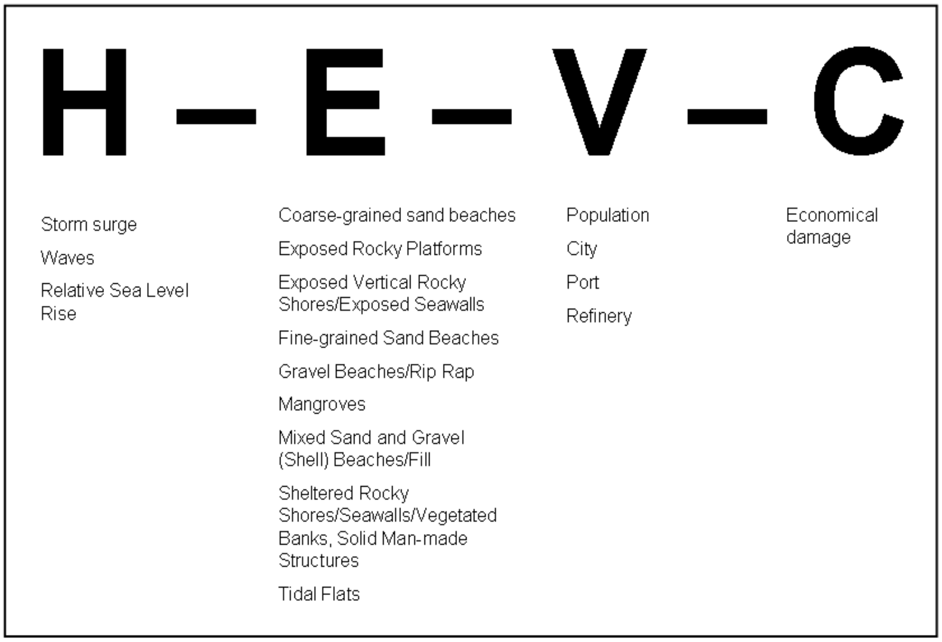
A state-of-the-art methodology, based on data mining, has been used to gather common vulnerability areas, and a scored index, based on expert judgment, has been assigned to each one.

A high resolution assessment of the hazard, exposure and vulnerability is carried out providing accurate spatial characteristics of the three factors of risk. However, the lack of spatial information about economic damages of the three historical cyclones used to calibrate the damage function at the regional scale prevents a high-resolution characterization of the economical damage.

RISK APPROACH

As described along the deliverables of the project, we follow the conceptual framework H-E-V-C approach to evaluate how the Hazards (waves, tide, storm surge, mean sea level) through the Exposure (the physical domain) affect the different sectors (Vulnerability) generating Consequences (economical damage), see Figure 1. The coarse resolution of the regional scale and the lack of exposure and vulnerability information motivated the simplification of the approach, taking into account only hazard and vulnerability factors (the exposure was taking into account as part of the vulnerability term). The integrated approach at local scale allows splitting up the complex problem of coastal flooding risk in Trinidad and Tobago in a number of sub-scale simple linear H-E-V-C problems, making the integration of risk easier.

Figure 1: Conceptual framework. H=Hazard, E=Exposure, V=Vulnerability, C=Consequences.



However, a major shortcoming in this approach is the lack of historical spatial damage information (economical consequences from Flora-1963, Iván-2004 and the event in 1933) which is a crucial point to calibrate the damage functions at resolution. The increase of resolution in the three factors of the approach and, as a consequence, the possibility of calculating a more accurate economical damage (in terms of total and spatial distributed damage) poses the necessity of fitting a damage function in each coastal receptor point. The calibration of each damage function implies the use of spatial data of economical consequences of historical tropical storms.

$$D_{CF,j} = \alpha_{CF,j} \cdot H_{CF,j} \cdot E_{CF,j} \cdot V_{CF,j} \qquad (1)$$

where j=1 to 355 receptor points, $\alpha_{CF,j}$ is the calibration parameter for the damage function for coastal flooding (CF) in point *j* (note that this parameter includes the non-direct damages of the tropical storm); $H_{CF,j}$ is the dimensionless scored value of coastal flooding in point *j*; $E_{CF,j}$ is the exposure type in a dimensionless scored scale in point *j* and $V_{CF,j}$ is the vulnerability classification parameter at a dimensionless scored scale in point *j*.

The calibration of each damage function will led to generate a population of economical damages for tropical storm events, both at present (Today's climate scenario) and in future climate change scenarios, having a more accurate spatial and total distribution of economical damage due to coastal flooding impact for tropical storms.

The lack of historical spatial information of economical damage could be addressed by spatially distributing the damage assigned to coastal flooding for the event on 1933, Flora-1963 and Iván-2004 using an expert criterion. This criterion will be based on the exposure and vulnerability distribution along the coast using a weighting factor. Those areas more vulnerable (with more population or economical activities such as port or refinery) and exposed (flat areas) will be supposed to suffer higher consequences.

COASTLINE TESSELLATION

To improve the impact, exposure and vulnerability characterization a coastal downscaling has been performed. A new coastal partitioning has been carried out considering a resolution of 2 km in Trinidad and 1 km in Tobago.

The tessellation of the coast is obtained dividing the coastline into segments of two (or one) km length and considering each central point as the representative coastal receptor point. Figures 2 and 3 show the coastal tessellation in Trinidad (divided into 229 segments), and Tobago (divided into 126 points), respectively.

Consequently, each receptor point will be represented by its coastal flooding impact, its vulnerability, as a function of population, and the existence of city, port or refinery, and by its exposure, considering geomorphological characteristics such as the presence of beach, mangrove, exposed rocky platform, etc.

Figure 2: High-resolution coastal division and receptor points in Trinidad.

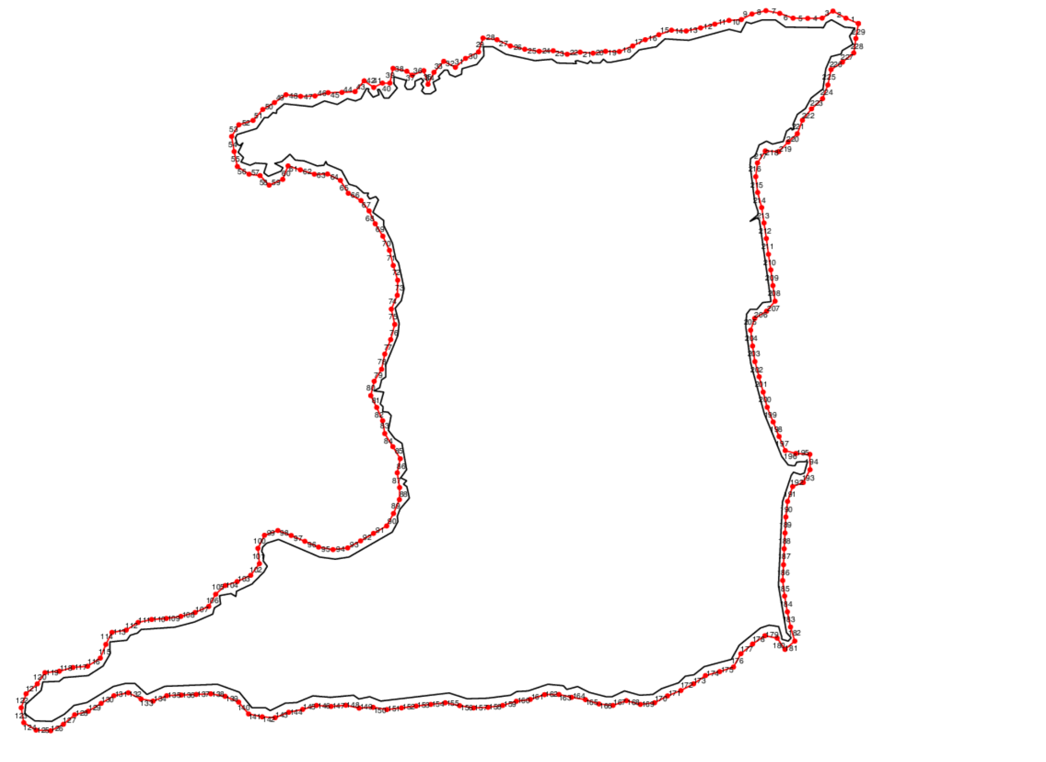
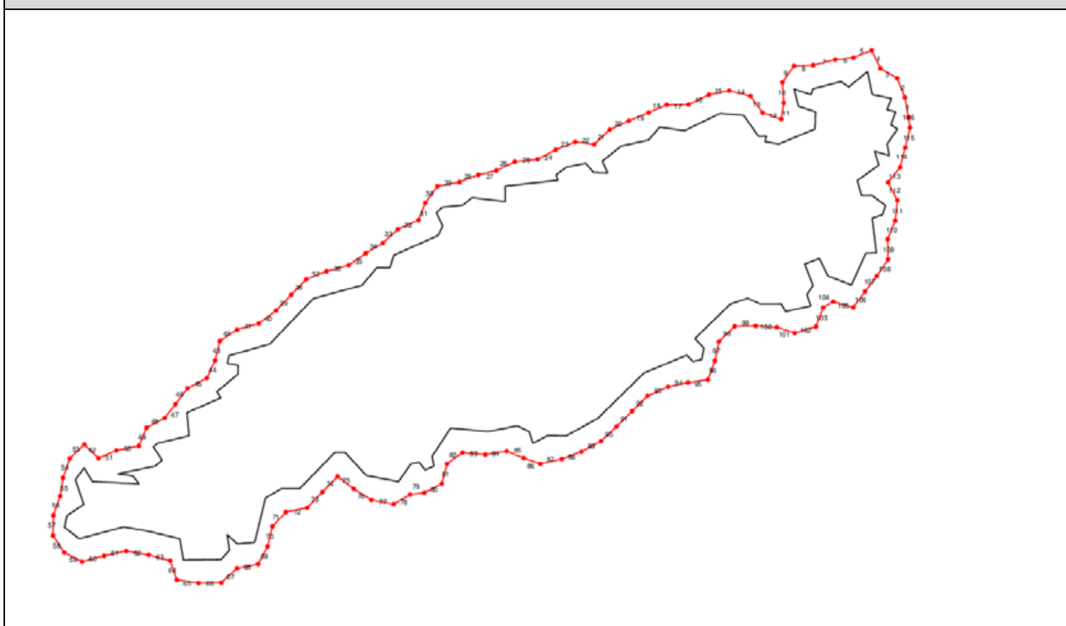


Figure 3: High-resolution coastal division and receptor points in Tobago.



HAZARD CHARACTERIZATION: COASTAL FLOODING IMPACT

The state-of-the-art numerical models used to characterize the storm surge, waves and sea level allows characterizing the coastal flooding impact along the coast at high resolution. As described in the deliverables, the coastal flooding index is expressed by:

$$CF_j = SS_j + 0.3H_{s,j} + RSLR_j \qquad (2)$$

where CF_j is the coastal flooding elevation at point *j*, SS_j is the storm surge elevation at point *j*, $H_{s,j}$ at the significant wave height at point *j* and $RSLR_j$ is the relative sea level rise (including mean sea level rise and subsidence) at point *j*. Units are given in meters.

Figures 4, 5 and 6 show the maximum coastal flooding generated by the hurricane on June 1933, hurricane Flora in 1963 and hurricane Iván in 2004, respectively. As can be seen, a more detailed spatial variability is evident at the local scale. In the cases of Flora and Iván a strong variability along the Gulf of Paria, especially at the sheltered zones, is identified.

Figure 4: Maximum coastal flooding (m) generated by the hurricane of June 1933 in TT.

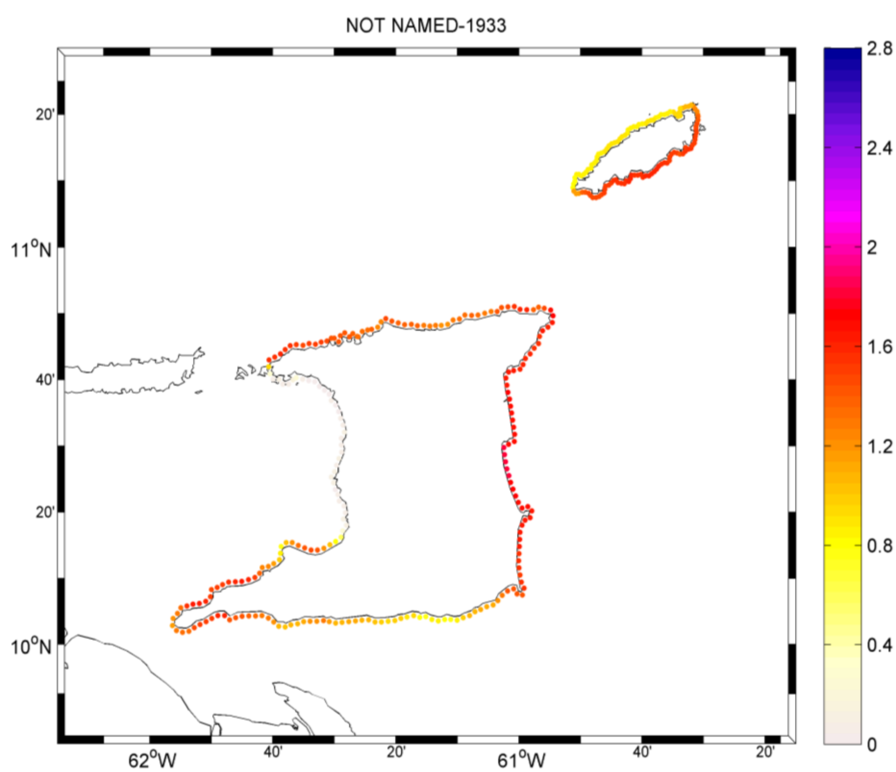


Figure 5: Maximum coastal flooding (m) generated by hurricane Flora-1963 in TT.

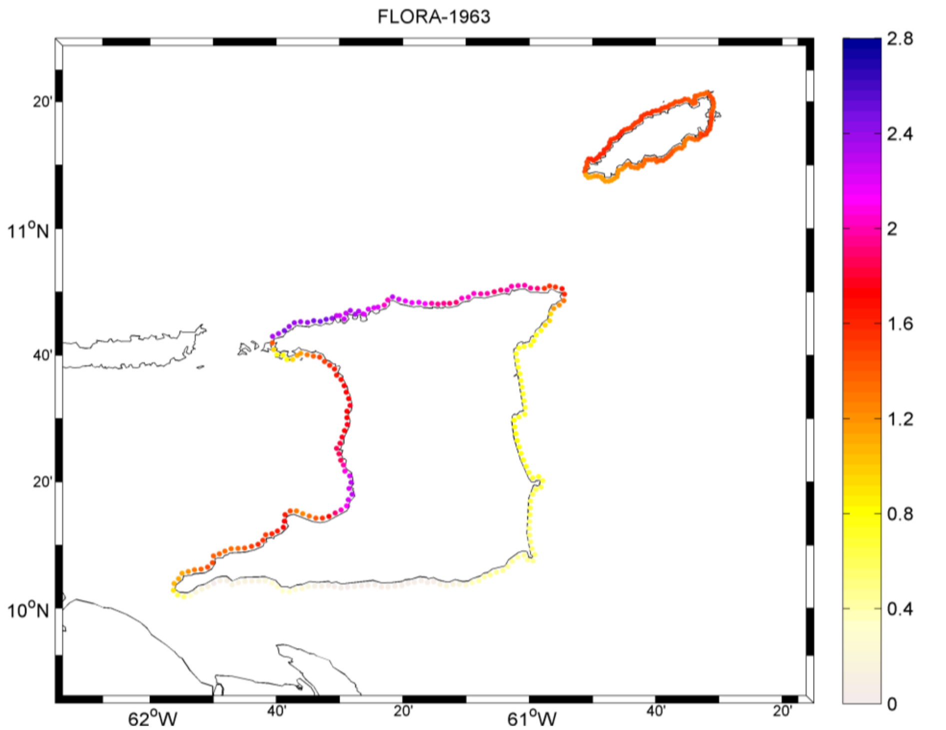
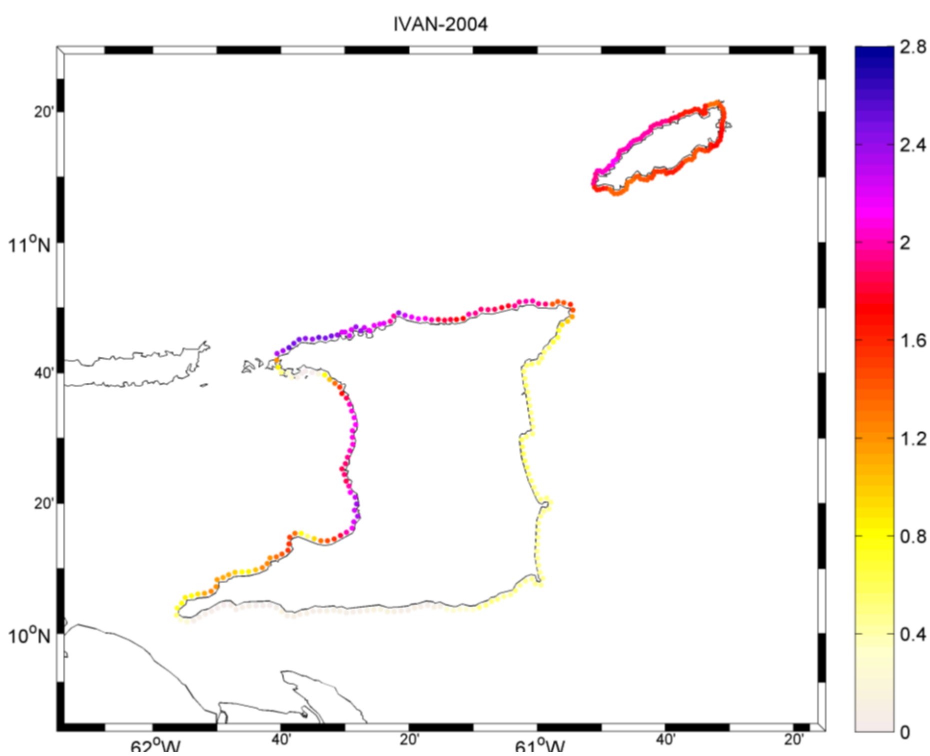


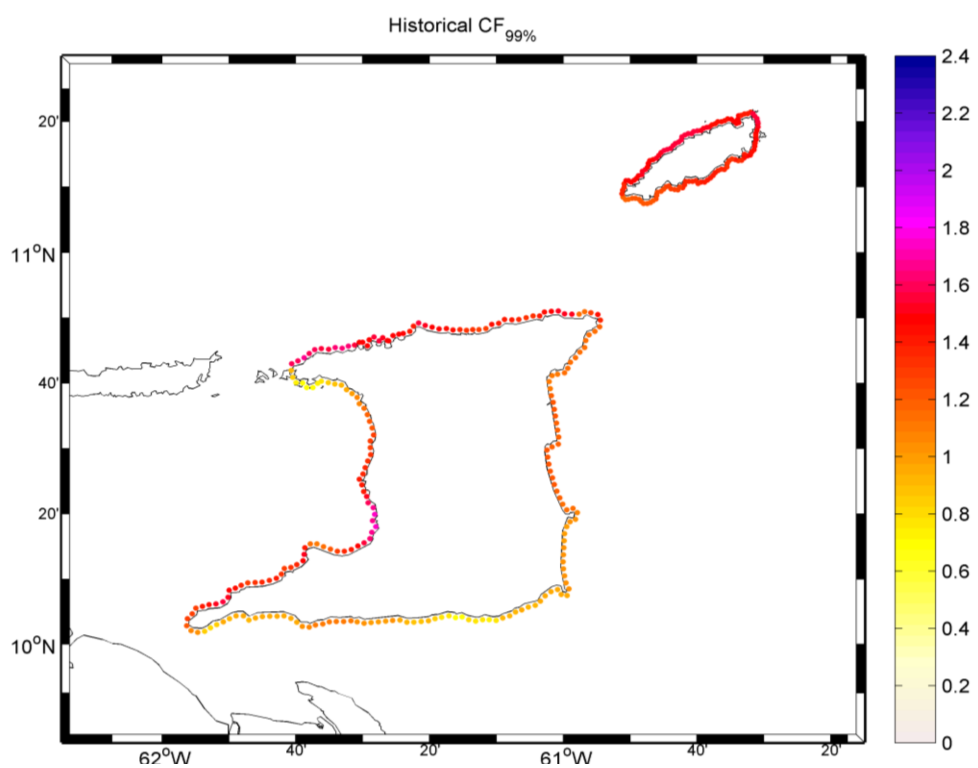
Figure 6: Maximum coastal flooding (m) generated by hurricane Flora-1963 in TT.



Observed Coastal Flooding Impact

Following the methodology described in the Third and Fourth Interim Reports we have calculated the historical distribution of coastal flooding elevation. The statistics corresponding to the 99 percentile of coastal flooding elevation for the present climate is shown in Figure 7. Higher values are observed in the area of San Fernando and Piparo Tabaquite (up to 1.8 m). The south coast of Trinidad experiments a milder coastal flooding elevation (about 0.8 m) and the island of Tobago presents an almost negligible spatial variability, with an almost constant value of about 1.4 m in the whole island.

Figure 7: Coastal flooding (m) corresponding to the 99 percentile for present climate.



Projected Coastal Flooding Impact

Two climate change scenarios were considered for the assessment of the hazard in the future. The moderate change scenario (C1) considers a mean sea level rise of +3 mm/year plus a subsidence (-0.29 mm/year) while the high change scenario (C2) considers changes in the sea level of +15 mm/year plus subsidence (-0.29 mm/year), both of them for the horizon year 2040. Applying the methodology described in the Third Interim Report we have obtained the distribution of projected coastal flooding elevation for both scenarios. Figures 8 and 9 present the 99 percentile of projected coastal flooding elevation for C1 and C2 scenarios.

Both figures show a similar spatial pattern, more intense in the case of C2. The highest values of projected coastal flooding elevation can be found in the Gulf of Paria (in the area of San Fernando), with 1.9 m in for C1 and around 2.2 m for C2. The north east boarder of the Gulf of Paria (in the area of Port of Spain) shows a sheltered zone to coastal flooding with clear spatial variability along an almost 20 km long stretch: from 0.6 m to 1.2 m for C1 and from 1.1 m to 1.7 m for C2.

Figure 8: Coastal flooding (m) corresponding to the 99 percentile for the Moderate Change scenario (C1).

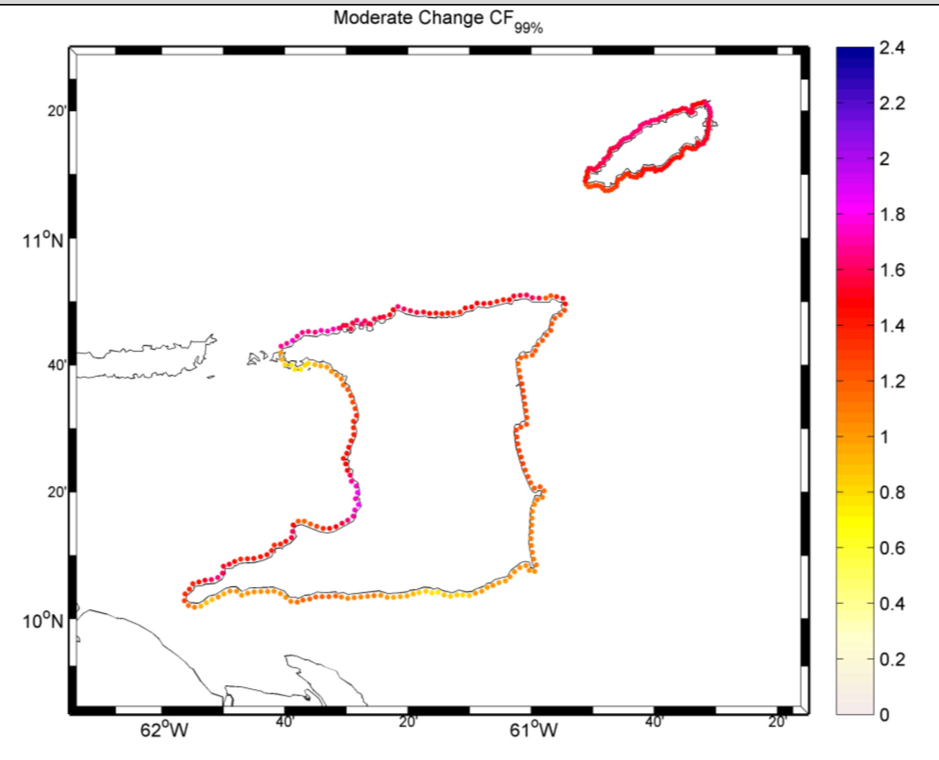
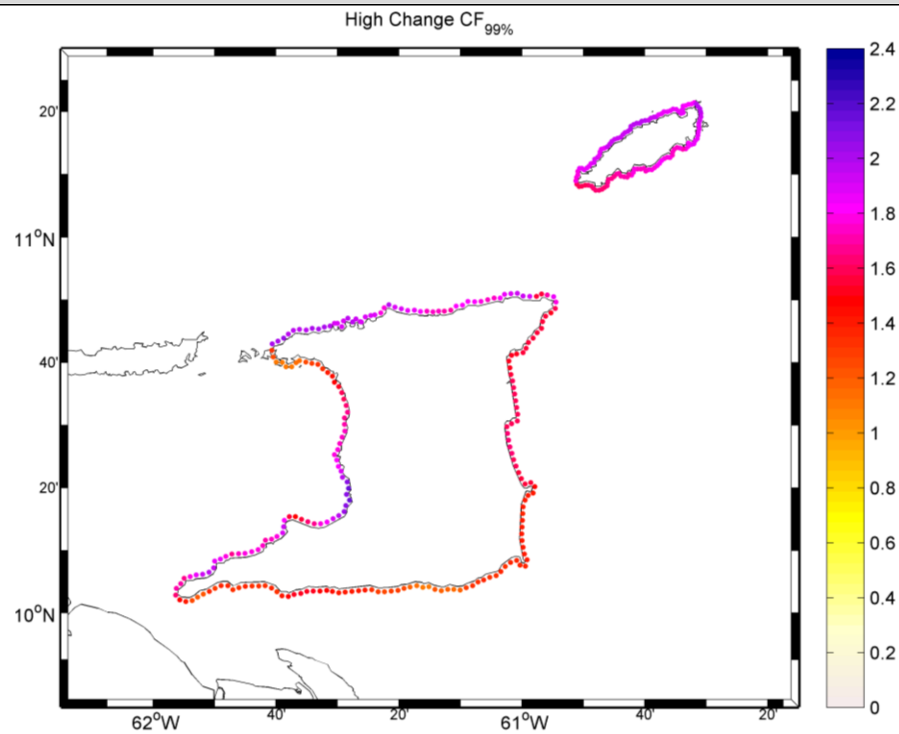


Figure 9: Coastal flooding (m) corresponding to the 99 percentile for the High Change scenario (C2).



EXPOSURE CHARACTERIZATION

The exposure information has been provided by Institute of Marine Affairs of Trinidad and Tobago. The coastline has been classified considering nine types of exposure, based on geomorphological characteristics:

- Coarse-grained sand beaches
- Exposed Rocky Platforms
- Exposed Vertical Rocky Shores/Exposed Seawalls
- Fine-grained Sand Beaches
- Gravel Beaches/Rip Rap
- Mangroves
- Mixed Sand and Gravel (Shell) Beaches/Fill
- Sheltered Rocky Shores/Seawalls/Vegetated Banks, Solid Man-made Structures
- Tidal Flats

A type of exposure has been assigned to each segment of the coast (receptor point). However, the damage function requires a nondimensional characterization of exposure. A Coastline Sensitivity Index (CSI) ranked from 1 to 10 has been applied, with 1 representing low sensitivity and 10 representing high sensitivity.

1 = Exposed Vertical Rocky Shores/Exposed Seawalls

2 = Exposed Rocky Platforms

3 = Fine-grained Sand Beaches

4 = Coarse-grained Sand Beaches

5 = Mixed Sand and Gravel (Shell) Beaches/Fill

6 = Gravel Beaches/Rip Rap

7 = Sheltered Rocky Shores/Vegetated Banks

8 = Tidal Flats

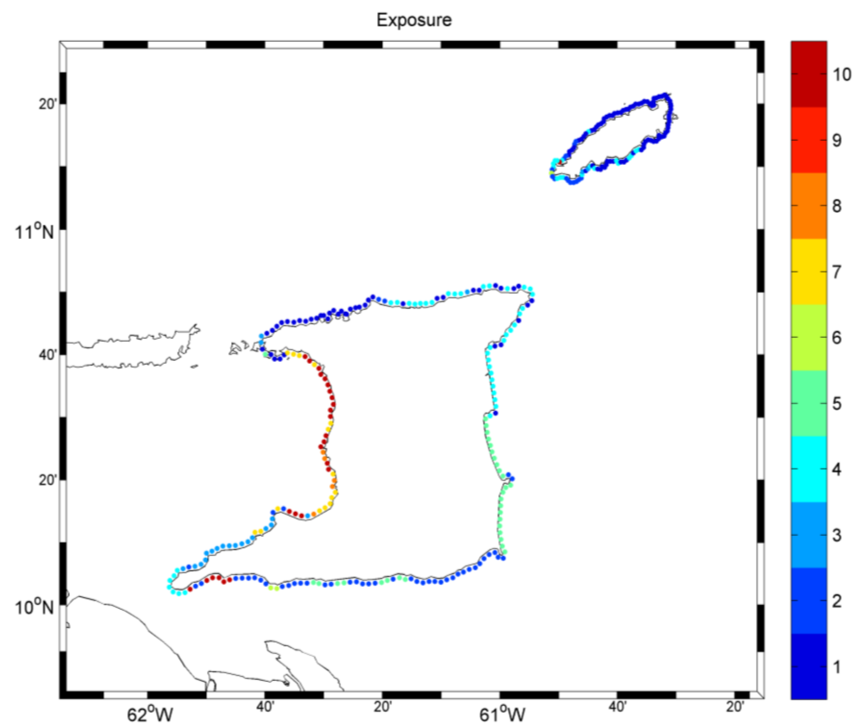
9 = NA

10 = Mangroves

In the case of Trinidad every type of exposure has been identified, while Tobago does not present mixed sand and gravel (shell) beaches/fill, sheltered rocky shores/vegetated banks, and tidal flats (levels of CSI rank 5, 7 and 8, respectively).

Figure 10 shows the exposure map, where the CSI rank has been plotted. The spatial variability shows higher exposure sensitivity in the Gulf of Paria where mangroves, tidal flats and vegetated banks are identified. The north east and south west coasts of Trinidad is characterized by vertical rocky shores, which present low sensitivity to coastal flooding, similar to most of the coastline of Tobago which presents a CSI of 1.

Figure 10: Exposure map based on the CSI rank.



Exposure information is considered to remain unchanged in the climate change scenarios proposed. The values shown here correspond to present climate, being the same for scenarios S1, S2 and S3, as defined in the Third and Fourth Interim Reports.

In order to follow the risk methodology proposed along the project the CSI rank has been converted to a 1 to 5 nondimenssional scored index.

VULNERABILITY CHARACTERIZATION

Vulnerability is defined as the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard (UN/ISDR, 2009). Vulnerability is determined by physical, environmental, social, economic and administrative factors and processes. This definition identifies vulnerability as a characteristic of the element of interest (community, system or asset) which is independent of its exposure.

The information provided by Institute of Marine Affairs of Trinidad and Tobago considers different factors of vulnerability at each receptor point: population, number of households, enumeration district area and the existence of a city, port or refinery. Due to the multivariate nature of the vulnerability and the need to consider all factors together, a multidimensional approach based on data mining and classification techniques is used to characterize the vulnerability to coastal flooding in Trinidad and Tobago. Using a classification algorithm that is fed by vulnerability indicators the aim is assigning common groups (spatially represented) with a representative level of vulnerability.

After a careful evaluation of the vulnerability factors provided, we have decided to consider as the most crucial indicators the population and the existence of a city, port or refinery. Besides, we have aggregated these last three indicators in only one, since we have considered as especially vulnerable zones, those places where at least exist one of the three factors (city, port or refinery) is present.

In order to obtain common vulnerable groups we have applied the K-means algorithm (KMA), which is an efficient classification method especially useful with a high number of data. The KMA clustering technique divides the high-dimensional data space into a number of clusters, each one defined by a prototype and formed by the data for which the prototype is the nearest. Given a database of *n*-dimensional vectors $X=\{x_1,x_2,\ldots,x_N\}$, where N is the total amount of data and n is the dimension of each data $x_k=\{x_{1k},\ldots,x_{nk}\}$, KMA is applied to obtain M groups defined by a prototype or centroid $v_k=\{v_{1k},\ldots,v_{nk}\}$ of the same dimension of the original data, being $k=1,\ldots,M$.

In this study ten vulnerability groups have been selected. A brief description and application of this technique can be found in Camus et al. (2011). Once the classification of common vulnerability classes is done, an expert criterion is applied to establish a scored value to each group. At this step, the vulnerability is characterized by a single scored nondimensional index that considers multivariate factors. Besides, it can be combined with the exposure CSI rank and transformed into a 1 to 5 scored index.

Following, we describe the vulnerability characterization made for the two vulnerability scenarios proposed.

Historical Vulnerability characterization

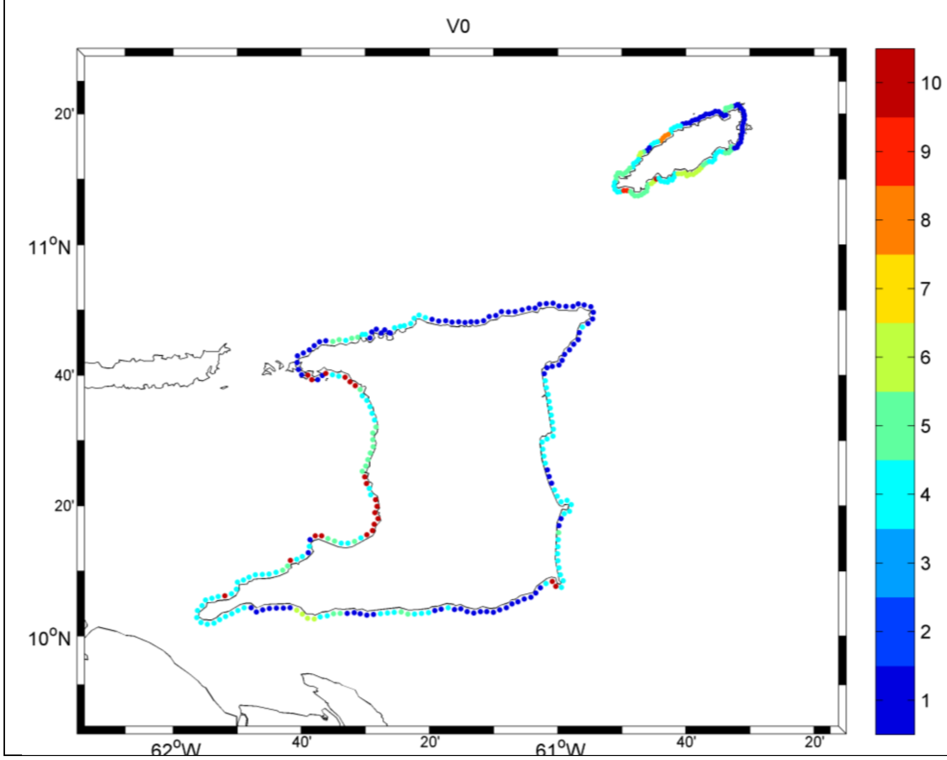
First, we have characterized the historical vulnerability, the so-called V0 scenario. Using the population and the indicator of the existence (1 if exists and 0 otherwise) of a city, port and refinery we have applied the KMA obtaining 10 common clusters. Table 1 shows the values of population and the existence or not of City/Port/Refinery for each classified cluster. The third column shows the number of coastal receptor points that are represented by each group and finally, the vulnerability scored index assigned using an expert criterion.

Table 1: Vulnerability characterization for the V0 scenario.

Population	*City/Refinery/Port*	*Number of receptor points*	*Vulnerability Index*
2247	0	2	9
84	1	3	10
181	0	129	1
1441	1	1	10
943	0	51	5
764	1	7	10
514	0	120	4
337	1	11	10
1898	0	4	8
1282	0	17	6

Figure 11 shows the spatial distribution of the vulnerability throughout the dimensionless scored index for each cluster. A higher vulnerability is observed in the Gulf of Paria, especially in the area of Port of Spain and San Fernando, where a higher population is found, as well as the presence of port and city. Other areas such as Point Fortin or the extreme south east of Trinidad in Guayaguayare region show maximum vulnerability due to the presence of ports and refineries.

Figure 11: Historical Vulnerability characterization (V0 scenario).



Vulnerability characterization under scenario V1

The V1 scenario, described in the Third Interim Report, represents changes in the vulnerability, concerning to population and economics. The available indicators or vulnerability and the new high resolution of the approach led to the necessity of posing new changes in the vulnerability.

The procedure to estimate future vulnerability in Trinidad and Tobago shows a combination of three phenomena:

- First, the population will decrease by a 7% between 2010 and 2040 according with UN Population Division

- Second, the available projections again from UN Population Division show an increasing trend in the quota of dependent population (under 15 or above 65) that is expected to double from 2010 (14%) to 2040 (29%).

- Third, the Human Development Index (HDI) spatial distribution in Trinidad and Tobago (Human Development Atlas 2012) shows a diverse distribution across the country and hence can be used as a proxy for vulnerability evolution.

Using the UN projections that suggest a 7% (g=7) decrease of population as a baseline, we have calculated equivalent population, both for present and future, adjusted to dependent population. For this purpose we have assigned to dependent population a weight of 2. As a result we predict that although the population is expected to decrease, this decrease is compensated by an increase its needs that will increase about 6% (v=6) for the whole country. Then we have adjusted vulnerability in all the spatial administrative units in the country with a factor obtained by division of national HDI by the local HDI. Hence if an area has a value of HDI over the mean, its vulnerability will decrease and if its HDI is below the mean its value will increase.

The result can be computed as follows:

$$P^*(t) = P(t,<15)\cdot a_1 + P(t,15-65)\cdot a_2 + P(t,>65)\cdot a_3 \tag{3}$$

Where P^* is the equivalent population, P is the population and a_1=a_3=2 and a_2=1 are based on an expert criterion. Hence:

$$P^*(2040) \big/ P^*(2010) = 1 + 0.06 = 1.06 \tag{4}$$

Eq. (4) means that although population decreases by 7 % its needs increases by 6%. Therefore, for each administrative unit we obtain

$$K_i = \frac{HDI}{HDI_i} \tag{5}$$

Each coastal receptor point is then corrected with the K_i correspondent to the affected spatial unit. As a summary, P_j^*, with j indicating each receptor point, will be estimated as:

$$P_j^* = P_j(t_0)\cdot(1-g)\cdot(1+v)\cdot K_j \tag{6}$$

Where the first factor stands initial population (P(t0)), the second for pure demographic decrease(1-g), the third for the increase in dependence ratio (1+v), and the fourth for the irregular spatial distribution of HDI (Kj)

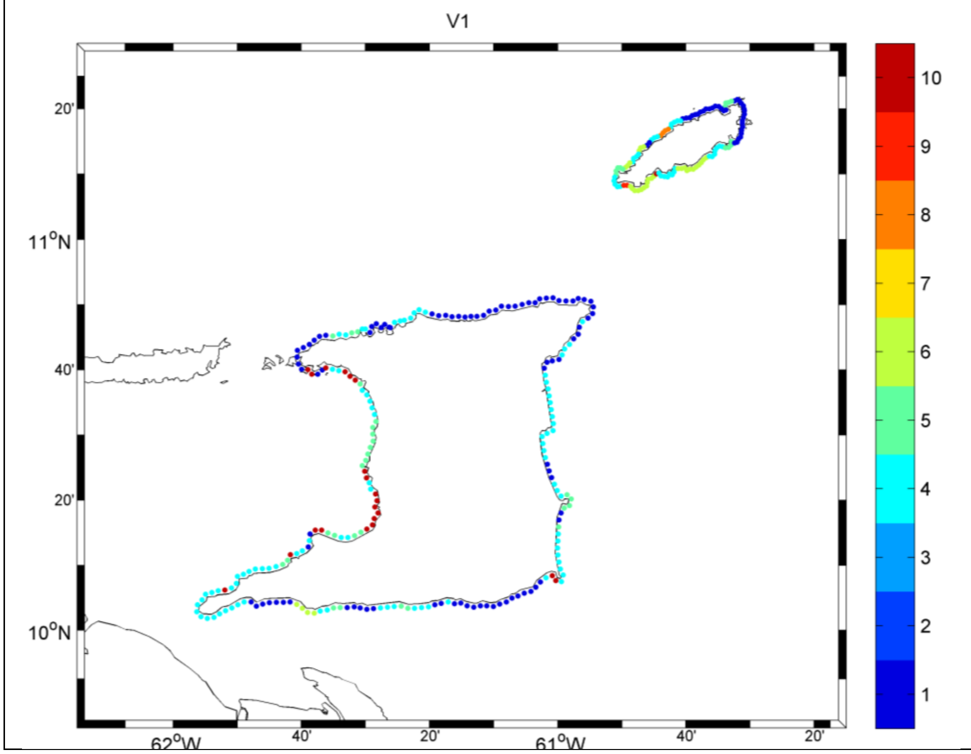
Using this new prognosis for future population, we have applied again the KMA to obtain new vulnerability groups for the V1 scenario. Table 2 shows the characteristics of each cluster, in terms of population and existence of a city, port or refinery, the number of receptor points represented by each cluster and the vulnerability scored index given by an expert criterion. Almost negligible differences of population can be seen.

Table 2: Vulnerability characterization for the V1 scenario.

Population	*City/Refinery/Port*	*Number of receptor points*	*Vulnerability Index*
2328	0	2	9
83	1	3	10
182	0	126	1
1493	1	1	10
871	0	40	5
781	1	6	10
515	0	119	4
1967	0	4	8
1232	0	32	6
347	1	12	10

The spatial representation of future vulnerability in Trinidad and Tobago under the V1 scenario can be seen in Figure 12, where the scored vulnerability index for each cluster is represented. Comparing Figures 11 and 12 only a slight difference in the receptor points of the east coast of Toco (in the northeast coast of Trinidad) and at some points in the area of Scarborough in Tobago is visible.

Figure 12: Historical Vulnerability characterization (V1 scenario).



RISK ASSESSMENT

As highlighted in section 4, where the Risk approach is described, the lack of spatial distribution of historical damage prevents from allowing a high-resolution estimation of economical damage. Although we have improved considerably the definition of the risk contributors, we only have an aggregated value of economical damage for the historical tropical storms used to calibrate the damage functions. This caveat implies the impossibility of assessing a high-resolution economical damage due to coastal flooding with the available information.

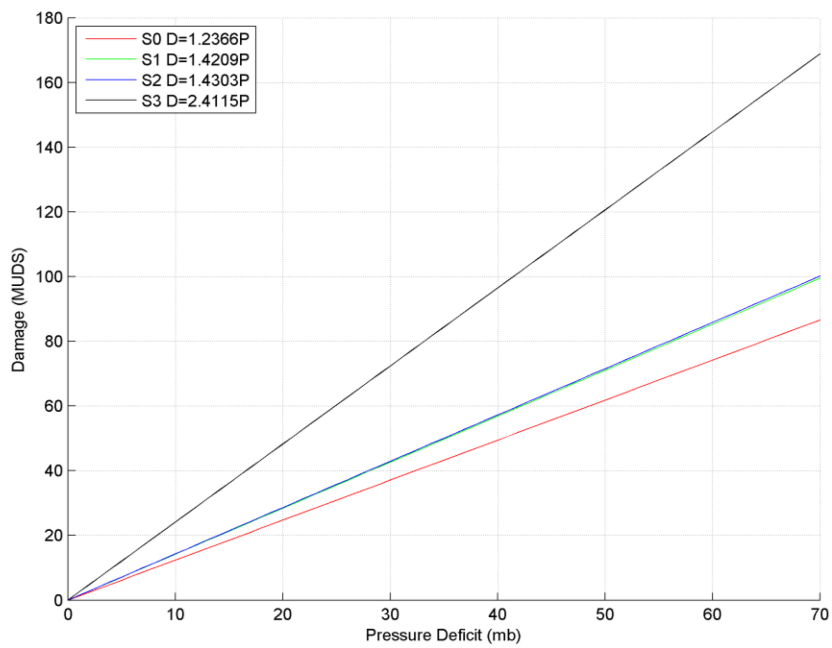
In spite of that, following the methodology proposed in the Second and Third Interim Reports and the risk approach described in section 4, we are going to calculate the total distribution of coastal flooding due to tropical storms under climate change scenarios.

First, we have calibrated the coastal flooding damage function. In this case, the alpha coefficient would change its value, but the distribution of damage is supposed to be the same. Due to the difference on the number of coastal receptor points (10 times more) the alpha coefficient has a value of 0.0364 (one less magnitude order). The aggregated damage function in this case is:

$$D_{CF} = 0.0364 \sum_{j=1}^{355} H_{CF,j} \cdot E_{CF,j} \cdot V_{CF,j} \quad (7)$$

The damage functions (or vulnerability functions) obtained with the new resolution and exposure and vulnerability characterization are shown in Figure 13. Note that scenarios S1 and S2 which are characterized by moderate changes in the hazard but different changes in the vulnerability (S1 keeps the historical vulnerability while S2 experiment future changes) led to almost the same damage curve. This is due to the very slight changes in the vulnerability for 2040.

Figure 13: Damage functions associated to coastal flooding due to tropical storms under climate change scenarios.



Applying the Pareto-Poisson distribution and statistical characterization, the distribution of the economical damage obtained under the climate change scenarios is summarized in Table 3. For example, one can see that from the 19.59 MUSD/year total Expected Annual Damage for present climate due to tropical storms, 5.79 MUSD/year come originate in coastal flooding.

Table 3: Mean and variance of damage distribution for each potential climate risk scenario. Present climate (scenario S0) is shown in grey color.

	Mean Damage (MUSD/year)	Variance (MUSD/year)
S0	5.79	13.45
S1	8.62	17.59
S2	8.67	17.71
S3	14.62	29.85

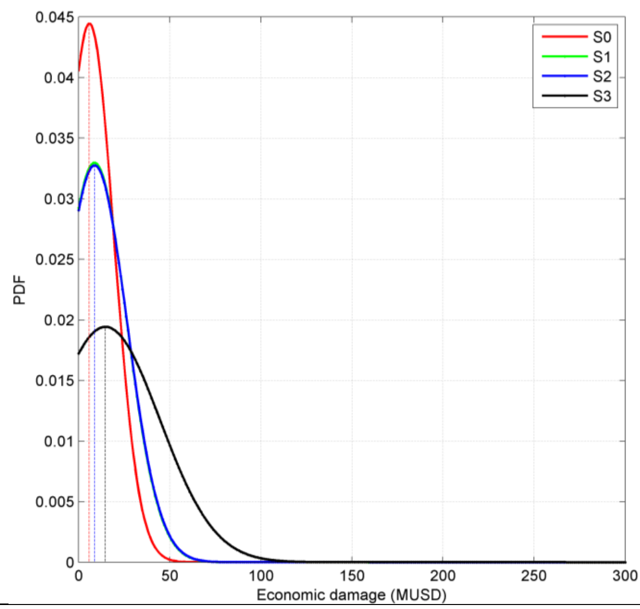
The damage associated with the return period corresponding to 50 and 200 years (probability of occurrence of 0.02 and 0.005) is obtained for each scenario as shown in Table 4.

Table 4: Damage associated with 50 and 200 years of return period for each climate change scenario and relative change with respect to S0.

Scenarios	D_{50} (MUSD)	D_{50}-D_{50S0} (%)	D_{200} (MUSD)	D_{200}-$D_{50\ -S0}$ (%)
S0	50.16	0	60.68	0
S1	65.04	29.7	78.38	29.17
S2	65.47	30,56	78.91	30.03
S3	110.38	120.12	133.03	119.22

Finally, Figure 14 shows the Probability Density Function (PDF) of the economical damage due to coastal flooding under climate change scenarios.

Figure 14: PDF of the economical damage due to coastal flooding under climate change scenarios.



CONCLUSIONS

A high resolution characterization of the hazard, exposure and vulnerability on the coast of Trinidad and Tobago has been carried out. This new study increases the resolution from a regional scale characterize by 29 receptor points to a local scale characterized by 355 receptor points each 2 km in Trinidad and 1 km in Tobago.

The vulnerability characterization has been carried out using a multivariate methodology to classify common vulnerability classes, based on socio-economic indicators, such as population and the existence of a city, port or refinery.

Finally, an aggregated damage for coastal flooding has been calculated and statistically characterized for each climate change scenario. Unfortunately, the lack of information on the spatial distribution of historical economical damages prevent from the assessment of coastal flooding damage at high resolution.

Annex 4: Hypotheses for the Cost - Benefit Calculations

In this section, the tables showing the cost and benefit calculations are presented. For each measure, this includes a table showing the data collected for the calculations, and a second table showing any technical calculations necessary (yearly rainfall, growth, etc.).

TTA 1. National Building Code

Cost/benefit	Concept	Description
Costs	*Sectoral audits*	Audits done at the beginning of the study to understand current situation.
	Consultancy work	Consultancy work to assist in developing new code.
	Salaries of civil engineers	Annual Salaries
	Unforeseen costs	Annual unforeseen costs to help ensure implementation of the new code.
Benefits	*Damages Evaded*	The amount of damages evaded during a natural disaster due to this measure. The expected damages were taken from the calculation of damages occurring from a Hurricane in 50 years of return period under scenario S (moderate climate change and expected future vulnerability) done for this report. A study on the national Building Code in Florida showed th 48.8% of the damages to a house are reduced due to a strong building code.
	Carbon Emissions Reduced from better insulation in new homes	The homes built under the new building code will be better insulated, and hence will consume less energy. This calculation takes into consideration the emissions factor of the electricity mix in Trinidad and Tobago and the social cost of carbon.
	Reduction in Electricity Costs due to better insulation in new homes	Given the better insulation in new homes built under the building code, less energy will be used to cool homes in the summer. The new houses expected to be built were estimated from a Trinidad and Tobago Housing Sub Committee Report and statistics on average housing size and number of houses came from the Central Statistics office of Trinidad and Tobago.

Additional costs and benefits that could occur but have not been included in this study include increased building costs per home due to the new building code´ stricter requirements and the potential increase in market value of the homes given their improved quality. These costs and benefits have not been included in thi study given that they depend on the technical requiements decided on in the building code and the markets preference for the increased building quality However, in a study done by Shimberg Center for Affordable Housing and Applied Research Associates, Inc. (2002), they state that "the cost increases var significantly, depending on the location, design option chosen, and the wind borne debris protection method. The wind resistance features represent the majorit of the cost increases...". They estimate that houses built for non-WBDR (wind-borne debris region), have an "estimated increased cost per square foot ranges fron $0.23 to $1.28 and the percent increase in selling price (building only, land cost not considered) ranges from 0.5 percent to 2.7 percent."

AUXILIARY DATA

Yearly salary of a civil engineer	36,317	PayScale, Inc., 2013. Ministry of Finance and the Economy, 2013.
Civil engineers hired	6	Author estimation
Audit cost	20,000	Author estimation
Audits per sector	5	Author estimation

% reduction in damages per household with Florida Building Code	48.8%	Based on Florida Building Code Cost and Loss Reduction Benefit Comparison Study of a masonr house in an area of Florida will winds at less than 200km/hr
Probability of occurrence in any given year	2%	Authors, Third Interim Report

Reduction in Energy consumption due to house insulation (kWh/m^2)	11.00	ECOFYS, EURIMA (2007). U-Values-For better energy performance of buildings".
CO2 Emissions for electricity generation (g CO_2 / kwh)	707	IEA Statistics, 2012
Average house area (m^2)	92.82	Central Statistical Office (2000). Population and Household and Household Size 2000.
Number of households	401,382	Central Statistical Office (2011). Trinidad and Tobago 2011 Population and Housing Census Demographic Report.
Number of sectors	3	Author estimation
Consultancy hours	1,600	Author estimation
Unforeseen costs	25,000	Author estimation
Estimated Losses due a tropical storm (D50)	221,607,000	Authors, Third Interim Report
% of damages (D50) that occur to building infrastructure	35%	Author estimation
% housing growth from 2015 to 2030	20%	Author calculation based on statistics below.
Price of Electricity for a household in 2011 (TT/kWh)	0.26	UN ECLAC (2011) An Assessment of the Economic Impact of Climate Change on the Energy Sector in Trinidad and Tobago

Social cost of carbon in year 2015, 2,5% discount rate (USD / tCO_2e)	61	The Interagency Working Group on Social Cost of Carb 2013
Houses to be demanded by 2020	443,410	Trinidad and Tobago Housing Sub Committee Repor
New houses needed to meet 202*0 demand	42,028	Author Calculation

TTA 2. Dike Construction in Trinidad

Cost/benefit	Concept	Description
Costs	*Site Investigations, Project Management and Engineering*	Major investment in first year for site investigations, and annual costs for project management and engineering.
	Mobilization	In the first year.
	Site clearing and preparation	In the first year of each section constructed.
	Excavation of dike root with excavator	In the first year of each section constructed.
	Hauling of dike root material	In the second year of each section constructed.
	Riprap delivered to site	In the third year of each section constructed.
	Excavator for placement of rip rap	In the fourth year of each section constructed.
	Fill gravel for dike construction	In the fifth year of each section constructed.
	Site revegetation	In the end of each section constructed.
	Site clean up	In the end of each section constructed.
	Maintenance	Annually after construction.
Benefits	*Damages Evaded*	The amount of damages evaded during a natural disaster due to this measure. The expected damages were taken from the calculation of damages occurring from a Hurricane in 50 years of return period under scenario S2 (moderate climate change and expected future vulnerability) done for this report. The average percentage of these damages related to flooding was taken by looking at the percentage of damages related to coastal flooding in the country's three w tropical extreme weather events, explained in this report.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA

1 km (clearing)	1,482.57	Mussetter Engineering, Inc., 2005.
1 km (excavation)	62,782.02	Mussetter Engineering, Inc., 2005.
1 km (hauling)	75,338.43	Mussetter Engineering, Inc., 2005.
1 km Riprap (delivered)	1,842,272.48	Mussetter Engineering, Inc., 2005.

Building km	26.73	Author estimation based on geographica data from Trinidad and Tobago
Estimated Losses due a tropical storm (D50)	221,607,000	Authors, Third Interim Report

Probability of occurrence in any given year	2%	Authors, Third Interim Report
Site Investigations, Project Management and Engineering	15%	Engineering costs for projects of this nature are typically 10-20% of capital cost. (Delcan, 2012)
1 km (excavator for placement of riprap)	433,475.87	Mussetter Engineering, Inc., 2005.
1 km (gravel)	794,705.77	Mussetter Engineering, Inc., 2005.
1 km (revegetation)	2,036.07	Mussetter Engineering, Inc., 2005.
1 km (clean up)	697.8	Mussetter Engineering, Inc., 2005.
Average percentage of damages related to coastal flooding in the Country's three worst tropical storms	28%	Author calculation based on historical data presented in the Third Interem Report
Assumption of damages due to flooding reduced during a tropical storm because of this measure	50%	Author estimation
Maintenance Costs	3,954,984	4% of total construction costs, as used in Whitehead, 2011

TTA 3. Alert System connected to the Monitoring System

Cost/benefit	Concept	Description
Costs	*(Web) Domain name*	Every three years
	(Web) Hosting	Annual.
	(Web) Design and development	First year.
	(Web) Maintenance	Annual
	Radio ads	Every three years.
	TV ads	Every three years
Benefits	*Cost Reductions in tropical storm Damages Due to Early Warning*	The expected damages were taken from calculations of damages occurring from a Hurricane in 50 years of return period under scenario S2 (moderate climate change and expected future vulnerability) done in this report. According to a report looking at the damage reductions due to the implementation of early warning systems, the author states that up to 35% of the damages in natural disaster can be avoided due to effective early warning systems. This percentage increases in function of number of hours before the event that the warning is given.
	Cost Reductions in Drought Damages Due to Early Warning	The expected increase in drought damage between 2008 and 2040 due to climate change that were calculated in this report were used to determine the measures effectiveness.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA

Number of radio ads	1	Author estimation
Number of TV ads	1	Author estimation
Cost producing radio ad	500.00	V Marketing & Media Inc., 2009
Cost producing TV ad	1,500.00	Demand Media, Inc., 2013

Web hosting ($/month)	50.00	MangoOrange, 2013
Estimated Losses due to a tropical storm (D50)	221,607,000	Authors, Third Interim Report
Probability of tropical storm occurrence in any given year	2%	Authors, Third Interim Report
Increase in drought damage between 2008 and 2040 due to climate change	34%	Authors, Third Interim Report

Cost registration web domain (3 years, $)	50.00	The Trinidad and Tobago Network Information Centre, 2010.
Cost maintenance web domain (3 years, $)	50.00	The Trinidad and Tobago Network Information Centre, 2010.
Cost designing website ($)	10,000.00	DesignQuote, 2013
Cost maintenance website ($/year)	500	Executionists, Inc., 2013
Maximum practical losses prevented from early warning	35%	A Cost Effective Solution to Reduce Disaster Losses in Developing Countries Hydro-Meteorological Services, Early Warning, and Evacuation
% of losses in the event of a tropical storm prevented by this measure	5%	Author Estimation, based on data presented in "A Cost Effective Solution to Reduce Disaster Losses in Developing Countries Hydro-Meteorological Services, Early Warning, and Evacuation"
% of losses during droughts prevented by this measure	10%	Author Estimation, based on data presented in "A Cost Effective Solution to Reduce Disaster Losses in Developing Countries Hydro-Meteorological Services, Early Warning, and Evacuation"
Current Damages due to droughts (TT)	1,354,000	Authors, Third Interim Report
Damages due to droughts (TT) in 2040	1,815,000	Authors, Third Interim Report

TTA 4 and TTA 6. Emergency Protocols & Institutional Training Program

TTA 4	Concept	Description
Costs	*Flood and rainfalls - Creation of protocol*	In the first year
	Flood and rainfalls - Revision of protocol	Every four years
	Flood and rainfalls - Creation of brochure	Every four years
	Flood and rainfalls - Printing of brochure	Annually
	tropical storms - Creation of protocol	In the first year
	tropical storms - Revision of protocol	Every four years
	tropical storms - Creation of brochure	Every four years
	tropical storms - Printing of brochure	Annually
	Heat waves - Creation of protocol	In the first year
	Heat waves - Revision of protocol	Every four years
	Heat waves - Creation of brochure	Every four years
	Heat waves - Printing of brochure	Annually
	Production of radio ad	Annually
	Emission of radio ad	Annually
	Production of TV ad	Annually
	Emission of TV ad	Annually

TTA 6	*Concept*	Description
Costs	*Workshop preparation*	In the first year
	Workshop revision	Annually
	Workshop conduction	Annually

TTA 4 and 6	*Concept*	Description
Benefits	*Damages prevented due to preparative measures*	The expected damages were taken from IH Cantabria´s calculations of damages occurring from a Hurricane in 50 years of return period under scenario S2 (moderate climate change and expected future vulnerability) found in this report.

An interesting note to point out is that the benefits are estimated for solely the actions covered within this measure, however, several reports highlight the fact that capacity building, covered in these measures, coupled with Early warning systems (TTA 2), have often been implemented together, as each measure can increase the impact of the other.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA TTA 4

Number of hours to create protocol	20.00	Author estimation
Number of hours to revise protocol	5.00	Author estimation
Brochure design (CAD $)	5,560.00	Sage Media, 2010
Brochure printing (10,000 copies, $)	1,200.00	PrintingForLess, 2013
Cost producing radio ad	500.00	V Marketing & Media Inc., 2009
Population (2012)	1,337,439	World Bank

Cost producing TV ad	1,500.00	Demand Media, Inc., 2013
Cost emitting radio ad per week ($)	2,500.00	V Marketing & Media Inc., 2009
Cost emitting 30 second TV ad ($)	1,500	Demand Media, Inc., 2013
Yearly weeks of radio campaign	6	Author estimation
Yearly weeks of TV campaign	3	Author estimation
Population growth rate (average annual %)	0.326%	World Bank

AUXILIARY DATA TTA 6

Hours to prepare workshops	100	Author estimation
Hours to review workshops	30	Author estimation

Number of workshops per year	6	Author estimation
Length of workshops	18	Author estimation

AUXILIARY DATA: BENEFITS FOR TTA 4 TTA 6

Estimated Losses due a tropical storm (D50)	221,607,000	Authors, Third Interim Report
Percentage of damages that could be prevented by these measures	5.0%	Author Estimation

Probability of occurrence in any given year	2%	Authors, Third Interim Report

TTA 5. Social Awareness Program

Cost/benefit	Concept	Description
Costs	*General design of the program*	In the first year
	Review of the program	Annually
	Development and review of farmers workshops	Every three years
	Review of farmers workshops	In the years of implementation of the workshops, without development.
	Farmers workshops conduction	Annually
	Creation of brochure for general population	Every two years
	Printing of brochure for general population	Annually
	Creation of brochure for farmers	Every two years
	Printing of brochure for farmers	Annually
Benefits	*Losses in crops avoided due to measure*	The estimated expected losses in crops were taken from a report by ECLAC, which estimated the economic impacts that climate change would have on the agricultural sector in Trinidad and Tobago. Calculations for this analysis used the estimations under the IPCC A2 scenario.
	Reduced water consumption from Public Campaign	Economic benefits of the reduction in water consumption were calculated by taking the price of water desalination, given that a reduction in the demand for water will mean that less water will need to go through this process.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA

Hours to create general content of the program	40.00	Author estimation
Hours to review the program	12.00	Author estimation
Hours to develop workshops for farmers	15.00	Author estimation
Review of farmers workshops (hours)	4.00	Author estimation
Improvement in the value of yields of farmers who implement tools learned at workshops	5%	Author estimation
Present Value of Coca Cumulative Losses in 2020 Relative to the Baseline (2% discount rate, TT)	116,650,000	ECLAC (2011) "AN ASSESSMENT OF THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE AGRICULTURE SECTOR IN TRINIDAD AND TOBAGO"
Loss per year of Coca between 2010 and 2020	11,665,000	Author Calculation

Present Value of Coca Cumulative Losses in 2030 Relative to the Baseline (2% discount rate, TT)	304,920,000	ECLAC (2011) "AN ASSESSMENT THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE AGRICULTURE SECTOR IN TRINID AND TOBAGO"
Loss per year of Coca between 2020 and 2030	18,827,000	Authors, Third Interim Repor
Number of holdings in TT	18,951	Central Statistics Office Trinid and Tobago 2004 Agricultur Census
Expected Number of Farmers per workshop	50	Author Estimation
Provided water (L/person/day)	50.00	Author estimation
Average Household Size	3.30	Ministry of Planning and Sustainable Development Central Statistical Office (201

		"Trinidad and Tobago 2011 Census Demographic Report"
Length farmers workshops (hours)	8.00	Author estimation
Number of farmers workshops	6.00	Author estimation
Brochure design (CAD $)	5,560.00	Sage Media, 2010
Brochure printing (10,000 copies, $)	1,200.00	PrintingForLess, 2013
Present Value of Root Crop Cumulative Losses in 2020 Relative to the Baseline (2% discount rate, TT)	34,800,000	ECLAC (2011) "AN ASSESSMENT OF THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE AGRICULTURE SECTOR IN TRINIDAD AND TOBAGO"
Loss per year of Root Crop between 2010 and 2020	3,480,000	Author Calculation
Present Value of Root Crop Cumulative Losses in 2030 Relative to the Baseline (2% discount rate, TT)	132,900,000	ECLAC (2011) "AN ASSESSMENT OF THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE AGRICULTURE SECTOR IN TRINIDAD AND TOBAGO"
Loss per year of Root Crop between 2020 and 2030	9,810,000	Author Calculation
Success Rate of Workshops (defined as the percentage of farmers who implement knowledge learned)	20%	Author Estimation
Success Rate of Campaign to public (defined as the percentage of public who read brochure and implement knowledge learned)	5%	Author Estimation
Water consumption reductions due to water conservation plans	Between 7 and 35%	Statistics from "Cases in Water Conservation: How Efficiency Programs Help Utilities Save and Avoid Costs"
Assumption of water consumption reduction in the household of those who implemented the information	15%	Author Estimation
Cost desalinated water (€/m^3)	0.45	Cetaqua. Water Technology Centre.

TTA 7. Rainwater harvesting

Cost/benefit	Concept	Description
Costs	*Tank*	Cost of tanks purchased per year.
	Roof harvest system	Cost of systems purchased per year.
	Filters	Cost of filters purchased per year.
	Labour	For installation of these sytems.
	Maintenance	Annually
Benefits	*The amount of rainwater harvested through these systems*	The economic benefits of the water harvested were calculated by taking the price of water desalination, given that harvesting rain wat will reduce the demand for water, which in turn means that less water will need to go through this process.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA

Harvest system cost ($)	68.10	The Caribbean Environmental Health Institute (2009). Rainwater Catch it While You Can, A Handbook on Rainwater Harvesting in the Caribbean. The United Nations Environment Programme (UNEP).
Tank cost ($/m³)	50.00	Unidad de Apoyo Técnico en Saneamiento Básico Rural (UNATSABAR). Guía de diseño para captación de agua de lluvia.
Tank volume per household (m³)	6.00	Own estimation based on the water demand of the inhabitants of Trinidad and Tobago.
Number of households	401,382	Ryan James (2012). Regional Workshop and Frequency Coordination meeting on the Transition to Digital Terrestrial Television and the Digital Dividend. Telecommunications Authority of Trinidad and Tobago.
Tanks to be installed per year	236	Author estimation
Provided water (L/person/day)	50.00	Author estimation
Average Household Size	3.30	Ministry of Planning and Sustainable Development Central Statistical Office (2011) "Trinidad and Tobago 2011 Census Demographic Report"

Filter costs ($)	10.30	Thomas, T.H. and Martinson, D.B. (2007). Roofwat Harvesting: A Handbook for Practitioners. Delft, Tl Netherlands, IRC International Water and Sanitati Centre.
Labour cost ($)	41.30	Thomas, T.H. and Martinson, D.B. (2007). Roofwat Harvesting: A Handbook for Practitioners. Delft, Tl Netherlands, IRC International Water and Sanitati Centre.
Maintenance cost (% of total cost)	2%	Thomas, T.H. and Martinson, D.B. (2007). Roofwat Harvesting: A Handbook for Practitioners. Delft, Tl Netherlands, IRC International Water and Sanitati Centre.
Objective percentage for 2030	1.00%	Author estimation
Runoff ratio	0.8	UNATSABAR
Roof surface	92.82	Central Statistical Office (2000). Population anc Household and Household Size 2000.
Cost desalinated water (€/m³)	0.45	Cetaqua. Water Technology Centre.

TTA 8. Infrastructure and Building Reinforcement

Cost/benefit	Concept	
Costs	*Ceiling isolation*	Costs to refurbish the ceilings of houses within the meaure
	Wall isolation	Costs to refurbish the walls of houses within the meaure
	Roof concrete reinforcement	Costs to refurbish the roofs of houses within the meaure
Benefits	*Damages evaded during a natural disaster due to this measure*	The expected damages were taken from the calculations of damages occurring from a Hurricane in 50 years of return period under scenario S2 (moderate climate change and expected future vulnerability) done in this report.
	Reduction in Electricity Costs	Given the better insulation in the homes reinforced, less energy will be used to cool homes in the summer. The new houses expected to be built were estimated from a Trinidad and Tobago Housing Sub Committee Report and statistics on average housing size and numbe of houses came from the Central Statistics office of Trinidad and Tobago.
	Carbon Emissions Reduced	The homes built that are reinforced will be better insulated, and hence will consume less energy. This calculation takes into considerati the emissions factor of the electricity mix in Trinidad and Tobago and the social cost of carbon.

Additional benefits that could occur but have not been included in this study include the potential increase in market value of the homes given their improved quality. These costs benefits have not been included in this study given that they depend the markets preference for the increased building quality. In a study don by Shimberg Center for Affordable Housing and Applied Research Associates, Inc. (2002), they estimate that houses built for non-WBDR (wind-borne debris region have a "percent increase in selling price (building only, land cost not considered) ranges from 0.5 percent to 2.7 percent." This number is based on new homes bui under the new building code, and can therefore will likely be higher than homes that are reinforced, but it can help give an idea of the maximum price increase th could occur from the implementation of this measure.

AUXILIARY DATA

Average house area (m^2)	92.82	Central Statistical Office (2000). Population and Household and Household Size 2000.
Wall height (m)	3.00	Author estimation
Wall surface (m^2)	115.61	Author estimation
Ceiling isolation width (cm)	3.00	ECOFYS, EURIMA (2007). U-Values-For better energy performance of buildings".
Number of households	401,382	Central Statistical Office (2011). Trinidad and Tobago 2011 Population and Housing Census Demographic Report.
% of households to reinforce	10%	Author estimation
Average Household Size	3.30	Ministry of Planning and Sustainable Development Central Statistical Office (2011) "Trinidad and Tobago 2011 Census Demographic

		Report"
Reduction in Energy consumption due to house insulation (kWh/m^2)	11.00	ECOFYS, EURIMA (2007). U-Values-Fo better energy performance of buildin
Price of Electricity for a household in 2011 (TT/kWh)	0.26	UN ECLAC (2011) An Assessment of t Economic Impact of Climate Change the Energy Sector in Trinidad and Tob
CO2 Emissions for electricity generation (g CO_2 / kwh)	707	IEA Statistics, 2012

Social cost of carbon in year 2015, 2,5% discount rate (USD / tCO_2e)	61	The Interagency Working Group on Social Cost of Carbon, 2013
Wall isolation width (cm)	2.00	ECOFYS, EURIMA (2007). U-Values-For better energy performance of buildings".
Ceiling isolation cost ($/cm/m²)	0.80	ECOFYS, EURIMA (2007). U-Values-For better energy performance of buildings".
Wall isolation cost ($/cm/m²)	1.25	ECOFYS, EURIMA (2007). U-Values-For better energy performance of buildings".
Ceiling isolation cost ($/household)	222.768	Own estimation based on data from ECOFYS, EURIMA (2007). U-Values-For better energy performance of buildings".
Wall isolation cost ($/household)	289.03	Own estimation based on data from ECOFYS, EURIMA (2007). U-Values-For better energy performance of buildings".
Roof concrete reinforcement cost ($/m²)	11.08	Remodelling Expense, 2013.
Estimated Losses due a tropical storm (D50)	221,607,000	Authors, Third Interim Report
Probability of occurrence in any given year	2.0%	Authors, Third Interim Report
% of damages (D50) that occur to building infrastructure	35.0%	Author Estimation
% reduction in damages per household due to better codes	48.8%	Based on Florida Building Code Cost and Loss Reduction Benefit Comparison Study of a masonry house in an area of Florida will winds at less than 200km/hr
% of building infrastructure damages (D50) related to housing	20%	Author Estimation

TTA 9. Retention ponds

Cost/benefit	Concept	Description
Costs	*Building ponds*	Costs of constructing the ponds for this measure
	Maintaining ponds	Annually.
Benefits	*Amount of water harvested*	The economic benefits of the water harvested were calculated by taking the price of water desalination, given that the water caught in the retention ponds will reduce the demand for water, which in turn means that less water will need to go through this process.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA

Building 1 m^3 pond	61.36	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Maintaining 1 m^2 pond per year	1.99	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Proposed pond diameter (m)	10.00	Author estimation
Pond surface area (m^2)	78.54	Author calculation
Runoff ratio	0.80	UNATSABAR
Water harvesting surface	235.62	Author estimation

Pond height (m)	2.00	Author estimation
Pond volume (m^3)	157.08	Author calculation
Cost of pond construction ($)	9,638	Author calculation, based on pond dimensions and c from bibliography
Cost of pond maintenance ($)	313	Author calculation, based on pond dimensions and c from bibliography
Cost desalinated water (€/m^3)	0.45	Cetaqua. Water Technology Centre.

TTA 10. Filter strips

Cost/benefit	Concept	Description
Costs	*Building filter strips*	Costs of construction
	Maintaining filter strips	Annually
Benefits	*Land protection from flooding*	The economic benefits were considered as the calculated the agricultural value of the land, which was the value of agricultural output in th country divided by the area of land used for agricultural purposes.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA

Building 1 m² strip	7.67	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Maintaining 1 m² strip per year	0.15	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
GDP by Sector: total agriculture (TT)	888,000,000	CSO in Trinidad
Improvement in flooding due to this measure	5%	Author Estimation

Agricultural land (m²)	540,000,000	World Bank, 2013.
% agricultural land used	0.01%	Author Estimation
GDP Growth Rate (2012)	1.24%	World Bank
Coverage of Filter Strip (m² land / m² of filter strip)	50	Author Estimation

TTA 11. Permeable pavements

Cost/benefit	Concept	Description
Costs	*Building permeable pavement*	Costs of construction
	Maintaining permeable pavement	Annually.
Benefits	*Number of Deaths avoided*	Deaths from vehicle accidents are estimated at about 200 per year, while about 3000 injuries are cause per year from traffic accide Many of these accidents occur due to dangerous roadways during heavy rainfall. The benefits of this measure are the deaths and inju that would be avoided due to permeable pavements, which create safer road conditions during these events.
	Number of Injuries avoided	
	Time Value saved through this measure	This measure is estimated to reduce traffic due to better road conditions during heavy rain. The economic value of this benefit is calculated by estimating the economic value of driving time.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA

Paved roads (km)	4,251.52	World Bank, 2013.
% of roads to be converted	10%	Author estimation
Building 1 m2 of paved road	82.84	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Building 1km of paved road ($)	828,400	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Statistical value of a life (in 1995 US dollars)	630,000	Statistical Life of a person In Trinidad and Tobago., 1995. Miller, Ted. "Variations between Countries in Values of Statistical Life"
Infliation from 1995	1.53	Oregon State University. Individual Year Conversion Factor Tables
Average length of commute during rush hour in Port of Spain (Hrs)	2	Author Interview
Number of Vehicles that commute to Port of Spain	5,000	The Cropper Foundation. "Port of Spain"

Percentage of additional time reduction due to measure	10%	Author Estimation
Number of Rainy Days per year	163	Vanessa Hyacinth-Ash. A Study of the Last F Years of Daily Rainfall Data in Trinidad to Examine Any Indications of Climate Chang and its Repercussions for the Farming Population in Trinidad and Tobago.
Maintaining 1km of paved road ($)	6,100.00	Royal Haskoning DHV (2012). Costs and Ben of Sustainable Drainage Systems.
Average width of roads (m)	10.00	Author estimation
Deaths in traffic accidents / total deaths	2.58%	LeDuc Media, 2013.
Deaths caused by traffic accidents per year	200	Third Interim Report
Injuries caused by traffic accidents per year	3,000	Third Interim Report
Reduction in accidents due to the measure	10%	Third Interim Report
Percentage of a life valued per serious injury	10%	Author Estimation

Value of driving time per vehicle (USD)	11.58	Clark et al. "Life-Cycle Cost Analysis in Pavement Design - In Search of Better Investment Decisions." Pavement Division Interim Technical Bulletin, September
Increase in Commute Time due to heavy Rain	0.25	Stern, Andrew D., et al. "Analysis of weather impacts on traffic flow in metropolitan Washington DC."
Number of Work Days per Year	233	Assuming 14 National Holidays and 14 days paid vacation. (Vacation Days taken from national Labour law information of TT from UN, Holidays from government website)

TTA 12. Beach Nourishment in Tobago

Cost/benefit	Concept	Description
Costs	*Nourishment*	Costs of nourishment
	Sand used	Cost of raw material
Benefits	*Losses to tourism sector avoided*	The losses in tourism due to climate change in Trinidad and Tobago were taken from a study Stockholm Environment Institute (US Centre) and Global Development and Environment Institute (Tufts University). These numbers were scaled down using the percentage of tourism that is related to Tobago for the country (8.75%). Tourism accounts for 96% of total exports 56.8 % of employment in Tobago, which makes it very important sector in terms of the economic and social viability of the island.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA

km to nourish	14.15	The Cropper Foundation (2010). Fourth National Report of Trinidad and Tobago to the Convention on Biological Diversity.
sand m³/km	1,041,795.82	Beach Nourishment Viewer. Western Carolina University, 2013.
Cost of sand ($/m³)	0.283786	Beach Nourishment Viewer. Western Carolina University, 2013.
Cost of 1 km nourishment ($/km)	1,378,440.00	Beach Nourishment Viewer. Western Carolina University, 2013.
Estimated reduction in losses to tourism due to measure	5%	Author Estimation
Proportion of land area in Tobago covered by coastal areas	2.57%	Water Resources Agency (2001) NATIIONAL REPORT ON Integrating The Management of Watersheds and Coastal Areas in Trinidad and Tobago
Value of 2007 dollar in 2013	0.89	Oregon State Univesty. Individual Year Conversion Factor Tables
Losses to tourism by 2025 expected to occur due to climate change (2007, USD)	40,000,000	Bueno, R. and others (2008), "The Caribbean and climate change: the cost of inaction", Stockholm Environment Institute (US Center) and Global Development and Environment Institute (Tufts University).

Yearly loss to tourism due to climate change 2007-2025 (USD)	2,352,941	Author calculation
Losses to tourism by 2050 expected to occur due to climate change without changes (USD)	80,000,000	Bueno, R. and others (2008), "The Caribbean and climate change: the c of inaction", Stockholm Environmen Institute (US Center) and Global Development and Environment Institu (Tufts University).
Yearly loss to tourism due to climate change 2025-2050 (USD)	1,600,000	Author calculation
Land area of Tobago (km²)	300	Water Resources Agency (2001) NATIIONAL REPORT ON Integrating The Management of Watersheds and Coastal Areas in Trinic and Tobago
% of Tourism in Tobago (Travel & Tourism Economy GDP Aggregates in Tobago / GDP Agregates for the country)	8.70%	Expected 2015 GDP from Tourism. Wo Travel and Tourism Council. (2005) "Trinidad and Tobago the impact of tr and tourism on jobs and the econom

TTA 13. Mangrove Restoration in Trinidad

Cost/benefit	Concept	Description
Costs	Restoration	Cost of Restoration
Benefits	*Total Direct Use Benefits for Restoration*	This estimated total direct benefits per hectare was taken from a report that looked at the cost benefit analysis of several different mangro restoration projects all over the world. As explained in the measure's description, mangroves are highly beneficial because they can provic forestry and fishery products. Furthermore they enhance the sustainability of the area protecting the coast from solar UV-B radiation, 'greenhouse' effects, and fury of cyclones, floods, sea level rise, wave action and coastal erosion. Mangrove swamps act as traps for sediments, and sinks for nutrients. The root systems of the plants keep the substrate firm, and thus contribute to a lasting stability of the coast
	Carbon Sequestration	This calculation takes into consideration the average burial rate of carbon by mangroves per year and the social cost of carbon.

The benefits from mangroves in terms of protecting from sea level rise and flooding was not calculated due to the fact that, under the 50 year storm, or higher, uncertain to what extent the mangroves will be able to help protect. However, they are known to have significant benefits in tropical storms of lower intensity c therefore are a good option for Trinidad.

AUXILIARY DATA

Length west coast (km)	4.7	Author estimation
Length east coast (km)	39.4	Author estimation
Cost of restoration ($/km²)	22,500	Roy R. Lewis III (2011). Mangrove Restoration - Costs and Benefits of Successful Ecological Restoration.
Plantation width (km)	0.75	Author estimation
Average burial rate of organic carbon from Mangrove Restoration (g/m²/year)	163.3	Science for Environment Policy. "Mangroves provide both climate change mitigation and adaptation services."
Molecular weight of CO_2 to Carbon	3.7	US EPA. "Unit Conversions, Emissions Factors, and Other Reference Data"
Area in the east coast (km²)	3.5	Author estimation

Area in the west coast (km²)	29.6	Author estimation
Annual performance	10%	Author estimation
Total Direct Use Value of Mangrove Restoration (USD/ha/year)	2,505	Roy R. Lewis III (2011). Mangrove Restorati Costs and Benefits of Successful Ecologic Restoration.
Social cost of carbon in year 2015, 2,5% discount rate (USD / tCO_2e)	61	The Interagency Working Group on Soci Cost of Carbon, 2013

TTA 14. Parametric Insurance Scheme

Cost/benefit	Concept	Description
Costs	*Strategic plan*	During design of scheme
	Finance engineering	During design of scheme
	Registration Web domain	Every three years
	Maintenance web domain	Every three years
	Web Design	During design of scheme
	Website maintenance	Annually

Benefits for this measure were not calculated, as it was considered that insurance programs do not change the overall damage caused by the extreme events. They are useful from a cost-efficiency perspective but not from a cost-benefit approach, because the economic damage is the same even if insurance programs are not developed, the only difference is the way in which that economic damage is covered.

AUXILIARY DATA

Strategic plan (consultant hours)	200.0	Author estimation
Financial engineering (consultant hours)	500	Author estimation
Web hosting ($/month)	50.00	MangoOrange, 2013
Cost registration web domain (3 years, $)	50.00	The Trinidad and Tobago Network Information Centre, 2010.
Cost maintenance web domain (3 years, $)	50.00	The Trinidad and Tobago Network Information Centre, 2010.
Cost designing website ($)	10,000.00	DesignQuote, 2013
Cost maintenance website ($/year)	500	Executionists, Inc., 2013

TTA 15. Sowing crops adapted to new climate conditions

Cost/benefit	Concept	Description
Costs	*Scientist's wage*	Annually
	Unforeseen costs	Annually
	Workshops	Annually
Benefits	*Losses in crops avoided due to measure*	The estimated expected losses in crops were taken from a report by ECLAC, which estimated the economic impacts that climate chan would have on the agricultural sector in Trinidad and Tobago. Calculations for this analysis used the estimations under the IPCC A2 scenario.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA

Scientist annual wage ($)	43,817	PayScale, Inc., 2013. Ministry of Finance and the Economy, 2013.
Number of scientists	5	Own estimation
Hours of workshop	16	Own estimation
Improvement in the value of yields	20%	Author estimation
Present Value of Coca Cumulative Losses in 2020 Relative to the Baseline (from 2011 with 2% discount rate, TT)	116,650,000	ECLAC (2011) "AN ASSESSMENT OF THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE AGRICULTURE SECTOR IN TRINIDAD AND TOBAGO"
Loss per year of Coca between 2011 and 2020	12,961,111	Author Calculation
Present Value of Coca Cumulative Losses in 2030 Relative to the Baseline (2% discount rate, TT)	304,920,000	ECLAC (2011) "AN ASSESSMENT OF THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE AGRICULTURE SECTOR IN TRINIDAD AND TOBAGO"
Loss per year of Coca between 2020 and 2030	18,827,000	Author Calculation
Number of holdings in TT	18,951	Central Statistics Office Trinidad and Tobago 2004 Agricultural Census

Unforeseen costs ($)	35,000	Author Estimation
Annual number of workshops	8	Author Estimation
Expected Number of Farmers per workshop	100	Author Estimation
Present Value of Root Crop Cumulative Losses in 2020 Relative to the Baseline (from 2011 2% discount rate, TT)	34,800,000	ECLAC (2011) "AN ASSESSMENT OF THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE AGRICULTURE SECTOR TRINIDAD AND TOBAG
Loss per year of Root Crop between 2011 and 2020 (TT)	3,866,667	Author Calculation
Present Value of Root Crop Cumulative Losses in 2030 Relative to the Baseline (2% discount rate, TT)	132,900,000	ECLAC (2011) "AN ASSESSMENT OF THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE AGRICULTURE SECTOR TRINIDAD AND TOBAG
Loss per year of Root Crop between 2020 and 2030	9,810,000	Author Calculation
Success Rate of Workshops (defined as the percentage of farmers who implement knowledge learned)	20%	Author Estimation

TTA 16. Green Roofs

Cost/benefit	Concept	Description
Costs	*Building green roofs*	Construction Costs
	Maintaining green roofs	Annually
Benefits	*Avoided storm water management costs*	Given that green roofs help filter rain water, and reduce storm water runoff, they create economic benefits in terms of reduced costs of storm water management. This cost reduction was estimated in a report analyzing the monetary value of the benefits of green roofs.
	Annual Carbon Uptake	Green roofs are a source of carbon sequestration. This benefit is calculated by the carbon absorption rate of the green roof, along with the social cost of carbon.
	Energy Savings due to Better Insulation by Green Roof	Green roofs act as a form of insulation for the roofs, which is one for the most important areas for heat flow in a building. Green Roofs will help keep buildings in Trinidad and Tobago cooler in the hot summer months, and therefore will reduce electricity consumption due to air conditioning units.

Additional Benefits include the reduction in other air pollutants such as SO_2, NO_2, PM_{10}, and O_3, sound attenuation, food production and security, and marketing value, and increased property values. These benefits have not been included in this assessment given their highly localized nature and the decisions of owners (for example, decisions regarding how the project is marketed and how any food produced is used on public or business buildings). To have an idea of what these benefits may look like, Ray Tomalty Ph.D. and Bertek Komorowski (2010) completed valuations of these benefits in five specific case studies for buildings in the US and Canada.

AUXILIARY DATA

Building 1 m² green roof ($)	84.37	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Maintaining 1 m² green roof per year ($)	0.23	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
m² of roof	12,000.00	Author estimation
Annual progress	25%	Author estimation
Price of Electricity for a household in 2011 (TT/kWh)	0.26	UN ECLAC (2011) An Assessment of the Economic Impact of Climate Change on the Energy Sector in Trinidad and Tobago

Avoided storm water management costs (US/m²)	9.06	The Monetary Value of the Soft Benefit Green Roofs Final Report
Annual Carbon Uptake (USD/ha)	28.46	The Monetary Value of the Soft Benefit Green Roofs Final Report
Stored Carbon (USD/ha)	213	The Monetary Value of the Soft Benefit Green Roofs Final Report
Reduced energy flow (by insulation) of buildings (kWh/m²)	29.70	FEMP Federal Technology Alert: Gree Roofs DOE-EE0298

TTA 17. Climate Change Survey for the General Public

Cost/benefit	Concept	Description
Costs	*Strategic plan*	In the first year
	Data Collection	During the two year survey period
	Results analyzation and presentation	At the end of the data collection
	Survey Hosting	In the first year

The benefits for this measure were not calculated given that the product of the implementation of this measure, namely the information that is learned from the results of this study, is unknown and therefore its consequences in terms of impact on future policies and programs cannot be predicted.

AUXILIARY DATA

Strategic plan for survey implementation and survey design (consultant hours)	200	Author estimation
Hours per worker for data collection per month	160	Author estimation, based on full time employment
Number of workers	15	Author estimation

Survey Hosting (Euros/year)	800	Platinum Membership at Survey Moneky, in order to completely personalize results
Wages paid to callers for data collection (12.50 TTD /hr)	12.5	Based on minimum wage in the country
Analyzation of the results an presentation/publication (consultant hours)	30	Author estimation

TTA 18. Mangrove Restoration in Tobago

Cost/benefit	Concept	Description
Costs	Restoration	Cost of Restoration
Benefits	*Total Direct Use Benefits for Restoration*	This estimated total direct benefits per hectare was taken from a report that looked at the cost benefit analysis of several different mangrov restoration projects all over the world. As explained in the measure's descrption, mangroves are highly beneficial because they can provid forestry and fishery products. Furthermore they enhance the sustainability of the area protecting the coast from solar UV-B radiation, 'greenhouse' effects, and fury of cyclones, floods, sea level rise, wave action and coastal erosion. Mangrove swamps act as traps for sediments, and sinks for nutrients. The root systems of the plants keep the substrate firm, and thus contribute to a lasting stability of the coast
	Carbon Sequestration	This calculation takes into consideration the average burial rate of carbon by mangroves per year and the social cost of carbon.

The benefits from mangroves in terms of protecting from sea level rise and flooding was not calculated due to the fact that, under the 50 year storm, or higher, it is uncertain to what extent the mangroves will be able to help protect. However, they are known to have significant benefits in tropical storms of lower intensity and therefore are a good option for Tobago. Additionally, implicit in these direct benefits yet not necessarily accounted for is the loss in tourism, which is specifically important to Tobago that could come from this measure. This benefit has not be calculated for this exercise due to the lack of information depicting the extent that tourists come to Tobago specifically for the mangroves (as opposed to Bucco Bay and the coral reefs, for example), and therefore would change their tourism habits due to the loss of this natural wildlife. It should be noted however, that those who run tours and excursions through the mangroves would be personally affected by this loss.

AUXILIARY DATA

ha of mangroves to restore	157.0	Author estimation
Cost of restoration ($/km²)	22,500	Roy R. Lewis III (2011). Mangrove Restoration - Costs and Benefits of Successful Ecological Restoration.
Molecular weight of CO_2 to Carbon	3.7	US EPA. "Unit Conversions, Emissions Factors, and Other Reference Data"

Average burial rate of organic carbon from Mangrove Restoration ($g/m^2/year$)	163.3	Science for Environment Policy. "Mangroves provide both climate change mitigation and adaptation services."
Total Direct Use Value of Mangrove Restoration (USD/ha/year)	2,505	Roy R. Lewis III (2011). Mangrove Restoration - Costs and Benefits of Successful Ecological Restoration.
Social cost of carbon in year 2015, 2,5% discount rate (USD / tCO_2e)	61	The Interagency Working Group on Social Cost of Carbon, 2013

TTA 19. Coastal Reef Protection and Restoration in Tobago

TTA 19	Concept	Description
Costs	*Creation of communication strategy to promote recruitment of awareness raisers*	In the first year
	Creation of brochure to promote recruitment of awareness raisers	In the first year
	Printing of brochures to promote recruitment of awareness raisers	In the first year
	Training sessions for awareness raisers -preparation	In the first year
	Training sessions for awareness raisers - revision	Annually
	Training sessions for awareness raisers -implementation	Annually
	Fisherfolk - Creation of strategy/information	In the first year
	Fisherfolk - Revision of information	Every four years
	Fisherfolk - Creation of brochure	Every four years
	Fisherfolk- Printing of brochure	Annually
	Fisherfolk - Creation of signage	Every four years
	Fisherfolk- Printing of signage	Every four years
	Local Community - Creation of strategy/information	In the first year
	Local Community - Revision of information	Every four years
	Local Community - Creation of brochure	Every four years
	Local Community - Printing of brochure	Annually
	Tourists - Creation of strategy/information	In the first year
	Tourists - Revision of information	Every four years
	Tourists - Creation of brochure	Every four years
	Tourists - Printing of brochure	In the first year
	Tourists - Creation of signage	Every four years
	Tourists - Printing of signage	Every four years
	Production of radio ad	Annually
	Emission of radio ad	Annually

	Workshop preparation	In the first year
	Workshop revision	Annually
	Workshop conduction	Annually
Benefits	*Losses in Tourism prevented due to this measure*	The losses in tourism due to climate change in Trinidad and Tobago were taken from a study Stockholm Environme Institute (US Center) and Global Development and Environment Institute (Tufts University). These numbers were "sc down" using the percentage of tourism that is related to Tobago for the country (8.75%) and the fact that an estir 40% of tourists to Tobago report visiting the Coral Reefs. Tourism accounts for 96% of total exports 56.8 % of employment in Tobago, which makes it very important sector ir of the economic and social viability of the island.
	Coastal damages prevented due to this measure	The expected damages were taken from the calculations of damages occurring from a Hurricane in 50 years of r period under scenario S2 (moderate climate change and expected future vulnerability), found in this report. The average percentage of these damages related to flooding was taken by looking at the percentage of damages related to coastal flooding in the country's three worst tropical extreme weather events, explained in thi report. A average percentage of these damages occurring in Tobago was also taken from this report.

The benefits from reduced overfishing are a known direct benefit that would occur from the implementation of this measure; however, they were not able to be included in this analysis due to lack of information on overfishing in the area.

AUXILIARY DATA

Number of hours to create communication strategy and determine information to include	20.00	Author estimation
Number of hours to revise information	5.00	Author estimation
Brochure design (CAD $)	5,560.00	Sage Media, 2010
Brochure printing (10,000 copies, $)	1,200.00	PrintingForLess, 2013

Signage design (CAD $)	5,560.00	Sage Media, 2010
Brochure printing (2ft by 3ft vinyl signs, $ each)	25.97	PrintingForLess, 2013
Hours to prepare community meetings/workshops	100	Author estimation
Hours to review community meetings/workshops	20	Author estimation
Hours to prepare training sessions	100	Author estimation

Hours to review training sessions	20	Author estimation
Estimated percentage of visitors to Tobago who visit for the Coral Reefs	40%	Burke, L. Greenhalgh, S., Prager, D. Cooper, E. (2008)
Annual economic benefits from Coral reefs associated fisheries (USD, 2006)	1,050,000	Burke, L. Greenhalgh, S., Prager, D. Cooper, E. (2008)
Shoreline protection from coral reefs - reduced erosion and wave damage (USD, 2006)	25,500,000	Burke, L. Greenhalgh, S., Prager, D. Cooper, E. (2008)
Value of USD in 2006 compared to today	0.865	Oregon State University. Individual Year Conversion Factor Tables
Tobago´s GDP in 2006	286,000,000	Burke, L. Greenhalgh, S., Prager, D. Cooper, E. (2008)
Proportion of land area in Tobago covered by coastal areas	2.57%	Water Resources Agency (2001) NATIIONAL REPORT ON Integrating The Management of Watersheds and Coastal Areas in Trinidad and Tobago
Estimated Losses due a tropical storm (D50, S2)	221,607,000	Authors, Third Interim Report

Probability of occurrence in any given year	2%	Authors, Third Interim Report
Percentage of damage due to coastal flooding	28%	Average of damage done by three largest hurricanes, Second interim report.
Estimated reduction in coastal damages due to this measure	2%	Author Estimation
Cost producing radio ad	500.00	V Marketing & Media Inc., 2009
Cost producing TV ad	1,500.00	Demand Media, Inc., 2013
Cost emitting radio ad per week ($)	2,500.00	V Marketing & Media Inc., 2009
Cost emitting 30 second TV ad ($)	1,500	Demand Media, Inc., 2013
Yearly weeks of radio campaign	6	Author estimation
Yearly weeks of TV campaign	3	Author estimation
Number of meetings/workshops per year	4	Author estimation

Length of meetings/workshops (hours)	16	Author estimation
Number of training sessions per year	1	Author estimation
Length of training sessions (hours)	24	Author estimation
Losses to tourism by 2025 expected to occur due to climate change (USD, 2007)	40,000,000	Bueno, R. and others (2008), "The Caribbean and climate change: the cost of inaction", Stockholm Environment Institute (US Center) and Global Development and Environment Institute (Tufts University).
Yearly loss to tourism due to climate change 2007-2025 (USD, 2007)	2,352,941	Author calculation
Losses to tourism by 2050 expected to occur due to climate change without changes (USD, 2007)	80,000,000	Bueno, R. and others (2008), "The Caribbean and climate change: the cost of inaction", Stockholm Environment Institute (US Center) and Global Development and Environment Institute (Tufts University).
Yearly loss to tourism due to climate change 2025-2050 (USD)	1,600,000	Author calculation
Land area of Tobago (km^2)	300	Water Resources Agency (2001) NATIIONAL REPORT ON Integrating The Management of Watersheds and Coastal Areas in Trinidad and Tobago
% of Tourism in Tobago (Travel & Tourism Economy GDP Aggregates in Tobago / GDP Aggregates for the country)	8.70%	Expected 2015 GDP from Tourism. World Travel and Tourism Council. (2005) "Trinidad and Tobago the impact of travel and tourism on jobs and the economy"
Estimated reduction in losses to tourism due to measure	5%	Author Estimation
Value of 2007 dollar in 2013	0.89	Oregon State University. Individual Year Conversion Factor Tables
Percentage of damage due to coastal flooding, occurring in Tobago	20%	Average of damage done by three largest hurricanes, Second interim report.

PT 1. Climate Change Adaptation Tool

Cost/benefit	Concept	Description	
Costs	*Development of the tool*	In the first year	
	Revision of the tool	Every three years	

Economic benefits were not calculated for this measure, given that it is hard to know the future information that will be learned and implemented from this tool. That being said, by having a tailor-made tool regarding the information related to climate change, Petrotrin will be better able to manage their risks and plan future projects, which will indirectly create economic benefits for the company.

AUXILIARY DATA

Development of the tool ($)	80,000.00	Author estimation	**Revision of the tool ($)**	7,500.00	Author estimation

PF 1. Coastal Zone and Guaracara River Protection

Costs/Benefits	Concept	Description
Costs	*Site Investigations, Project Management and Engineering*	Major investment in first year for site investigations, and annual costs for project management and engineering.
	Mobilization	In the first year.
	Site clearing and preparation	In the first year of each section constructed.
	Excavation of dike root with excavator	In the first year of each section constructed.
	Hauling of dike root material	In the second year of each section constructed.
	Riprap delivered to site	In the third year of each section constructed.
	Excavator for placement of rip rap	In the fourth year of each section constructed.
	Fill gravel for dike construction	In the fifth year of each section constructed.
	Site revegetation	In the end of each section constructed.
	Site clean up	In the end of each section constructed.
	Maintenance	Annually after construction.
Benefit	*Value of Land Protected by Measures*	The land value is taken from a study done by John Whitehead for Petrotrin. The study done by Bhawan Singh provided the projections related to land loss due to storm surge, land erosion, and inundation due two different climate change scenarios: CGCM2 and HADCM3. For these calculations, the average of the estimated land loss from the two scenarios was used.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA

1 km (clearing)	1,482.57	Mussetter Engineering, Inc., 2005.
1 km (excavation)	62,782.02	Mussetter Engineering, Inc., 2005.
1 km (hauling)	75,338.43	Mussetter Engineering, Inc., 2005.
1 km Riprap (delivered)	1,842,272.48	Mussetter Engineering, Inc., 2005.

Building km	1.65	Own estimation based on geographical data of Trinidad and Tobago.
Land Value (2011, USD/ha)	4,448	Cost-Benefit Analysis of Climate Change Adaption and Mitigation Projects inTrinidad and Tobago: Draft Final Report (Revised)
Percentage of industrial land protected (not lost) by this measure	7.5%	Author Estimation

Maintenance Costs	248,746	4% of total construction costs, as used in Whitehead, 2011
1 km (excavator for placement of riprap)	433,475.87	Mussetter Engineering, Inc., 2005.
1 km (gravel)	794,705.77	Mussetter Engineering, Inc., 2005.
1km (revegetation)	2,036.07	Mussetter Engineering, Inc., 2005.
1 km (clean up)	697.80	Mussetter Engineering, Inc., 2005.
Land values are assumed to grow at the annual rate of GDP growth	1.2%	World Bank
Industrial Land protected per year, assuming linear (2007-2031, ha)	7.24	Author Calculation
Land Affected by Storm Surge, Erosion, and Inundation in 2031 (average of the two scenarios) (ha)	173.67	DETAILED VULNERABILITY ASSESSMENT SURVEY AND STORM SURGE MODELLING OF THE WEST COAST OF TRINIDAD: VESSIGNY TO CAP-DE-VILLE QUADRANT
Site Investigations, Project Management and Engineering	15%	Engineering costs for projects of this nature are typically 10-20% of capital cost. (Delcan, 2012)

PF 2. Retention Ponds in Point Fortin

Costs/Benefits	Concept	Description
Costs	*Building 2 ponds*	Costs of construction
	Maintaining 2 ponds	Annually
Benefits	*Value of Land Protected by Measures*	The land value is taken from a study done by John Whitehead for Petrotrin. The study done by Bhawan Singh provided the projections related to land loss due to storm surge, land erosion, and inundation due two different climate change scenarios: CGCM2 and HADCM3. For these calculations, the average of the estimated land loss from the two scenarios was used.
	Value of water harvested	Similar to TTA 7 and 9, the economic benefits of the water harvested were calculated by taking the price of water desalination, given that harvesting rain water will reduce the demand for water, which in turn means that less water will need to go through this process.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA

Building 1 m³ pond ($)	61.36	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Maintaining 1 m² pond per year ($)	1.99	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Pond volume (m³)	1,875.00	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Water harvesting surface	1,875.00	
Land Value (2011, USD/ha)	4,448	Cost-Benefit Analysis of Climate Change Adaption and Mitigation Projects in Trinidad and Tobago: Draft Final Report (Revised)

Percentage of industrial land protected (not lost) by this measure	1.0%	Author Estimation
Cost desalinated water (€/m3)	0.45	Cetaqua. Water Technology Center.
Runoff ratio	0.80	UNATSABAR
Pond surface area (m²)	625.00	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Land values are assumed to grow at the annual rate of GDP growth	1.2%	World Bank

Industrial Land protected per year, assuming linear (2007-2031, ha)	7.24	Author Calculation
Land Affected by Storm Surge, Erosion, and Inundation in 2031 (average of the two scenarios) (ha)	173.67	DETAILED VULNERABILITY ASSESSMENT SURVEY AND STORM SURGE MODELLING OF THE WEST COAST OF TRINIDAD: VESSIGNY TO CAP-DE-VILLE QUADRANT

PF 3. Construction of Swales and Berms in Point Fortin

	Concept	Description
Costs	*Building swales*	Cost of construction
	Swales regular maintenance	Annually
	Swales irregular maintenance	Every ten years
	Building Berms	Cost of construction
	Berms regular maintenance	Annually
Benefits	*Value of Land Protected by Measures*	The land value is taken from a study done by John Whitehead for Petrotrin. The study done by Bhawan Singh provided the projections related to land loss due to storm surge, land erosion, and inundation due two different climate change scenarios: CGCM2 and HADCM3. For these calculations, the average of the estimated land loss from the two scenarios was used.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA

Number of swales	8	Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R., Shaffer, P. (2007). The SUDS manual. Ciria Books.
m^2 per swale	10	Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R., Shaffer, P. (2007). The SUDS manual. Ciria Books.

Land Affected by Storm Surge, Erosion, and Inundation in 2031 (average of the two scenarios) (ha)	173.67	DETAILED VULNERABILITY ASSESSMENT SURVEY AND STORM SURGE MODELLING OF THE WEST COAST OF TRINIDAD: VESSIGNY TO CAP-DE-VILLE QUADRANT

PF 4. Mangrove Restoration in Point Fortin

Cost/benefit	Concept	Descrip`tion
Costs	*Restoration*	Cost of Restoration
Benefits	*Carbon Sequestration*	This calculation takes into consideration the average burial rate of carbon by mangroves per year and the social cost of carbon.

It is important to note that there will be other benefits related to mangrove restoration in this area, as seen in TTA 13, however, it was decided not to include them in this calculation given that many of these economic benefits (to fisherman, for example) are unknown, given that these mangroves will be built near the industrial sites. Additionally, these benefits would not be directly useful for Parroting, for whom this pilot study was carried out.

Mangroves enhance the sustainability of the area protecting the coast from solar UV-B radiation, 'greenhouse' effects, and fury of cyclones, floods, sea level rise, wave action and coastal erosion. Mangrove swamps act as traps for sediments, and sinks for nutrients. The root systems of the plants keep the substrate firm, and thus contribute to a lasting stability of the coast. The benefits from mangroves in terms of protecting from sea level rise and flooding was not calculated due to the fact that, under the 50 year storm, or higher, it is uncertain to what extent the mangroves will be able to help protect. However, they are known to have significant benefits in tropical storms of lower intensity and therefore are a good option for Petrotrin, specifically in helping to reduce flooding in the short term and provide time to move infrastructure.

Additionally, in the case of Point Fortin, given that the mangroves are to be restored in front of the Dike, they could help reduce maintenance costs. This benefit was not calculated in this exercise given the fact that this measure's cost-benefit analysis is calculated independently from whether or not that measure is implemented for comparative purposes.

AUXILIARY DATA

Surface of mangrove to plant (km^2)	0.30	Author estimation
Plantation width (km)	0.75	Author estimation
Cost of restoration ($/$km^2$)	22,500	Roy R. Lewis III (2011). Mangrove Restoration - Costs and Benefits of Successful Ecological Restoration.
Molecular weight of CO_2 to Carbon	3.7	US EPA. "Unit Conversions, Emissions Factors, and Other Reference Data"

Plantation length (km)	0.4	Own estimation based on geographical data
Annual performance	10%	Author estimation
Average burial rate of organic carbon from Mangrove Restoration (g/m^2/year)	163.3	Science for Environment Policy. "Mangroves provide both climate change mitigation and adaptation services."
Social cost of carbon in year 2015, 2,5% discount rate (USD / tCO_2e)	61	The Interagency Working Group on Social Cost of Carbon, 2013

PF 5. Relocation of Infrastructure in Point Fortin

Cost/benefit	Concept	Description
Costs	*Engineering of a Tank*	Cost of engineering during construction
	Raw Materials	Cost of raw materials during construction
	Welding	Cost of welding during construction
	Machinery	Cost of machinery during construction
	Labour	Labour costs during construction
	Other Costs	Additional costs during construction
Benefits	*Value of new infrastructure that has been relocated*	The benefits of this measure are the newly constructed infrastructure that has been relocated. Its value was determined using the accounting principle of valuing infrastructure based on its cost of construction. This value was then depreciated at 6.875% per year, given that the range o depreciation used by Petrotrin for Infrastructure assets is 3.75% to 10% - as stated in the company's financial statement for 2012.

Given the lack of information regarding the physical infrastructure in the area and is use, an estimation of the number of tanks in use was taken from mo available. The volume of these tanks was estimated by calculating the base area of these tanks, and assuming their height was 17 meters, as the height of t tanks could not be extracted from the maps. The cost of building new tanks with the same total volume was estimated. Other infrastructure that was seen in t maps, but was not able to be identified by its use, such as buildings, and therefore was not included in this study. Additionally, the potential costs of land purcha for relocation, in the event that the company does not already own land on which this infrastructure can be moved to, has not been included in the c estimation. The costs of removing the current infrastructure have also not been calculated due to the lack of information regarding the physical infrastructure c the status of the soil in this area.

It should be noted that by 2031, the projections of inundation in the area show that the port and terminalling areas will be inundated. Therefore, in a business usual scenario, this area would not offer significant economic benefits to Petrotrin in terms of productive use - given that it is currently used primarily for termina purposes. If the port and terminalling stations are not elevated to ensure their productivity in the future (see PF 6), then this newly relocated infrastructure may n provide much use to Petrotrin. Therefore, the economic benefits due to the productive value of the infrastructure are contingent on the fact that the port a terminalling stations are available in the future (see PF 6). Due to lack of information regarding the level of activity at the Port Fortin's terminalling station and po the economic benefits related with productive use of the infrastructure have not been included in the analysis. This economic benefit, however, is likely the m important benefit from this activity.

Given the lack of specific information regarding infrastructure in the vulnerable area, about the infrastructures' current value (estimated useful life remaining of t assets) and about its current and future expected uses, it should be considered that this is a rough estimate could be improved if specific details were ma available.

AUXILIARY DATA

Raw Materials (USD)	462,017	Design of a Petroleum Tank with a floating roof with the capacity of 1000,000 barrels for the Tesca Company in Ecuador (De la Cadena Ramos, C, Larrea Esparaza, P. , 2012)
Welding (USD)	2,329.3	Design of a Petroleum Tank with a floating roof with the capacity of 1000,000 barrels for the Tesca Company in Ecuador (De la Cadena Ramos, C, Larrea Esparaza, P. , 2012)
Volume of tank with cost estimates (m^3)	159,000.0	Design of a Petroleum Tank with a floating roof with the capacity of 1000,000 barrels for the Tesca Company in Ecuador (De la Cadena Ramos, C, Larrea Esparaza, P. , 2012)
Area m^2 of tank to relocate	25,093.5	Based on maps of the area
Depreciation assumed for tanks	7%	Manufacturing plant and equipment 3.75% to 10% - straight-line according to financial statements of Petrotrin (2012)
Machinery (USD)	12483.62	Design of a Petroleum Tank with a floating roof with the capacity of 1000,000 barrels for the Tesca Company in Ecuador (De la Cadena Ramos, C, Larrea Esparaza, P. , 2012)
Labour (USD)	374,760.0	Design of a Petroleum Tank with a floating roof with the capacity of 1000,000 barrels for the Tesca Company in Ecuador (De la Cadena Ramos, C, Larrea Esparaza, P. , 2012)
Other Costs (USD)	9,287	Design of a Petroleum Tank with a floating roof with the capacity of 1000,000 barrels for the Tesca Company in Ecuador (De la Cadena Ramos, C, Larrea Esparaza, P. , 2012)
Number of tanks to relocate	34.0	Based on maps of the area
Volume of tanks, assuming same height of 17 meters	426,589	Author Estimation
Engineering of a Tank (USD)	3,000.00	Design of a Petroleum Tank with a floating roof with the capacity of 1000,000 barrels for the Tesca Company in Ecuador (De la Cadena Ramos, C, Larrea Esparaza, P. , 2012)

Diameter of tanks (m)	52.0	Based on maps of the area
	71.0	
	72.0	
	20.0	
	10.0	
	20.0	
	18.0	
	14.0	
	14.0	
	7.0	
	7.0	
	10.0	
	8.0	
	7.0	
	11.0	
	73.0	
	41.0	

Diameter of tanks (m)	41.0	Based on maps of the area
	41.0	
	14.0	
	14.0	
	6.0	
	6.0	
	37.0	
	37.0	
	37.0	
	38.0	
	9.0	
	9.0	
	9.0	
	9.0	
	9.0	
	9.0	
	10.0	

PF 6: Infrastructure Elevation in Point Fortin

The economic costs and benefits have not been estimated given the lack of specific information regarding infrastructure in the vulnerable area, about the infrastructures' current value (estimated useful life remaining of the assets) and about its current and future expected uses. Without specific information, it is hard to estimate the costs of the elevation of this infrastructure. Given that Point Fortin is one of Petrotrin's best terminalling services, this could be a beneficial measure to undertake. However, due to lack of information regarding the level of activity at the Port Fortin terminalling station and port, these economic benefits have not been included in the analysis.

PAP 1. Dike Construction in Pointe-à-Pierre

Costs/Benefits	Concept	Description
Costs	*Site Investigations, Project Management and Engineering*	Major investment in first year for site investigations, and annual costs for project management and engineering.
	Mobilization	In the first year.
	Site clearing and preparation	In the first year of each section constructed.
	Excavation of dike root with excavator	In the first year of each section constructed.
	Hauling of dike root material	In the second year of each section constructed.
	Riprap delivered to site	In the third year of each section constructed.
	Excavator for placement of rip rap	In the fourth year of each section constructed.
	Fill gravel for dike construction	In the fifth year of each section constructed.
	Site revegetation	In the end of each section constructed.
	Site clean up	In the end of each section constructed.
	Maintenance	Annually after construction.
Benefit	*Value of Land Protected by Measures*	The value of the infrastructure in Pointe-à-Pierre was estimated by taking the value of the value of the refinery and marketing assets, declared in the financial statement of the company in 2012 and dividing this number by the number of acres in Pointe-à-Pierre. This calculation was performed given that Pointe-à-Pierre is the only refinery in the company, and therefore the assets declared by the company in the area of refinery and marketing should be close to the value of this land for the company. It should be mentioned however, that since the portion of "marketing" assets is unknown, this value has not been taken out of the asset value used in this calculation and therefore the estimation could be slightly over estimated.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA

1 km (clearing)	1,482.57	Mussetter Engineering, Inc., 2005.
1 km (excavation)	62,782.02	Mussetter Engineering, Inc., 2005.
1 km (hauling)	75,338.43	Mussetter Engineering, Inc., 2005.
1 km Riprap (delivered)	1,842,272.48	Mussetter Engineering, Inc., 2005.
Building km	1.118	Own estimation based on geographical data of Trinidad and Tobago.
Percentage of industrial land protected (not lost) by this measure	7.5%	Author Estimation
Refining and Marketing Assets for Petrotrin (TT)	12,680,536,000.00	Petrotrin Financial Statements 2012
Size of Pointe-à-Pierre (acres)	2,000.00	Petrotrin (2013)
Site Investigations, Project Management and Engineering	15%	Engineering costs for projects of this nature are typically 10-20% of capital cost. (Delcan, 2012)
1 km (excavator for placement of riprap)	433,475.87	Mussetter Engineering, Inc., 2005.

1 km (gravel)	794,705.77	Mussetter Engineering, Inc., 2005.
1km (revegetation)	2,036.07	Mussetter Engineering, Inc., 2005.
1 km (clean up)	697.80	Mussetter Engineering, Inc., 2005.
Industrial Land protected per year, assuming linear (2007-2031, ha)	0.49	Author Calculation
Land Affected by Storm Surge, Erosion, and Inundation in 2031 (average of the two scenarios) (ha)	11.72	Phase 2 Vulnerability Assessment Survey for the Pointe-à-Pierre Foreshore Area
Land Value in Pointe-à-Pierre (TT/acre)	6,340,268.00	Petrotrin Financial Statements 2012
Maintenance Costs	169,827	4% of total construction costs, as used in Whitehead, 2011

PAP 2. Construction of Retention Ponds in Pointe-à-Pierre

Costs/Benefits	Concept	Description
Costs	*Building 2 ponds*	Costs of construction
	Maintaining 2 ponds	Annually
Benefits	*Value of Land Protected by Measures*	The value of the infrastructure in Pointe-à-Pierre was estimated by taking the value of the value of the refinery and marketing assets, declared in the financial statement of the company in 2012 and dividing this number by the number of acres in Pointe-à-Pierre. This calculation was performed given that Pointe-à-Pierre is the only refinery in the company, and therefore the assets declared by the company in the area of refinery and marketing should be close to the value of this land for the company. It should be mentioned however, that since the portion of "marketing" assets is unknown, this value has not been taken out of the asset value used in this calculation and therefore the estimation could be slightly over estimated.
	Value of water harvested	Similar to TTA 7, TTA 9 and PF 2, the economic benefits of the water harvested were calculated by taking the price of water desalination, given that harvesting rain water will reduce the demand for water, which in turn means that less water will need to go through this process.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA

Building 1 m^3 pond ($)	61.36	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Maintaining 1 m^2 pond per year ($)	1.99	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Pond volume (m^3)	1,875.00	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Water harvesting surface	1,875.00	

Percentage of industrial land protected (not lost) by this measure	1.0%	Author Estimation
Refining and Marketing Assets for Petrotrin (TT)	12,680,536,000.00	Petrotrin Financial Statements 2012
Size of Pointe-à-Pierre (acres)	2,000.00	Petrotrin (2013)

Cost desalinated water (€/m3)	0.45	Cetaqua. Water Technology Center.
Runoff ratio	0.80	UNATSABAR
Pond surface area (m^2)	625.00	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Industrial Land protected per year, assuming linear (2007-2031, ha)	0.49	Author Calculation

Land Affected by Storm Surge, Erosion, and Inundation in 2031 (average of the two scenarios) (ha)	11.72	Phase 2 Vulnerability Assessment Survey for the Pointe-à-Pierre Foreshore Area
Land Value in Pointe-à-Pierre (TT/acre)	6,340,268.00	Petrotrin Financial Statements 2012

PAP 3. Sustainable Drainage Systems in Pointe-à-Pierre

Concept		Description
Costs	*Building swales*	Cost of construction
	Swales regular maintenance	Annually
	Swales irregular maintenance	Every ten years
	Building Berms	Cost of construction
	Berms regular maintenance	Annually
Benefits	*Value of Land Protected by Measures*	The value of the infrastructure in Pointe-à-Pierre was estimated by taking the value of the value of the refinery and marketing assets, declared in the financial statement of the company in 2012 and dividing this number by the number of acres in Pointe-à-Pierre. This calculation was performed given that Pointe-à-Pierre is the only refinery in the company, and therefore the assets declared by the company in the area of refinery and marketing should be close to the value of this land for the company. It should be mentioned however, that since the portion of "marketing" assets is unknown, this value has not been taken out of the asset value used in this calculation and therefore the estimation could be slightly over estimated.

The result calculated includes all potential costs and benefits that were considered for this measure.

AUXILIARY DATA

Number of swales	11	Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R., Shaffer, P. (2007). The SUDS manual. Ciria Books.
Swale construction cost per m^2 ($)	19.17	Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R., Shaffer, P. (2007). The SUDS manual. Ciria Books.
m^2 per swale	10	Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R., Shaffer, P. (2007). The SUDS manual. Ciria Books.
Annual swale maintenance cost per m^2 ($)	0.15	Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R., Shaffer, P. (2007). The SUDS manual. Ciria Books.
Irregular swale maintenance cost ($/10 years)	4,125	Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R., Shaffer, P. (2007). The SUDS manual. Ciria Books.

Kilometers of berm to construct	5.97	based on author estimation of berms needed based on maps and inundation/erosion studies provided for the area
Annual berm maintenance cost per m ($)	0.15	Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R., Shaffer, P. (2007). The SUDS manual. Ciria Books.
Percentage of industrial land protected (not lost) by this measure	1.5%	Author Estimation
Refining and Marketing Assets for Petrotrin (TT)	12,680,536,000.00	Petrotrin Financial Statements 2012
		-
Size of Pointe-à-Pierre (acres)	2,000.00	Petrotrin (2013)

Sand filter volume (m^3)	1,167.9	Woods-Ballard, B., Kellagher, R., Martin, P., Jefferies, C., Bray, R., Shaffer, P. (2007). The SUDS manual. Ciria Books.
Sand filter cost per m^3 ($)	230.12	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Sand filter maintenance cost per m^3 ($)	1.22	Royal Haskoning DHV (2012). Costs and Benefits of Sustainable Drainage Systems.
Oil separator cost ($)	32,796.00	Xerxes, 2011.
Oil separator monthly maintenance cost ($)	102.00	United States Environmental Protection Agency, 2009.

Bern Construction per ft (USD)	15.00	"Unit Prices" Department of Inspections and Permits, Anne Arundel County, Mayrland
Industrial Land protected per year, assuming linear (2007-2031, ha)	0.49	Author Calculation
Land Affected by Storm Surge, Erosion, and Inundation in 2031 (average of the two scenarios) (ha)	11.72	Phase 2 Vulnerability Assessment Survey for the Pointe-à-Pierre Foreshore Area
Land Value in Pointe-à-Pierre (TT/acre)	6,340,268.00	Petrotrin Financial Statements 2012

PAP 4. Mangrove Restoration in Pointe-à-Pierre

Cost/benefit	Concept	Descrip`tion
Costs	*Restoration*	Cost of Restoration
Benefits	*Carbon Sequestration*	This calculation takes into consideration the average burial rate of carbon by mangroves per year and the social cost of carbon.

It is important to note that there will be other benefits related to mangrove restoration in this area, as seen in PF 4, however, it was decided not to include them in this calculation given that many of these economic benefits (to fisherman, for example) are unknown, given that these mangroves will be built near the industrial sites. Additionally, these benefits would not be directly useful for Petrotrin, for whom this pilot study was carried out.

Mangroves enhance the sustainability of the area protecting the coast from solar UV-B radiation, 'greenhouse' effects, and fury of cyclones, floods, sea level rise, wave action and coastal erosion. Mangrove swamps act as traps for sediments, and sinks for nutrients. The root systems of the plants keep the substrate firm, and thus contribute to a lasting stability of the coast. The benefits from mangroves in terms of protecting from sea level rise and flooding was not calculated due to the fact that it is uncertain to what extent the mangroves will be able to help protect under the scenarios projected for the seal level intrusions expected in the long run (2051 projected by CGCM). However, they are known to have significant benefits in tropical storms of lower intensity and therefore are a good option for Petrotrin, specifically in helping to reduce some flooding in the short term and provide time to move infrastructure.

AUXILIARY DATA

Surface of mangrove to plant (km^2)	0.387	Author estimation
Cost of restoration ($/$km^2$)	22,500	Roy R. Lewis III (2011). Mangrove Restoration - Costs and Benefits of Successful Ecological Restoration.
Molecular weight of CO_2 to Carbon	3.7	US EPA. "Unit Conversions, Emissions Factors, and Other Reference Data"

Annual performance	10%	Author estimation
Average burial rate of organic carbon from Mangrove Restoration (g/m^2/year)	163.3	Science for Environmen Policy. "Mangroves provi both climate change mitigation and adaptati services."
Social cost of carbon in year 2015, 2,5% discount rate (USD / tCO_2e)	61	The Interagency Workin Group on Social Cost o Carbon, 2013

PAP 5. Relocation of Infrastructure in Pointe-à-Pierre

Cost/ benefit	Concept	Description
Costs	*Engineering of a Tank*	Cost of engineering during construction
	Raw Materials	Cost of raw materials during construction
	Welding	Cost of welding during construction
	Machinery	Cost of machinery during construction
	Labour	Labour costs during construction
	Other Costs	Additional costs during construction
Benefits	*Value of new infrastructure that has been relocated*	The benefits of this measure are the newly constructed infrastructure that has been relocated. Its value was determined using the accounting principle of valuing infrastructure based on its cost of construction. This value was then depreciated at 6.875% per year, given that the range of depreciation used by Petrotrin for Infrastructure assets is 3.75% to 10% as stated in the company's financial statement for 2012.

In this measure, the economic costs have been estimated; however, several expected costs have not been included in the estimation due to lack of information. Firstly, given the lack of information regarding the physical infrastructure in the area and is use, an estimation of the number of tanks in use was taken from maps available. The volume of these tanks was estimated by calculating the base area of these tanks, and assuming their height was 17 meters, as the height of the tanks could not be extracted from the maps. The cost of building new tanks with the same total volume was estimated. Additionally, the potential costs of land purchase for relocation, in the event that the company does not already own land on which this infrastructure can be moved to, has not been included in the cost estimation. The costs of removing the current infrastructure have also not been calculated due to the lack of information regarding the physical infrastructure and the status of the soil in this area.

Given the lack of specific information regarding infrastructure in the vulnerable area, about the infrastructures' current value (estimated useful life remaining of the assets) and about its current and future expected uses, it should be considered that this is a rough estimate could be improved if specific details were made available.

AUXILIARY DATA

Engineering of a Tank (USD)	3,000.00	Design of a Petroleum Tank with a floating roof with the capacity of 1000,000 barrels for the Tesca Company in Ecuador (De la Cadena Ramos, C, Larrea Esparaza, P. , 2012)
Raw Materials (USD)	462,017	Design of a Petroleum Tank with a floating roof with the capacity of 1000,000 barrels for the Tesca Company in Ecuador (De la Cadena Ramos, C, Larrea Esparaza, P. , 2012)
Welding (USD)	2,329.3	Design of a Petroleum Tank with a floating roof with the capacity of 1000,000 barrels for the Tesca Company in Ecuador (De la Cadena Ramos, C, Larrea Esparaza, P. , 2012)
Volume of tank with cost estimates (m^3)	159,000.0	Design of a Petroleum Tank with a floating roof with the capacity of 1000,000 barrels for the Tesco Company in Ecuador (De la Cadenza Ramos, C, Larrea Esparaza, P. , 2012)
Area m^2 of tank to relocate	67,781	Based on maps of the area
Depreciation assumed for tanks	7%	Manufacturing plant and equipment 3.75% to 10% - straight-line according to financial statements of Petrotrin (2012)
Machinery (USD)	1,2483.62	Design of a Petroleum Tank with a floating roof with the capacity of 1000,000 barrels for the Tesca Company in Ecuador (De la Cadena Ramos, C, Larrea Esparaza, P. , 2012)
Labour (USD)	374,760.0	Design of a Petroleum Tank with a floating roof with the capacity of 1000,000 barrels for the Tesca Company in Ecuador (De la Cadena Ramos, C, Larrea Esparaza, P. , 2012)

Other Costs (USD)	9,287	Design of a Petroleum Tank with a floating roof with the capacity of 1000,000 barrels for the Tesca Company in Ecuador (De la Cadena Ramos, C, Larrea Esparaza, P. , 2012)
Number of tanks to relocate	21.0	Based on maps of the area
Volume of tanks, assuming same height of 17 meters	159,000	Author Estimation
Diameter of tanks (m)	97.0	Based on maps of the area
	87.0	
	67.0	
	66.0	
	71.0	
	52.0	
	90.0	
	78.0	
	65.0	
	63.0	
	62.0	
	66.0	
	63.0	
	66.0	
	60.0	
	42.0	
	41.0	
	38.0	
	37.0	
	42.0	
	47.0	

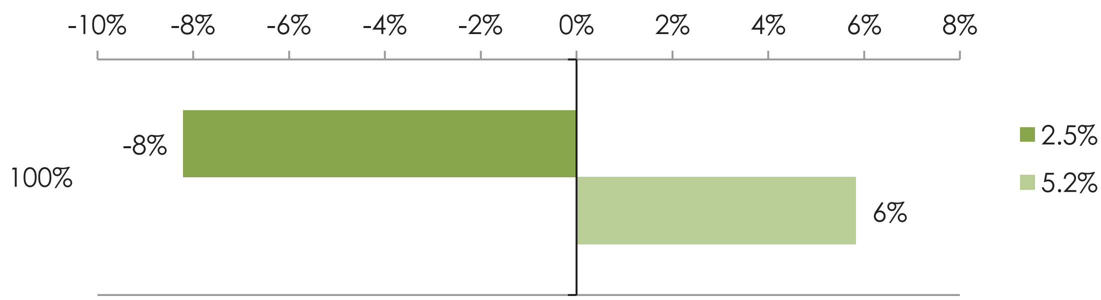
PAP 6. InfrastructureElevation in Pointe-à-Pierre

The economic costs and benefits have not been estimated given the lack of specific information regarding infrastructure in the vulnerable area, about the infrastructures' current value (estimated useful life remaining of the assets) and about its current and future expected uses. Without specific information, it is hard to estimate the costs of the elevation of this infrastructure.

Annex 5: Sensitivity Test

The following graph shows the sensitivity tests done for both the country level economic analysis and the pilot case economic analysis.

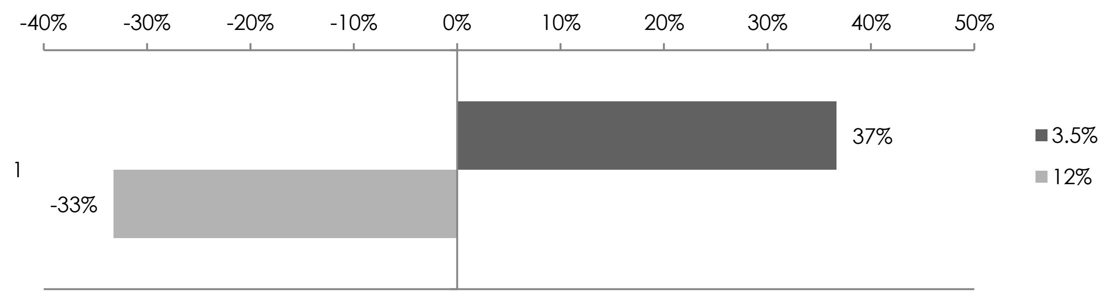
The for country level measures, sensitivity levels of 2.5% and 5.2% were used. These levels were chosen due to the fact that government bonds issued in September of 2012, with a maturity period of 15 years were sold with a rate per annum of 5.2% and bonds issued in August of 2013, with a maturity period of only 10 years, were sold with a rate per annum of 2.5%.



These results show how the Net Present Value for all of the measures changes, according to the dicsount rate used. The Net Present Value decreasesd by 8%, from at the lower discount rate of 2.5% while the Net Present Value increased by 6% at the higher discount rate of 5.2%, This shows that the Net Present Value is relatively insensitive to the discount rate, given that the test discount rates decreased by 38.5% (2.5%) and increased by 30% (5.2%).

The rates for Petrotrin were taken from another economic analysis study done for the company by John C. Whitehead (2011). These same discount rates were used for continuity for Petrotrin, so that this study may be compared with previous studies done for the company. Whitehead's explanation for choosing these rates, he states, "we use two discount rates for the present value calculations. The first is the discount rate of 12% prescribed by the Inter-American Development Bank guidelines for cost-benefit analysis. The second is the social discount rate of 3.5% advocated by Moore et al. (2004)[18]".

[18] This work was not included in the references list in this study.



These results show how the Net Present Value for all of the measures changes, according to the dicsount rate used. The Net Present Value increasesd by 37%, from at the lower discount rate of 3.5% while the Net Present Value decreased by 33% at the higher discount rate of 12%. This shows that the Net Present Value is relatively more sensitive to changes in the discount rate; the test discount rates increased by 71% (12%) and decreased by 50% (3.5%).

Annex 6: Adaptation Measures For Coastal Zones In Trinidad And Tobago

The following annex provides additional information regarding coastal adaptation measures, provided by IH Cantabira.

1. INTRODUCTION

The high-resolution study of coastal flooding due to tropical storm events carried out includes the information needed to propose a set of adaptation measures in the coastal zones under future scenarios of climate change.

Considering the importance of coastal areas in Trinidad and Tobago, the aim of this report is to extend previous work to include additional and more specific coastal adaptation measures for different coastal sections of Trinidad and. Based on the high-resolution risk assessment a set of adaptation options are proposed, while two specific measures that include sea dike construction and beach nourishment for coastal defence protection are developed defining design parameters.

2. METHODOLOGY

The methodology used for the proposal of coastal adaptation measures follows the next steps:

- High-resolution coastal flooding risk analysis
- Classification of coastal front exposure
- Selection of potential common coastal sections at risk and set of potential coastal measures
- Definition of coastal measures

Using the high-resolution information on vulnerability, exposure and coastal flooding we have performed the risk analysis for the proposed climate change scenarios, obtaining risk maps for Trinidad and Tobago. In those maps one can see the spatial variability and identify the areas with the highest potential risks. Besides, using the information on exposure provided by the Institute of Marine Affairs of Trinidad and Tobago we have identified five common groups of coastal fronts in which different set of adaptation measures can be developed.

The risk and coastal front information is used to propose a set of adaptation options in each coastal section identified. A summary chart with a brief description is provided for each proposed measure where some characteristics as the objective, a description, and the degree of efficiency or the timing are given.

Finally, the side-specific definition of each adaptation option should be carried out. As an example of the procedure to be followed, have defined the cross- section of a riprap protection and the cross-shore profile of a beach nourishment, providing the design parameters for these two adaptation measures for coastal defense.

3. COASTAL ADAPTATION MEASURES

The coastal systems present a natural capacity to respond by themselves to external climate pressures. This capacity determines their resilience and resistance to these external pressures. More resilient and resistant coastal systems are less vulnerable to future changes such as those due to sea level rise. For example, wetlands are able to respond to sea level rise by accumulating sediment and adapting their morphodynamics to the new conditions. This dynamic behavior present in coastal zones is refereed as "self-adaptation" and can be evaluated from historic and geologic observations (e.g., Hopley y Kinsey, 1988; Ellison and Stoddart, 1991).

However, human activities at the coast such as contamination, the construction of infrastructures or interventions in the sediment budget have influence on the natural processes; reducing resilience of coastal natural systems and, consequently, their self-adaptation capacity.

Likewise, in order to protect population settlements, assets and relevant sectors affected by coastal impacts adaptation measures can be implemented (e.g. the construction of sea dikes to protect from coastal flooding), but these responses will depend on socio-cultural factors. These measures will be sectorial and frequently of very local scale that, and sometimes they may induce negative effects on adjacent coastal zones if not properly considered in the design of the adaptation measures, resulting in maladaptation.

Within the available coastal zone adaptation strategies to climate change different options can be identified: protection to minimize the expected future impacts, accommodation to the new circumstances and retreat. However, adaptation consists of more than a simple choice between the three strategies and the pure implementation of measures. The most successful adaptation policy requires collaboration between the relevant stakeholders involved in coastal planning instead of in an isolated way (Tompkins et al., 2005; USAID, 2009). Besides, the whole context of coastal impacts, including climatic and non-climatic considerations should be integrated (Tol et al., 2008).

Concerning to the objectives of adaptation measures it is important to be aware that, probably, they will not be totally achieved due to the nature of the problems to be faced. It is necessary to assume that there is always a residual risk that should be defined a priori.

For adaptation in the coasts of Trinidad and Tobago we propose the following strategic objectives to be reached, Table 1.

Table 1: Strategic objectives proposed for the coasts of Trinidad and Tobago.

A	Functional and healthy coastal ecosystems
B	Exposure reduction of coastal system
C	Improve human and coastal security
D	Planning and overall governance

Following, a brief description of each group of strategic measures and the options to fulfil the objective proposed is given. A more complete description for each adaptation measure is shown in Annex 1, where a file for each adaptation measure is provide.

Functional and wealthy coastal ecosystems

The coast is a complex and dynamic system where different uses and ecosystems are implied. Coastal ecosystems provide a large number of benefits, such as ecological functions, the touristic resources or the natural protection from erosion and flooding. The maintenance of coastal ecosystems in good conditions and the restoration of degraded zones due to natural or anthropogenic causes is a fundamental objective of adaptation. In this way, the natural and human protection will be achieved in a combined way. This approach is directly linked to the so-called Ecosystem Based Adaptation (EBA).

Table 2: Adaptation measures proposed to obtain Functional and healthy coastal ecosystems.

	Functional and healthy coastal ecosystems
A1	Wetland restoration & protection
A2	Marine conservation agreements & protection areas

Wetland restoration & protection

The importance of wetlands falls on their capacity of dissipating wave and storm surge energy and, therefore, the protection provided to the coastal areas behind. Besides, they act as sediment trap and provide substratum to the vegetation root, helping to the stabilization of the coastline and reduced erosion. Therefore, the aim of wetlands conservation and restoration is, among others, reducing coastal flooding and erosion, create new habitats and generate environmental benefits maintaining the coastline position.

Marine Conservation Agreements (MCA) & Protection Areas (MPA)

The implementation of strategies and policies for the conservation and protection of coastal areas ensure greater resilience and adaptive capacity of regions of a great natural interest. Proclamation and promotion of conservation and protection agreements benefit the Ecosystem Based Adaptation (EBA) strategies thanks to the functions and services provide by the protected ecosystems.

Exposure reduction of coastal systems

It is of paramount interest to reduce the risks and damages to the population, loss of property and damage to public and private assets on the coast through measures to reduce the exposure and vulnerability of the coastal system. For this purpose, protection, accommodation or those options that contribute to reduce the impacts of climate change along the coast are considered.

Table 3: Adaptation measures proposed to Reduce the exposure of coastal systems.

	Exposure reduction of coastal system
B1	Beach nourishment
B2	Artificial sand dunes and dune rehabilitation
B3	Living shorelines
B4	Seawalls
B5	Sea Dikes
B6	Coastal Setbacks
B7	Flood-proofing

Beach nourishment

This is considered a "flexible" engineering measure for coastal protection involving the artificial sediment input in a beach with deficit of sediment. Therefore, the area of dry-beach is enlarging for the protection of the coast from storms, dissipating the incident energy. Beach nourishment is, mainly, a solution for coastal erosion problems, but it is also of interest for protection against floods.

Artificial sand dunes and dune rehabilitation

Sand dunes provide stability to the coast: they bring sand to the beach during periods of erosion and stored it during periods of accretion, preventing the loss of sand. In addition, they are very effective protecting elements to extreme coastal flooding events. They are highly sensitive and are often altered and destroyed because of the anthropogenic action. Rehabilitation is achieved by means of addition of sand or dune revegetation.

Living shorelines

The coast stabilization with vegetation or sandy or rocky materials constitute an ecosystem to maintain natural processes and overcomes coastal erosion in protected areas and wetlands (low and medium energy environments). This measure also can improve the habitats and provide multiple benefits.

Seawall

This is considered a "hard "engineering measure that consists of building seawalls parallel to the coast in order to protect the current coastline. The part facing to the sea is designed to dissipate and reflect the incident wave energy. They are normally used to protect elements of high value such as roads or buildings with high interests. They are heavy, rigid, difficult and expensive structures. The main function is to prevent from coastal erosion and from flooding events.

Sea Dikes

This measure consists of high-volume coastal structures able to withstand the actions of severe storms and reduce the overtopping. It consists of a core of sand protected by one or more layers of rock of varying size, able to withstand the forces of the waves. The aim is to reduce and protect the coastal zone from flooding events.

Coastal Setbacks

It consists of creating unused areas (coastal setbacks) to protect developed coastal zones from flooding and erosion. It reduces the infrastructure damage and the flooding risk for population. It defines a minimum distance to implement a coastal component (e.g. line of permanent vegetation or buildings) in which all types of development and land use is prohibited. This measure is a solution for coastal flooding and erosion.

Flood-proofing

The objective is to reduce or eliminate the impacts of coastal flooding on structures by adapting their design to withstand flooding. It consists, normally, of solutions as rising buildings, the use of stronger materials, benefiting drainage, or the protection of buildings from contact with water.

Improve human and coastal security

The increase of human and coastal security can be achieved by developing actions to improve the risk management, including actions related with training and response, as well as by introducing actions to improve risk management, preparation and response, A relevant measure is also the development and dissemination of information regarding flooding prone areas, exposure and vulnerability.

Table 4: Adaptation measures proposed to Improve human and coastal security.

Improve human and coastal security	
C1	Flood hazard mapping

Flood hazard mapping

In order to determine the appropriate use of the coast, this measure proposes mapping the potential zones affected by extreme coastal flooding. Easy understanding files and quick access to the information can identify risk areas where it is necessary to give priority to adaptation efforts.

Planning and overall governance

The monitoring, planning and resource assignment, as well as reinforcing political and institutional commitment increase adaptive capacity and reduce the vulnerability of coastal systems to climate change. The development of good practices and the reconsideration and improve of management practices will led to a long-term benefit results.

Table 5: Adaptation measures proposed for planning and governance.

	Planning and overall governance
D1	Coastal watershed management
D2	Integrated Coastal Zone Management
D3	Special area management planning

Coastal watershed management

Integrated management of water resources in coastal areas includes the management of rivers, groundwater extraction (river basins) and estuarine waters. It aims to coordinate the development and management of water, maintaining quality, and managing land uses and the rest of coastal resources. This measure seeks to increase the economic and social welfare so that the sustainability of ecosystems and water quality are not compromised.

Integrated Coastal Zone Management (ICZM)

The ICZM allows treating current and long-term coastal problems coordinating and integrating actors and sectors in a general framework. It is a continuous and dynamic process through which decisions are made in a sustainable way, integrating the development and protection of coastal and marine areas and their resources. It is a multisectorial activity that analyses the consequence of development, the conflict of interest between the different actors and the relationships between the physical processes and human activities. Besides, the ICZM benefits the harmony between the coastal sector and the activities. With a long-term approach, it can facilitate adaptation to climate change.

Special area management planning

This measure refers to specific planning for relatively large geographical area of great interest, normally integrated into a management plan for coastal resources in national or municipal scale. These unique areas can be selected for various reasons: a large economic and touristic value, great ecological risks, a national interest, etc. This measure aims to create a comprehensive management plan for areas of special interest, and it includes multiple objectives to protect natural resources and promote coastal economic activities of these unique areas.

Summary of coastal adaptation options

The adaptation measures described above fulfil different objectives that can be set out in the same coastal zone. Depending on the physical exposure, but also on the vulnerability of the area, a set of adaptation options can be selected. In order to facilitate the selection of the appropriate adaptation measures, Table 6 shows the combination of possible adaptation measure in a coastal zone depending on the geomorphology (physical exposure) and on the land use (vulnerability).

Table 6: Adaptation measures proposed for planning and governance.

		GEOMORPHOLOGY				
		Wetlands	*Sandy coasts without dune*	*Sandy coasts with dune*	*Low rocky coast*	*Cliffs*
LAND USE	*Highly urbanized*	A1,A2	A2	A2	A2	A2
		B3,B4,B5	B1,B2,B4,B5,	B1,B2		B5
		B7	B7			
		C1	C1	C1	C1	C1
		D1,D2,D3	D1,D2,D3	D1,D2,D3	D1,D2,D3	D1,D2,D3
	Residential areas (moderately urbanized)	A1,A2	A2	A2	A2	A2
		B3,B4,B5	B1,B2,B4,B5,	B1,B2		B5
		B6,B7	B6,B7	B6	B6	B6
		C1	C1	C1	C1	C1
		D1,D2,D3	D1,D2,D3	D1,D2,D3	D1,D2,D3	D1,D2,D3
	Tourist areas (hotels)	A1,A2	A2	A2	A2	A2
		B3,B4,B5	B1,B2,B4,B5,	B1,B2		B5
		B6,B7	B6,B7	B6	B6	B6
		C1	C1	C1	C1	C1
		D1,D2,D3	D1,D2,D3	D1,D2,D3	D1,D2,D3	D1,D2,D3
	Transport infrastructures	A1,A2	A2	A2	A2	A2
		B4,B5	B4,B5			B5
		B6,B7	B6,B7	B6	B6	B6
		C1	C1	C1	C1	C1
		D1,D2,D3	D1,D2,D3	D1,D2,D3	D1,D2,D3	D1,D2,D3
	Industry	A1,A2	A2	A2	A2	A2
		B4,B5	B4,B5			B5
		B6,B7	B6,B7	B6	B6	B6
		C1	C1	C1	C1	C1
		D1,D2,D3	D1,D2,D3	D1,D2,D3	D1,D2,D3	D1,D2,D3
	Agriculture	A1,A2	A2	A2	A2	A2
		B6,B7	B6,B7	B6	B6	B6
				C1		C1
		D1,D2,D3	D1,D2,D3	D1,D2,D3	D1,D2,D3	D1,D2,D3

4. ADAPTATION MEASURES PROPOSED FOR COASTAL ZONES IN TRINIDAD AND TOBAGO

Risk analysis and coastal front classification

The combination of high-resolution coastal flooding, exposure and vulnerability information allows assessing the disaggregated spatial risk to coastal flooding in Trinidad and Tobago for the three future climate change scenarios proposed in the 3rd Interim Report. The risk in every receptor point (j) is considered as the product of its coastal flooding (H), exposure (E) and vulnerability (V).

$$R_j = H_j \cdot E_j \cdot V_j \qquad (1)$$

Figures 1, 2 and 3 show the disaggregated coastal flooding risk for scenarios S1, S2 and S3, respectively. Note that exposure remains constant for each scenario while scenarios S1 and S2 experiment a moderate change in coastal flooding (+ 0.07 m of local sea level rise) but different vulnerability (V0 and V1 respectively) and S3 experiments a high change in coastal flooding (+ 0.4 m of local sea level rise) and a future change in vulnerability (V1). Differences in the vulnerability scenarios are minor, so that the main change in the risk is induced by sea level rise. One can see that coastal flooding risk for scenarios S1 and S2 is almost the same while some differences are obtained for scenario S3. Due to this fact, in the following, the adaptation measures will be proposed for scenarios S2 and S3.

Figure 1: High-resolution risk analysis to coastal flooding for scenario S1.

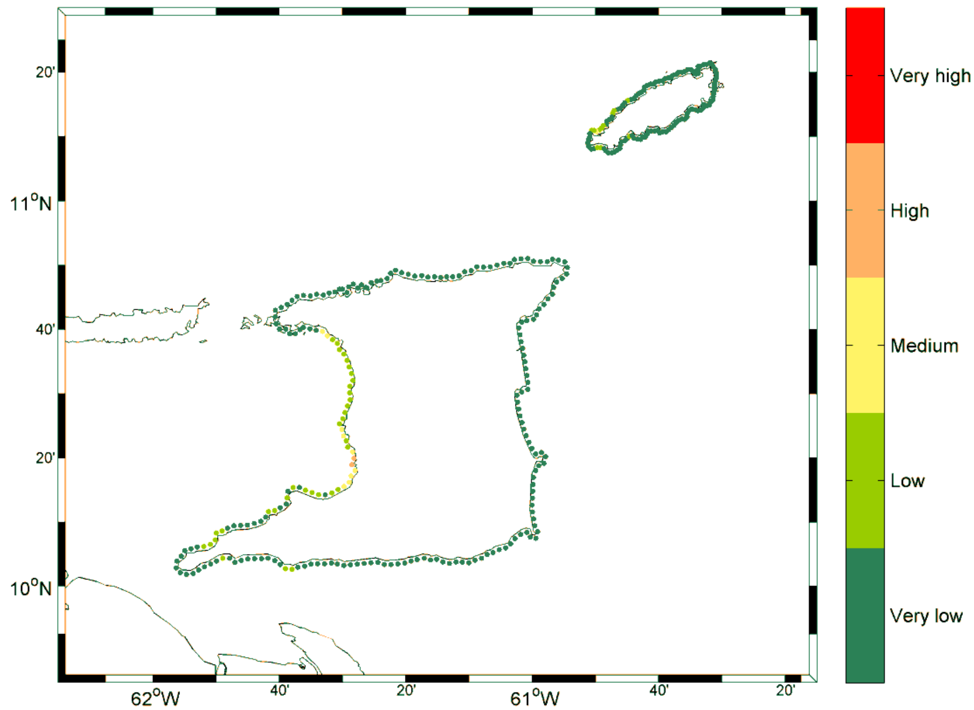


Figure 2: High-resolution risk analysis to coastal flooding for scenario S2.

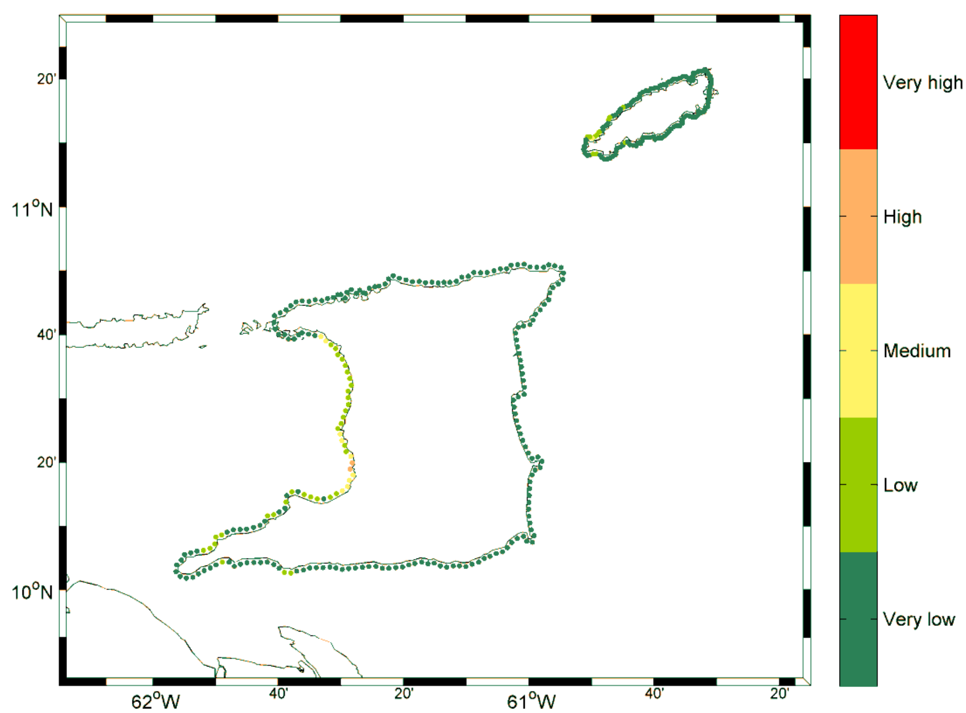
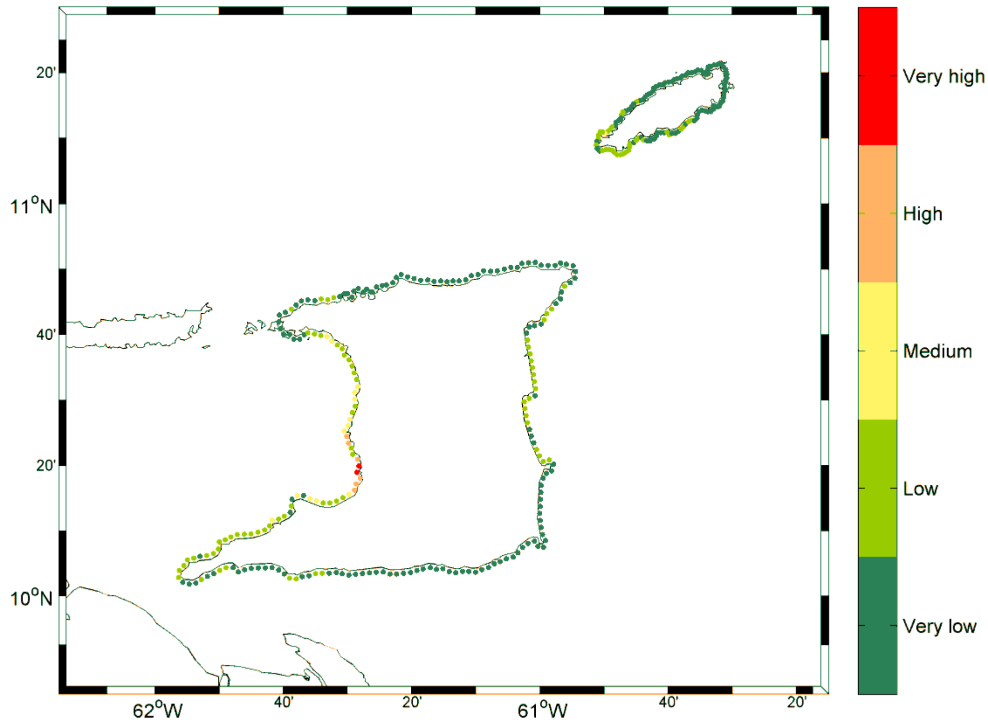


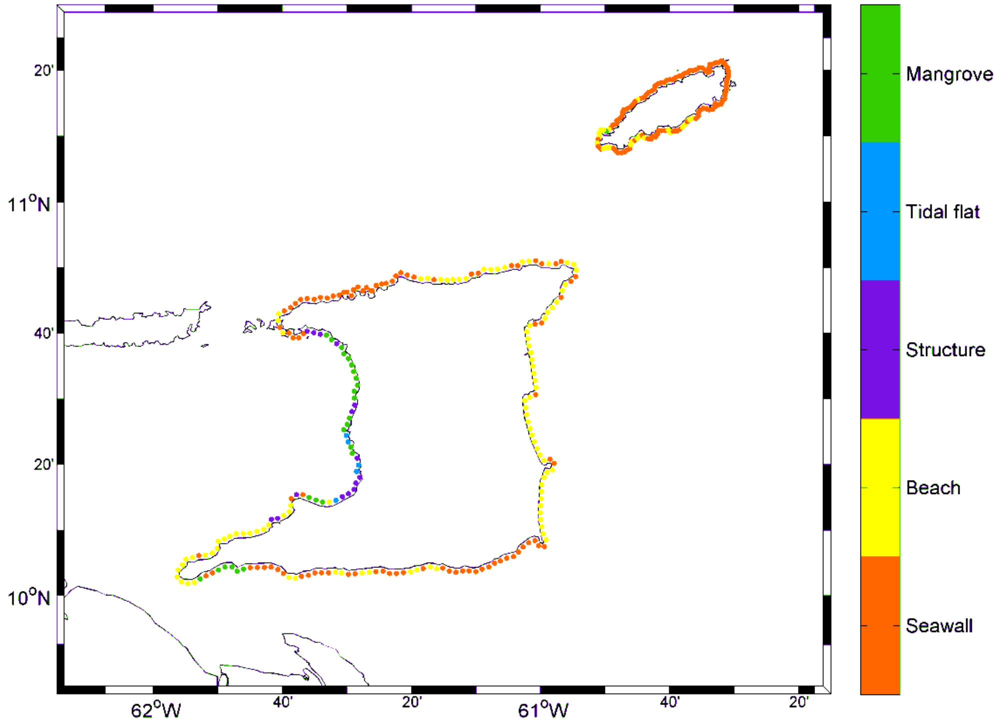
Figure 3: High-resolution risk analysis to coastal flooding for scenario S3.



From figures 2 and 3, it can be seen that areas subject to highest risks are concentrated in the Gulf of Paria, where there is a higher concentration of population and, therefore, higher vulnerability. Besides low lying areas exist with higher exposures. A medium risk is observed in the area of Port of Spain, while high (in S2 scenario) and very high (in S3 scenario) risks are present in the area of San Fernando. The coastline stretch between these important cities shows low coastal flooding risk, as well as the south west part of the Gulf.

As suggested previously, the possible adaptation measures for each coastal area will depend on the coastal front, which includes the physical exposure but also the vulnerable assets (in terms of land use). In order to take into account this information when suggesting different adaptation measures in Trinidad and Tobago we have considered the exposure information, provided by the Institute of Marine Affairs of Trinidad and Tobago, and the high-resolution vulnerability information, obtained in the High Resolution Coastal Flooding Risk Report. Combining these, we have obtained the results presented in figure 4 where we show the coastal front classification. We have considered five groups, giving special relevance to coastal ecosystems, such as mangroves and beaches, types of exposure, such as tidal flats or seawalls/cliffs (that both can be also considered coastal ecosystems), and urban fronts, represented by man-made structures (in the figure named as structures).

Figure 4: Coastal front classification.



Proposed adaptation measures

Using the information of the spatial disaggregated coastal flooding risk (figures 2 and 3) and the coastal front classification (figure 4) we have developed an adaptation measures proposal. Figures 2 and 3 show that the area with the highest risk is the Gulf of Paria, where all kind of coastal fronts can be found. In the rest of Trinidad Island, the coastal flooding risk is very low or low and the coastal front is characterized by natural ecosystems (beaches and cliffs) with natural adaptive capacity. In the case of Tobago, figures 2 and 3, show that coastal flooding risk is very low or low, while figure 4 indicates that seawalls are found almost along the entire coastline except for some beaches in the south.

Therefore, we have decided to consider the need for adaptation measures only in the Gulf of Paria and in the south of Tobago, where the coastal flooding risk is higher or, at least, vulnerable assets are identified.

Design and economic assessment of beach nourishment and riprap protection measures

The previous analysis and proposal of adaptation measures is focused on a portfolio of generic adaptation options. However, the final decision of a particular adaptation option will need a functional design and an economic cost-benefit analysis. As an example, we have considered two adaptation options that contribute to the exposure reduction of coastal systems (coastal defences): beach nourishment for a beach in the south east of Tobago (near Scarborough) and a riprap protection in the area of Port of Spain, in the Gulf of Paria.

Beach nourishment in Tobago

The south coast of Tobago is characterized by touristic beaches that will be affected by flooding and erosion due to climate change. Considering semi-empiric formulations we have designed the future beach profile in order to avoid the retreat of the beach due to sea level rise.

We are going to design it for S3 scenario considering a sea level rise of 0.4 m. The input data for the dimension of the beach profile are as follows:

D50 = 0.25 mm

$H_{s,12}$ = 3.45 m

Ts = 8.3 s

Berm height = 1 m

Sea level rise = 0.4 m

The depth of closure has been determined through the formulation of Hallermeier (1981):

$$h^* = 2.28 \cdot H_{s,12} - 68.5 \cdot \frac{H_{s,12}{}^2}{g \cdot T_s^2} = 6.66\ m \quad (2)$$

The profile extent has also been calculated:

$$W^* = \left(\frac{h^*}{A}\right)^{3/2} = 479.85 \quad (3)$$

Where:

A is the sediment scale parameter that has been obtained through the formulation of Dean (1987).

$$A = 0.51 \cdot w^{0.44} = 0.10866 \quad (4)$$

For $0.1\ mm \leq D_{50} \leq 1\ mm \ \rightarrow\ w = 273 \cdot D_{50}^{1.1} = 0.0298$

Using the Bruun´s rule, we have a first estimation of the retreat of the beach due to the 0.4 m of sea level rise that is 25 m.

$$R = \frac{W^*}{\left(h^* + B\right)} \cdot SLR = 25 \text{ m} \qquad (5)$$

In order to ensure that the coastline will remain in the same position it is necessary to add the following volume of sediment:

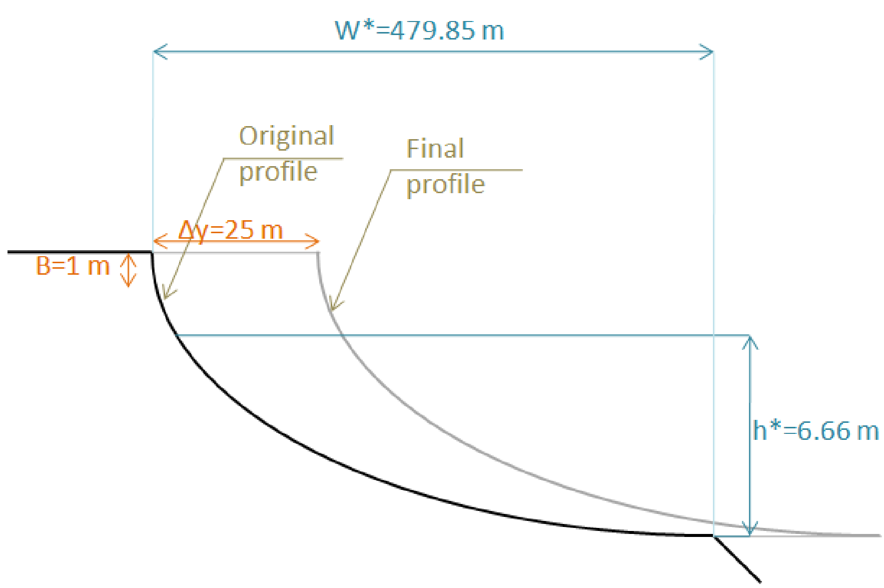
$$\boldsymbol{V} = B \cdot \Delta y + \frac{3}{2} \cdot h_* \cdot \left\{ \left[\frac{\Delta y}{h_*{}^{3/2}} + \left(\frac{1}{A_V}\right)^{3/2} \right]^{5/3} \cdot A_N - \left(\frac{1}{A_V}\right)^{3/2} \right\} = \mathbf{194.41}\ \boldsymbol{m^3/m}$$

(6)

Where Δy is the dry beach width, B is the berm and A_N and A_V are the sediment scale parameters of the native and the dumping sediment, respectively.

Figure 5 shows the beach profile scheme of calculation.

Figure 5: Beach profile scheme.



Finally, considering that the cost of the dumping sediment is 9 US€/m2, and considering the exchange into TT dollars, the cost of beach nourishment rises to 11,500 $TT/m.

Riprap protection in the area of Port of Spain

One of the proposed adaptation measures for the urbanized coastal front of Port of Spain is the seawall protection. Here, we present the design for a riprap protection section.

The design parameters for the dimension of the seawall are as follows:

$H_{S,50}$ = 2,5 m

T_p = 7.3 s

Duration of the extreme event = 3 hours

Number of waves = 1923 waves

Depth of the seawall = 0 m

Bottom slope = 0.01

Sea level = + 2.3 m (0.5 m of Astronomical Tide, 1.4 m of storm surge and 0.4 m of sea level rise due to climate change)

Design depth = + 2.3

H_{50} of the extreme event = 2,5 m

Crest height above water level = 1 m

Mass density of the rock (ρs) = 2600 kp/m^3

Mass density of the water (ρw) = 1025 kp/m^3

The calculation of the stability function has been carried out on the basis of the start of damage and a slope of 1.5/1 by means of the following expression (Losada & Gimenez-Curto, 1979):

$$\psi = A \cdot \left(I_{ric} - I_{ro}\right) \cdot \exp\left[B \cdot \left(I_{ric} - I_{ro}\right)\right] = 0.0553 \qquad (7)$$

Where A and B are adjustment parameters that depend on the type of units and the slope.

$$I_{ric} = \frac{\tan\alpha}{\sqrt{H_{ic}/L_{0ic}}} \qquad (8)$$

$$I_{ro} = 2.654 \cdot \tan\alpha \qquad (9)$$

The weight needed in the different layers that form the riprap protection are calculated next.

Primary layer

$$W_p = \rho_w \cdot g \cdot R \cdot \psi \cdot H^3 = 619\ kp \tag{10}$$

Where

$$R = \frac{\frac{\rho_S}{\rho_w}}{\left(\frac{\rho_S}{\rho_w} - 1\right)^3} = 0.699 \tag{11}$$

The wave height has been chosen as HS,50 previously defined. The weight calculated is in the range: 400-1500 kp. Thus, it is decided to use 1 tonne rubble mounds distributed over 2 layers.

Transition layer:

Two layers of stones with weight among 75-150 kp will be disposed.

Core

The core will be constructed of quarry run whose weight will be within the range of 1-100 kp and subject to the following restrictions:

- Maximum 10% of weight less than 1 kp
- Maximum 5% of weight higher than 100 kp

Crest height

The design of the crest height will be determined by the tolerable discharge in order to ensure the safety of pedestrians (Eurotop 2007). In this case, the mean discharge admissible is q = 0.1 l/m/s, which will define the crest height and the berm width using the following formulation:

$$\frac{q}{\sqrt{g \cdot H^3}} = 0.2 \exp\left[-2.3 \frac{R_c}{H \cdot \gamma_f \cdot \gamma_\beta}\right] \tag{12}$$

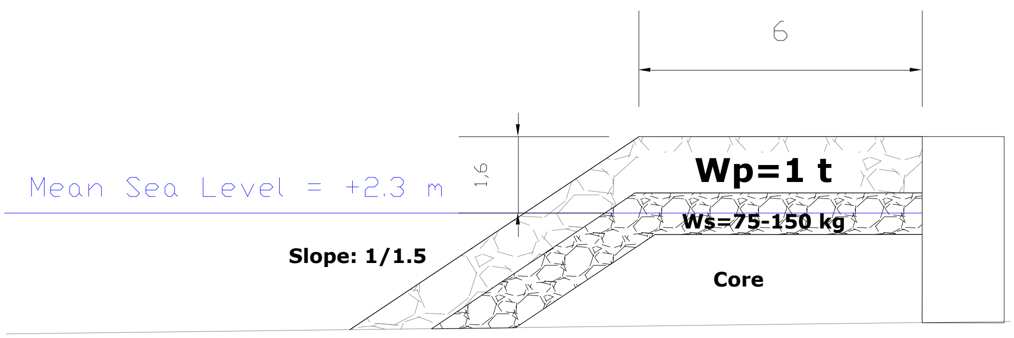
Where q is the admissible overtopping (0.1 l/s/m), H is the H_s= 2.11 m, Rc is the crest height, in this case 1.6 m and $\gamma_f = 0.4$ and $\gamma_\beta = 0.703$ are the roughness and wave incidence diminishing parameters respectively.

Single straight slopes including an armoured crest berm of less than 3 nominal diameters ($G_c \approx 3D_n$) will reduce overtopping. It is, however, possible to reduce overtopping with a wide crest as much more energy can be dissipated in a wider crest. With that purpose, we have defined a berm of 6 m width, having a final overtopping of 0.086 l/m/s, which fulfil the design criteria.

$$C_r = 3.06\exp\left(-1.5 \, G_c / H_{m0}\right) = 0.034$$
$$q_d = C_r \cdot q = 0.0867 \text{ l/s/m}$$

Figure 6 shows the scheme of the cross-shore section of the riprap protection seawall.

Figure 6: Scheme of the section of the riprap seawall protection.



Finally, an estimation of the execution cost is carried out. Using the execution prices shown in Table 7 and updated into TT dollars, the cost of the lineal meter of seawall rises to 23.500 $TT/m.

Primary layer of stones disposed in two layers of 0.60 meters width: 10.600 $TT /lm

Transmission layer of stones disposed in two layers of 0.20 meters width: 3.600 $TT/lm

Fill gravel for dike constructed: 5700 $TT/lm

Impermeable core made of quarry run: 3600 $TT/lm

Finally, note that neither geotextile nor other extra element has been included in the cost.

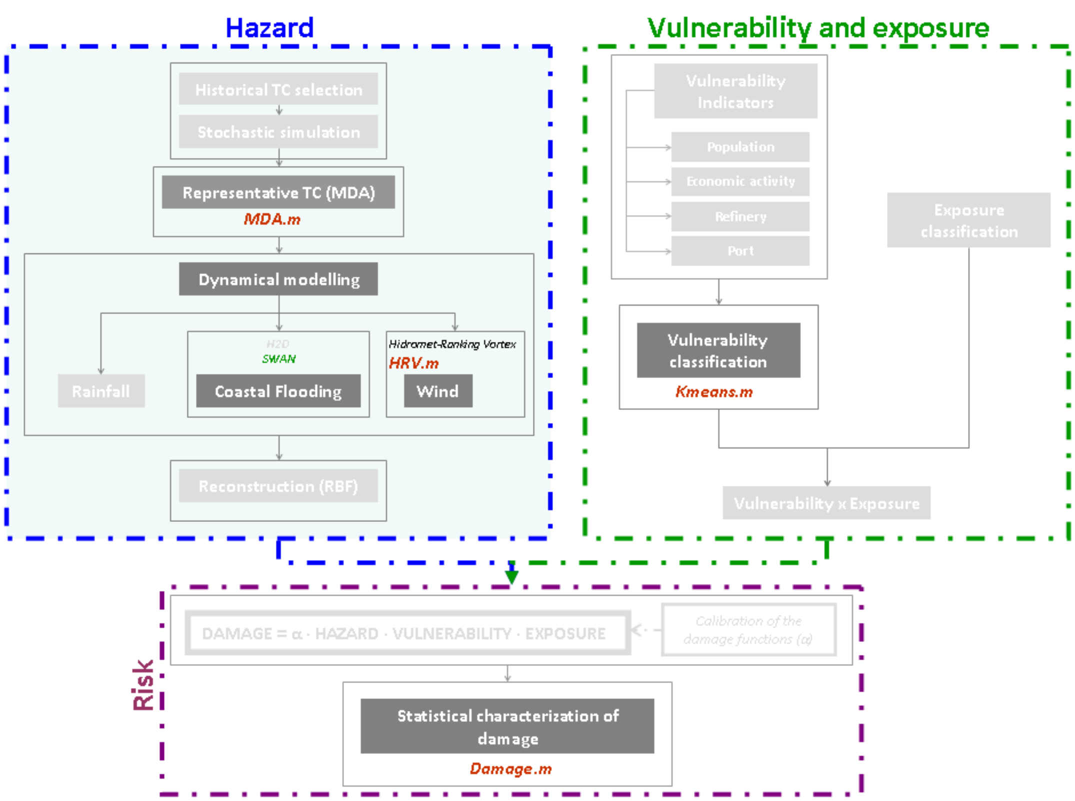
Table 7: Prices of execution cost for a riprap protection.

Execution Cost	
Site clearing and preparation	44 TT/m^3
Excavation of dike root with excavator	220 TT/m^3
Hauling of dike root material	132 TT /m^3
Riprap delivered on site	263 TT /m^3
Excavator for placement of riprap	-
Fill gravel for dike construction	350 TT /m^2
Site revegetation	-
Site clean up	-

Annex 7: Matlab Codes Information

This annex provides a brief description of the sources and organization of the matlab codes provided in the software application. The scheme of figure 1 shows the methodological scheme followed across de project and the corresponding matlab codes provided. Note that the names of the codes are shown in red color while the step of the methodology considered is highlight in dark grey. Only scientific-tested codes have been included.

Figure 1: Methodological scheme with the matlab codes provided.



Four scientific-tested codes are provided as described as follows:

1. **Representative TC (MDA)**

Objective: To select a sample of representative tropical cyclones using maximum dissimilarity selection algorithm (Camus et al. 2011a) in order to dynamically modeling these cases and, hence, reduce the computational cost.

Code: MDA.m

2. **Wind**

Objective: To model the wind velocities of tropical cyclones using the Hydromet-Ranking Vortex model.

Code: HRV.m

3. Vulnerability classification

Objective: To integrate the multivariate dimension of the vulnerability obtaining representative classes using the clustering algorithm K-Means (Camus et al. 2011).

Code: Kmeans.m

4. Statistical characterization of damage

Objective: To characterize the damage through its mean and variance modelling the intense using the Generalized Pareto Distribution (GDP) and frequency using Poisson model. Further description is found in Katz (2002).

Code: Damage.m

Finally, the SWAN model used to propagate wave climate into nearshore is free software from Delft University of Technology. A description of the model and a download page can be found in: http://www.swan.tudelft.nl//.

References

Abuodha P.A.O. and C.D. Wooddroffe (2006). "Assessing vulnerability of coast to climate change: a review of approaches and their application to the Australian coast". University of Wollongong, Faculty of Science Paper, Research Online.

Alavian, V. et alt 2009 "Water and Climate Change: Understanding the Risks and Making Climate-Smart Investment Decisions" World Bank WP 52911

Anderberg M.R. (1973). "Cluster analysis for applications". Academic Press, 359 pp.

Anrooy, R. et al. (2009) "Review of the current state of world capture fisheries insurance" FAO. Viale delle Terme di Caracalla, 00153 Rome, Italy

Asia-Pacific Network for Global Change Research (2011) "Awareness Raising And Capacity Building On Alternative Water Management For Communal Irrigators' Associations In The Philippines"

Asia-Pacific Network for Global Change Research. (2005) "Community Relocation as an Option for Adaptation to the Effects of Climate Change and Climate Variability in Pacific Island Countries (PICs)" 2005-14-NSY-Campbell

Baban S.J. and Sant, K.J. "Mapping landslide susceptibility for the Caribbean island of Tobago using GIS, multi-criteria evaluation techniques with a varied weighted approach" Caribbean Journal of Earth Science, 38 (2005), 11-20.

Bonjean F. and G.S.E. Lagerloef (2002). "Diagnostic model and analysis of the surface currents in the tropical Pacific ocean". J. Phys. Oceanogr.. 32. 2.938-2.954.

Booij N., Ris, R. C. and L. H. Holthuijsen (1999). "A third-generation wave model for coastal regions, Part I: Model description and validation". J. Geophys. Res. Vol. 104, C4, 7649-7666.

Bord, Fisher and O'Conner. (1998). "Public Perceptions of global warming: United Stated and international perspectives" CLIMATE RESEARCH Clim Res. Vol. 11: 75–84, 1998

Botzen. W, (2013) "Climate Change and Natural Disasters: Economic Analysis of Flood Risk Adaptation" Institute for Environmental Studies. University of Amsterdam. 3er Congreso National – 17 October, 2013

Box GEP. Jenkins GM. Reinsel GC (1994). "Time Series Analysis: Forecasting and Control. Prentice-Hall International". New Jersey. NJ.

Bretschneider C.L. (1990). "Tropical cyclones. handbook of coastal and oceanengineering". Houston: Gulf Publising co. 1, 249-370.

Brockwell PJ. Davis RA (1991). "Time series: Theory and methods". 2nd edn. Springer-Verlag. New York. NY.

Brooke A. Kendrick D. Meeraus A. Raman R (1998) GAMS. "A user's guide". GAMS Development Corporation. Washington.

BSR. "Adapting to Climate Change: A Guide for the Energy and Utility Industry"

Bueno. R. Et al. (2008). "The Caribbean and climate change: the cost of inaction". Stockholm Environment Institute (US Center) and Global Development and Environment Institute (Tufts University).

Burke, L. Greenhalgh, S., Prager, D., Cooper, E. (2008) "Coastal Capital: Tobago. The Economic Contribution of Tobago´s Coral Reefs" World Resources Institutue 2008

Campos, C. (20??) "The Economics of Desalination for Various Uses" CETaqua Water Technology Center.

Camus P.. F.J. Mendez and R. Medina (2011). "A hybrid efficient method to downscale wave climate to coastal areas". Coastal ENgineering 58 (2011) 851-862.

Camus P.. F.J. Mendez. R. Medina and A.S. Cofiño (2011). "Analysis of clustering and selection algorithms for the study of multivariate wave climate". Coastal Engineering 58(6) (2011) 453-462.

Caplan, K., Gomme, J., Mugabi, J., and Stott, L. (2007) "Assessing Partnership Performance: Understanding the Drivers for Success" Building Partnerships for Development ISBN Number: 0-9551073-6-9

Caribbean Regional Fisheries Mechanism (2008). "Trinidad and Tobago". Website available at http://www.caricom-fisheries.com/Members/MemberStates/TrinidadandTobago/tabid/81/Default.aspx

Carton, JA, BS Giese, and S.A. Grodsky, 2005. "Sea level rise and the warming of the oceans in the SODA ocean reanalysis". J. Geophys. Res., 110, art# 10.1029/2004JC002817.

Carton, J. A. and B. S. Giese, 2008. "A Reanalysis of Ocean Climate Using Simple Ocean Data Assimilation (SODA)". Mon. Weather Rev., 136, 2999-3017.

CCRIF (2010). "Enhancing the Climate Risk and Adaptation Fact Base for the Caribbean: An informational brochure highlighting the preliminary results of the ECA Study". Caribbean Catastrophe Risk Insurance Facility (CCRIF). Cayman Islands.

CCRIF (2013a). "Trinidad and Tobago. Country Risk Profile". Caribbean Catastrophe Risk Insurance Facility (CCRIF). Cayman Islands.

CCRIF (2013b) "CCRIF ANNUAL REPORT 2012-13" Caribbean Catastrophe Risk Insurance Facility (CCRIF). Cayman Islands.

Central Bank Trinidad and Tobago, 2000. "Annual Economic Survey"

Central Bank Trinidad and Tobago, 2012. "Annual Economic Survey"

Central Bank Trinidad and Tobago, 2011. "Annual Report"

Central Bank of Trinidad and Tobago and the Securities and Exchange Commission.(2013) “Primary Bond Market Activity in Trinidad and Tobago: January 2012 –October 2013”

Central Statistical Office T&T 2008. “National Income survey 2000-2006”.

Central Statistical Office T&T 2008. “2004 Agricultural Census”.

Central Statistical Office (2000). “Population and Household and Household Size 2000”.

Central Statistics Office (2004) “Trinidad and Tobago 2004 Agricultural Census”

Central Statistical Office (2011). “Trinidad and Tobago 2011 Population and Housing Census Demographic Report.”

Central Statistical Office (2012a). “Trinidad and Tobago 2011 Population and Housing Census: Demographic Report”. Port of Spain: The Central Statistical Office. Ministry of Planning and Sustainable Development. Government of the Republic of Trinidad and Tobago (GORTT).

Central Statistical Office (2012b). “Trinidad and Tobago Human Development Atlas 2012”. Port of Spain: The Central Statistical Office. Ministry of Planning and Sustainable Development. Government of the Republic of Trinidad and Tobago (GORTT).

Central Statistics Office (2014). “About Us”. Available at: <http://www.cso.gov.tt/about>

Chen et al. (2008). Caribbean Natural Resources Institute Technical Report No. 381. “Climate Trends and Scenarios for Climate Change in the Insular Caribbean”

Church J.A. and N.J White (2011). “Sea-Level Rise from the Late 19th to the Early 21st Century”. Surveys in Geophysics. Volumen 32. Issue 4-5. pp 585-602.

Clark et al. (1998). "Life-Cycle Cost Analysis in Pavement Design - In Search of Better Investment Decisions." Pavement Division Interim Technical Bulletin. September

Clements, R., J. Haggar, A. Quezada, and J. Torres (2011). “Technologies for Climate Change Adaptation – Agriculture Sector”. X. Zhu (Ed.). UNEP Risø Centre, Roskilde, 2011

“Climate Change: Realities Of Relocation For Alaska Native Villages” (2011) Tribal Climate Change Profile Project, The University of Oregon and the USDA Forest Service Pacific Northwest Research Station

EPA. “Climate Ready Estuaries Program”. EPA 430-F-08-024, January 2009.

Coastal and Hydraulics Laboratory, Engineer Research and Development Center. (20??) “Beach Nourishment: How Beach Nourishment Projects Work”

Colbert. Angela J.. Brian J. Soden (2012). “Climatological Variations in North Atlantic Tropical Cyclone Tracks”. J. Climate. 25. 657–673. doi: http://dx.doi.org/10.1175/JCLI-D-11-00034.1

Coleman TF. Li Y (1994). "On the convergence of reflective newton methods for large-scale nonlinear minimization subject to bounds". Mathematical Programming 67(2):189-224.

Coleman TF. Li Y (1996). "An interior. trust region approach for nonlinear minimization subject to bounds". SIAM Journal on Optimization 6:418-445.

Compo, G. P., J. S. Whitaker, and P. D. Sardeshmukh 2008. "The 20th century reanalysis project, paper presented at Third WCRP International Conference on Reanalysis". Univ. of Tokyo, Tokyo, 28 Jan. to 1 Feb.

Comstock, M. et al. (2012) "Case Study: Colombia's National Climate Change process" Center For Clean Air Policy (CCAP)

"Cross-Cutting Perspective C: Capacity Development and Social Learning" 4th World Water Forum. Mexico, 2006

Daniel C.B., R. Maharaj and G. De Souza 2001. "Tropical cyclones affecting Trinidad and Tobago 1725 to 2000". Meteorological Services of Trinidad and Tobago.

Dean, R.G. (1987). "Coastal Sediment Processes: Toward Engineering Solutions". Proc. ASCE, Specialty Conference on Coastal Sediments´87.

De La Cadena Ramos, C, Larrea Esparaza, P. (2012) "Diseño de un tanque de almacenamiento de petróleo Tip Techo Flotante de 100,000 Barriles de Capacidad para la Empresa Tesca Ingeniería del Ecuador" Facultad de ingeniería Mecánica Ecuela Politécnica Nacional, Ecuador

Delcan (2012) "Cost of Adaptation - Sea Dikes & Alternative Strategies", Ministry of Forests, Lands and Natural Resource Operations. October 2012. EB3762

Dell'Acqua el at (2012) "Freeway crashes in wet weather: the comparative influence of porous and conventional asphalt surfacing" Procedia - Social and Behavioral Sciences 54 (2012) 618 – 627

Department of Economic. The University of the West Indies (2008). "Implementation of Adaptation Measures to Climate Change Impact and Development of Tools to Evaluate the Economic Effects". Belmopan. Belize: Caribbean Community Climate Change Centre. Project Report.

DINAS-COAST Consortium (2006). "DIVA 1.5.5". Potsdam institute for climate impact research. Potsdam. Germany. CD-ROM. http://www.pik-potsdam.de/diva. Accessed 10 July 2009.

E.C. van Ierland, K. de Bruin, R.B. Dellink and A. Ruijs (2007). A qualitative assessment of climate adaptation options and some estimates of adaptation costs. Environmental Economics and Natural Resources, Wageningen UR.

ECA Working Group (2009). "Shaping Climate-Resilient Development: A Framework for Decision-Making. A Report of Economics of Climate Adaptation (ECA) Working Group." Available at:

ww.mckinsey.com/clientservice/Social_Sector/our_practices/Economic_Development/Knowledge_Highlights/Economics_of_climate_adaptation.aspx.

ECLAC 2009. "Statistical Yearbook for Latin America and the Caribbean"

ECLAC, 2010. "Economics of climate Change in Latin America and the Caribbean"

ECLAC (2011a) "An Assessment of the Economic Impact of Climate Change on the Energy Sector in Trinidad and Tobago"

ECLAC (2011b) "An Assessment Of The Economic Impact Of Climate Change On The Agriculture Sector In Trinidad And Tobago"

Economic Commission for Latin America and the Caribbean (2009a). "Economics of Climate Change in Latin America and the Caribbean: Summary 2009". United Nations. Santiago. Chile.

Economic Commission for Latin America and the Caribbean (2009b). "Climate Scenarios. FOCUS: Newsletter of the Caribbean Development and Cooperation Committee (CDCC)". July-September 2009. 6-7. Port of Spain: ECLAC Subregional Headquarters for the Caribbean.

Economic Commission for Latin America and the Caribbean (2010). "The Economics of Climate Change in Central America: Summary 2010". Santiago. Chile: The United Nations.

ECOFYS. EURIMA (2007). "U-Values-For better energy performance of buildings".

Emanuel. Kerry. Sai Ravela. Emmanuel Vivant. Camille Risi (2006). "A statistical deterministic approach to hurricane risk assessment". Bull. Amer. Meteor. Soc.. 87. 299–314. doi: http://dx.doi.org/10.1175/BAMS-87-3-299

Environment Agency (2013). "Prepare your property for flooding" <http://www.environment-agency.gov.uk/homeandleisure/floods/31644.aspx>

Environmental management Authority, EMA. (2011). "Environmental Management Authority" Available at: <www.ema.co.tt/new/images/pdf/hydrodynamic_guidebook.pdf>

EPA (2002). "Cases in Water Conservation: How Efficiency Programs Help Utilities Save and Avoid Costs"

EPA "Building Codes for Energy Efficiency" National Action Plan for Energy Efficiency

European Commission. (201?a) "Protecting the coast from erosion using hard rock measures – BG"

European Commission. (201?b) "Adapting existing dykes and dams (Adaptation option)" <http://climate-adapt.eea.europa.eu/viewmeasure?ace_measure_id=1101>

European Commission. (201?b) "Case Study 13: Hadyard Hill Community Energy Project Energy Agency – Scotland, UK"

European Union (2011) "Integrated Coastal Zone Management Information And Technology In ICZM Practices Around Europe"

EurOtop Manual. 2007. "Overtopping Manual; Wave Overtopping of Sea Defences and Related Structures – Assessment Manual". UK: N.W.H. Allsop, T. Pullen, T. Bruce. NL: J.W. van der Meer. DE: H. Schüttrumpf, A. Kortenhaus. www.overtopping-manual.com.

FAO (2005) "Global Forest Resources Assessment 2005: Thematic Study on Mangroves Trinidad and Tobago" FOA, Rome Italy Forestry Department

FEMA (2009) "Homeowner's Guide to Retrofitting: Six Ways to Protect Your Home From Flooding" FEMA P-312, Second Edition / December 2009

FEMP (2004) "Federal Technology Alert: Green Roofs DOE-EE0298"

Franklin, James L., Richard J. Pasch, Lixion A. Avila, John L. Beven, Miles B. Lawrence, Stacy R. Stewart, Eric S. Blake (2006). "Atlantic Hurricane Season of 2004". Monthly Weather Review, 134, 981–1025.

Finger, R. and S. Schmid. 2007. "Modelling Agricultural Production Risk and the Adaptation to Climate Change". MPRA Paper No. 3943. Paper prepared for presentation at the 101st European Association of Agricultural Economists Seminar Management of Climate Risks in Agriculture', Berlin, Germany, July 5-6, 2007

Framiñán, D. (201?) "¿Qué Es Agroseguro?" http://queaprendemoshoy.com/que-es-el-agroseguro.

Green, CH. And haney, R. "Filter Strips" USDA-ARS, Temple, Texas

Goddard Institute for Space Studies. New York.

Gornitz V.M (1990). "Vulnerability of the East Coast, USA to future sea level rise. Journal of Coastal Research". (Special Issue No. 9), 201-237.

Government of the Republic of Trinidad and Tobago (2011). "National Climate Change Policy" July 2011.

Government of the Republic of Trinidad and Tobago (2013). "DRAFT Second National Communication of the Republic of Trinidad and Tobago" April 2013.

Government of the Republic of Trinidad and Tobago (2006). "DRAFT National Action Programme To Combat Land Degradation In Trinidad And Tobago: 2006-2020".

Guerra, J. et al (2010) "Cuba Risk Reduction Management Centres Best Practices In Risk Reduction" Caribbean Risk Management Initiative – UNDP Cuba

Hall. T.M.. and S. Jewson (2007). "Statistical modelling of North Atlantic tropical cyclone tracks". Tellus. 59A. 486-498. doi:10.1111/j.1600-0870.2007.00240.x.

Hallegatte S. (2012) "A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-Meteorological Services. Early Warning. and Evacuation". Policy Research Working Paper 6058

Hallermeier, R. J. (1981). “A Profile Zonation for Seasonal Sand Beaches from Wave Climate”. Coastal Engineering, Vol. 4, 253-277.

Harris M. 2000. “The current situation of small and medium-sized industrial enterprises in Trinidad & Tobago, Barbados and St. Lucia ECLAC

Heim R.R., Jr. (2002). “A review of twentieth century drought indices used in the United States”. Bulletin of the American Metereological Society, vol 83, no 8, 1149-1165.

Hardy. R.L.. 1990. “Theory and applications of the multiquadric-biharmonic method”. Computers and Mathematics with Applications 19 (8–9). 163–208.

Hodell D.A., J.H. Curtis and M. Brenner (1995). “Possible role of climate in collapse of the Classic Maya civilization”. Nature, vol 375, 391-394.

Holland. Greg J. (1980). “An Analytic Model of the Wind and Pressure Profiles in Hurricanes”. Mon. Wea. Rev.. 108. 1212–1218. doi: http://dx.doi.org/10.1175/1520-0493(1980)108<1212:AAMOTW>2.0.CO;2

Holland. Greg J. (1983). “Tropical Cyclone Motion: Environmental Interaction Plus a Beta Effect”. J. Atmos. Sci.. 40. 328–342. doi: http://dx.doi.org/10.1175/1520-0469(1983)040<0328:TCMEIP>2.0.CO;2

Holland G.J and P.J Webster (2007). “Heightened Tropical Cyclone Activity in the North Atlantic: Natural Variability or Climate Trend?”. Mesoscale and Microscale Meteorology Division. ESSL. National Center for Atmospheric Research. Boulder. Co 80307. USA.

Hoorman, J. (2009) “Using Cover Crops to Improve Soil and Water Quality”. The Ohio State University.

Hyacinth-Ash. V. (2011) “A Study of the Last Forty Years of Daily Rainfall Data in Trinidad to Examine Any Indications of Climate Change and its Repercussions for the Farming Population in Trinidad and Tobago”.

IDB 2007. “Trinidad & Tobago: Economic Growth in a Dual Economy”.

International Energy Agency. (2012) “CO2 Emissions From Fuel Combustion Highlights”

International Federation of Red Cross and Red Crescent Societies (2004). World Disasters Report Focus on community resilience.

International Fund for Agricultural Development (2011) “Weather Index-based Insurance in Agricultural Development: A Technical Guide” ISBN 9789290722762

Indo-Asian News Service (2007). “Cyclone Gonu kills 12 in Iran. Gulf toll 61”. Archived from the original on June 22. 2007. Retrieved June 10. 2007.

Iowa Department of Agriculture and Land Stewardship “Iowa Watershed Project Status — One Paragraph Summaries”

IPCC TAR WG2 (2001) McCarthy, J. J.; Canziani, O. F.; Leary, N. A.; Dokken, D. J.; and White, K. S., ed. “Climate Change 2001: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change". Cambridge University Press, ISBN 0-521-80768-9 (pb: 0-521-01500-6).

M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds) (2007). "IPCC AR4 WG2" Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 976 pp.

Izaguirre C., M. Menéndez, P. Camus, F.J. Méndez, R. Minguez (2012). "Exploring the interanual variability of extreme wave climate in the Northeast Atlantic Ocean". Ocean Modelling 59-60 (2012) 31-40.

Jarvinen B.R.. C.J. Neumann. and M.A.S. Davis (1984). "A tropical cyclone data tape for the North Atlantic Basin". 1886-1983: Contents. limitations. and uses. NOAA Tech. Memo.NWS NHC Vol 22. 21 pp.

Joint Typhoon Warning Center (2007). "Northern Indian Ocean Tropical Cyclone Best Track Data: Cyclone Gonu". Retrieved May 27. 2008.

Jonkman. S. et al. (2013) "Costs of Adapting Coastal Defences to Sea-Level Rise—New Estimates and Their Implications" Journal of Coastal Research 29 5 1212–1226 Coconut Creek, Florida September 2013

Kathiresan, K. "3.5. Importance of Mangrove Ecosystem" Centre of Advanced Study in Marine Biology. Annamalai University

Katz R.W. (2002). "Stochastic modelling of hurricane damage". Journal of Applied Meteorology, 41, 754-762.

Kelley, A. (2011) "Seawater Desalination: Climate Change Adaptation Strategy or Contributor?"

Knutson T.R. et al. (2013). "Dynamical Downscaling Projections of 21st Century Atlantic Hurricane Activity: CMIP3 and CMIP5 Model-based Scenarios". Jounal of Climate. Geophysical Fluis Dynamics Laboratory/Noaa. Princeton. NJ 08542.

Koschikowski, J. (2011) "Water Desalination: When and Where Will it Make Sense?" Fraunhofer Institute for Solar Energy Systems ISE. Freiburg, Germany

Landsea C.W.. C. Anderson. N. Charles. G. Clark. J. Dunion. J. Fernandez-Partagas. P. Hungerford. C. Neumann. and M. Zimmer. (2004). "The Atlantic hurricane database re-analysis project: Documentation for the 1851-1910 alterations and additions to the HURDAT database". Hurricanes and Typhoons: Past. Present and Future. R.J. Murname and K.-B. Liu. Eds.. Columbia University Press. 177-221 pp.

Landsea C.W (2007). "Counting Atlantic Tropical Cyclones Back to 1900". EOS. Transaction. American Geophysical Union. Vol. 88. No. 18.

Landsea C.W.. D.A. Glenn. W. Bredemeyer. M. Chenoweth. R. Ellis J. Gamache. L. Hufstetler. C. Mock. R. Perez. R. Prieto. J. Sanchez-Sesma. D. Thomas. and L. Woolcock

(2008). “A reanalysis of the 1911-20 Atlantic hurricane database”. J. Climate. Vol 21. 2138-2168.

Lapointe, B., Langton, R., Bedford, B., Potts, A., Day, o., Chuanmin, H. (2010). “Land-based nutrient enrichment of the Buccoo Reef Complex and fringing coral reefs of Tobago, West Indies”. Marine Pollution Bulletin. Volume 60, Issue 3, March 2010, Pages 334–343

LaquaR Consultants CC. (2008) “Final Report Sea-Level Rise Adaptation and risk mitigation measures for the City of Cape Town Report prepared by Anton Cartwright (SEI Cape Town) in collaboration with Prof. G. Brundrit and Lucinda Fairhurst July 2008”

Laydoo, Richard S. Kurt Bonair, and Gerard Alleng. 1998. “Buccoo Reef and Bon Accord Lagoon, Tobago, Republic of Trinidad and Tobago, in CARICOMP- Caribbean coral reef, seagrass and mangrove site”. Coastal Region and small island papers 3, UNESCO Paris, xiv +347 pp

Losada, M. A. y Jíménez-Curto L. A., 1979. “The joint effect of wave heigt and periodo n the stability of rubble mound breawaters using Iribarren´s number”. Coastal Eng., Vol. 3.

Leendertse J.J. (1970). “A water quality simulation model for well mixed estuaries and coastal seas. Vol. 1”. Principles of computation. RM-6230-RC. The Rand Corporation, Santa Mónica, California.

Lewis, R. (2001) “Mangrove Restoration - Costs and Benefits of Successful Ecological Restoration”

Lewsey et al. (2004). “Assessing climate change impacts on coastal infrastructure in the Eastern Caribbean” Marine Policy 28 (2004) 393–409

Lewsey et al. (2007). "Mainstreaming Adaptation to Climate Change (MACC): Climate Change Impacts on Land Use Planning and Coastal Infrastructure". The National Oceanic and Atmospheric Administration’s National Ocean Service (NOS)

Linnean Solutions et al. (2013) “Building Resilience in Boston: Best Practices for Climate Change Adaptation and Resilience for Existing Buildings”.

Liu PL. Der Kiureghian A (1986). “Multivariate distribution models with prescribed marginals and covariances”. Probabilistic Engineering Mechanics 1(2):105-112.

Lalla, H. (2001) “National reports and technical papers presented at the First Meeting Of The Wecafc Ad Hoc Working Group On The Development Of Sustainable Moored Fish Aggregating Device Fishing In The Lesser Antilles” FAO. Available at: http://www.fao.org/docrep/005/y4260e/y4260e0f.htm#bm15

Mahabir, D. and Nurse, L. 2007. “An assessment of the vulnerability of the Cocal area, Manzanilla, Trinidad, to coastal erosion and projected sea level rise and some implications for land use”. CERMES (UWI)

Mallela, J. (200?) “Tobago: A Sustainable Future fo Buccoo Reef” World Resources institutue available at :<http://www.wri.org/tobago-sustainable-future-buccoo-reef>

Marks. D. (1992). "The beta and advection model for hurricane forecasting". NOAA Technical Memo NWS NMC 70. Camp Springs. MD: National Meteorological

Marks F.D.. S.R. Stewart (2001). "TRMM Satellite Data - Applications to Tropical Cyclone Analysis and Forecasting. TRMM Workshops". Boulder. Colorado: University Corporation for Atmospheric Research. 7–25.

Martín et al. (2013). "An assessment of the economic and social impacts of climate change on the energy sector in the Caribbean". Economic Commission for Latin America and the Caribbean (ECLAC)

Massey FJ (1951). "The kolmogorov-smirnov test for goodness of fit". Journal of the American Statistical Association 46(253):68-78.

McDowell, C. A. (2011). "Climate Change Adaptation and Mitigation: Implications for land acquisition and population relocation" (Report No. WP3). London, UK: BIS Government Office for Science.

MCII (2013) "For Individuals: The Livelihood Protection Policy"

Mcleod, Elizabeth. (1999). "Report on the Intergovernmental Panel on Climate Change (IPCC) Expert Meeting on Small Island States in Connection with Chapter 17, IPCC-TAR" Valletta – Malta

McLeod, Elizabeth and Salm, Rodney V. (2006). "Managing Mangroves for Resilience to Climate Change". IUCN. Gland. Switzerland. 64pp.

Mellor G.L. (1993). "A three-dimensional, primitive equation, numerical ocean model". Technical Report. Atmospheric and Oceanic Sciences Program, Princeton University.

Mendelsohn, R., R. Dinar, A. and Williams, L (2006). "The distributional impact of climate change on rich and poor countries". Environment and Development Economics 11: 159–178 Cambridge University Press

Metroeconomica (2004). "Costing the impacts of climate change in the UK: Overview of guidelines." Oxford: UKCIP. Technical Report.

Ministry of the Environment and Water Resources (2011) "BUCCOO REEF/ BON ACCORD LAGOON COMPLEX" Available at: <http://www.biodiversity.gov.tt/home/protected-areas-and-species/ramsar-sites/buccoo-reefbon-accord-lagoon.html>

Ministry of Planning and the Economy (2012). "Working for Sustainable Development in Trinidad and Tobago"

Murtagh BA. Saunders MA (1978). "Large-scale linearly constrained optimization". Mathematical Programming 14:41-72.

Murtagh BA. Saunders MA (1998) "MINOS 5.5 User's Guide. Report SOL 83-20R SOL 83-20R". Department of Operations Research. Stanford University. Stanford. California.

Narafu, T. et al (201?) "Knowledge Note 1-2: Cluster 1: Structural Measures: Building Performance".

NASA Earth Observatory. “Tropical Cyclone Gonu”. NASA. (2007). Retrieved June 5. 2007.

Neal, T. (2011) “Climate Change: Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use in British Columbia”

Nitkin, D. et al. (2008) “Case studies & tools: A Systematic Review of the Literature on Business Adaptation to Climate Change 3 of 4” Network for Business Sustainability.

ODPM (2013) “Phase III of Communities Organised and Ready for Emergencies launched on”, Office of Disaster Preparedness and Management <http://www.odpm.gov.tt/node/697>

Olivo, María de Lourdes. (1997). “Assessment of the vulnerability of Venezuela to sea-level rise”. Climate Research Clime Res. Vol 9: 57-65, 1997

Organization of American States. “1.1 Rainwater harvesting from rooftop catchments” <http://www.oas.org/dsd/publications/Unit/oea59e/ch10.htm>

Organization of American States. “1.2 Rainwater harvesting in situ” <http://www.oas.org/dsd/publications/Unit/oea59e/ch11.htm>

Oregon State Universty. “Individual Year Conversion Factor Tables”.

Palmer W (1965). “Meteorological drought”. (Research Paper no 45). Us Departament of Commerce, Washintong, DC.

Parish, J. (2011) “Grand Isle Takes Building Codes seriously”

Penn State College of Agricultural Sciences (2006). “Cover Crops for Conservation” Tillage Systems. Conservation Tilage Series Number Five. The Pennsylvania State University 2006.

Petroleum Company of Trinidad and Tobago Limited. “Consolidated Financial Statements”. 2012 September 30.

Petrotrin (2013) “Refining and Marketing” Available at: <http://www.petrotrin.com/Petrotrin2007/PapRefinery.htm>

Pevensey Coastal Defence Ltd (200?) “Pevensey Bay Sea Defences” Available at: <http://www.pevensey-bay.co.uk/ppp.html>

Pidgeon, N. (2006) “Public Risk Perceptions, Climate Change and Reframing of UK Energy Policy” Economic and Social Research Council/ Available at: < http://www.esrc.ac.uk/my-esrc/grants/RES-152-25-1011/read/keyfindings>

Pielke, R. Et al. (2003). ”Hurricane Vulnerability in Latin America and The Caribbean: Normalized Damage and Loss Potentials.” Nat. Hazards Rev., 4(3), 101–114.

Piexe, C. Et al (2011) “Rainwater Harvesting for Sustainable Drainage and Non Potable Use in the Schools of Rio de Janeiro, Brazil” 12nd International Conference on Urban Drainage, Porto Alegre/Brazil, 10-15 September 2011.

Porter, M.G. (2013). “A Tale of Two Cities: Desalination and Drought in Perth and Melbourne”

Pulwarty, R.S., Nurse, L.A. & Trotz, U. (2010). “Caribbean Islands”. Environment, November/December 2010. Available at (12/05/2011) <http://www.environmentmagazine.org/Archives/Back%20Issues/November-December%202010/caribbean-islands-full.html>

Purdue University. “Sand Filters” <https://engineering.purdue.edu/~frankenb/NU-prowd/sand.htm>

Rasmusson E.M. and T.H. Carpenter (1982). “Variations in Tropical Sea Surface Temperature and Surface Wind Fields Associated with the Southern Oscillation/El Niño”. Monthly Weather Review, Vol 110, 354–384.

Rasmussen E.M., R.E. Dickinson, J.E. Kutzbach and M.K. Cleveland (1993). “Climatology”. D. R. Maidment (ed) Handbook of Hydrology, McGraw-Hill, New York, 2.1-2.44.

Reser, J. (2011) “Channging Perceptions about Climate Change” National Climate Change Adaptation Reasearch Facility. Available at: < http://www.nccarf.edu.au/content/changing-perceptions-about-climate-change>

Reynolds. Richard W.. Thomas M. Smith. Chunying Liu. Dudley B. Chelton. Kenneth S. Casey. Michael G. Schlax (2007). “Daily High-Resolution-Blended Analyses for Sea Surface Temperature”. J. Climate. 20. 5473-5496.

Ris R.C., L.H. Holthuijsen and N. Booij (1999). “A third-generation wave model for coastal regions”. Part II: Verification, J. Geophys. Res. Vol. 104, C4, 7667-7681.

Rogers, D. and Tsirkunov, V. (2011). “Costs and Benefits of early Warning Systems”

Romieu E., T. Welle, S. Schneiderbauer, M. Pelling , C. Vinchon (2010). “Vulnerability assessment within climate change and natural hazard contexts: revealing gaps and synergies through coastal applications”. Integrated Research System for Sustainability Science, United Nations University. 5:159–170.

Rosenzweig, C., S. Gaffi n, and L. Parshall (Eds.) 2006. “Green Roofs in the New York Metropolitan Region: Research Report”. Columbia University Center for Climate Systems Research and NASA

Rosenzweig C. and D. Hillel (2008). “Climate Variability and the Global Harvest: Impacts of El Niño and Other Oscillations on Agro-Ecosystems”. Oxford University Press, 280 pp.

Roy R. Lewis III (2001). “Mangrove Restoration - Costs and Benefits of Successful Ecological Restoration”.

Royal Haskoning DHV (2012). “Costs and Benefits of Sustainable Drainage Systems.” Project developed within the Economics of Flood Risk Adaptation Measures project.

Rubinstein BV (1981). “Simulation and the Monte Carlo Method”. John Wiley & Sons. New York.

Science for Environment Policy. (2013) "Mangroves provide both climate change mitigation and adaptation services." 24 September 2013 Thematic Issue 42

Scott, S. Clements, R., J. Haggar, A. Quezada, and J. Torres (2011). “Technologies for Climate Change Adaptation”.

– Agriculture Sector. X. Zhu (Ed.). UNEP Risø Centre, Roskilde, 2011” Jamaica Observer October 14, 2013 http://www.jamaicaobserver.com/business/New-weather-insurance-policy-may-protect-the--small-man-_15238966

Schneiderbauer, S. y Ehrlich, D. 2004. “Risk, hazard and people’s vulnerability to natural hazards. A review of definitions, concepts and data”. European Commission. Joint Research Centre. Luxemburgo. ISBN 92-894-8732-1.

Scruggs, G. and Bassett, T. (2013). “Coastal Zone Management: The Barbados Model”. Land Lines. Lincoln Institute Of Land Policy. October 2013

Sheffield J. and E.F. Wood (2011). “Drought Past Problems and Future Scenarios”. Earthscan, 210 pp.

Shimberg Center for Affordable Housing and Applied Research Associates, Inc. (2002). “Florida Building Code Cost and Loss Reduction Benefit Comparison Study.”

Silva R., G. Govaere, P. Salles, G. Bautista and G. Díaz (2002). “Oceanographic vulnerability to hurricanes on the mexican coast”. Proc. 28th International conference on coastal engineering. World scientific. Singapore.

Singh, B., (1997). “Climate changes in the greater and southern Caribbean”. International Journal of Climatology, 17, 1093–1114.

Simpson et al. (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”. The CARIBSAVE Partnership for UNDP Barbados and the OECS for CARICOM Member States.

Singh. B. (1997). “Climate Changes in the Greater and Southern Caribbean.” International Journal of Climatology 17:10936-1114.

Singh. B. and A. El Fouladi (2006). “Phase 2 Vulnerability Assessment Survey of for the Pointe-à-Pierre Foreshore” Report Submitted to the Petroleum Company of Trinidad and Tobago Limited (PETROTRIN).

Singh. B. and A. El Fouladi (2007). “Detailed Vulnerability Assessment Survey And Storm Surge Modelling Of The West Coast Of Trinidad: Vessigny To Cap-de-ville Quadrant”

Smagorinsky J. (1963). “General circulation experiments with the primitive equations. I: The basic experiment”. Monthly Weather Review. Vol. 91, 99-164.

Soomai, S., (2005) “Status Of Coastal Zone And Fisheries Resources Management And The Incorporation Of Demographic And Socio-Economic Considerations/Indicators: Trinidad and Tobago” Letter of Agreement (PO 152094) in support of FAO Regular Programme Activity on Fisheries Activities

Stern. Andrew D.. et al. "Analysis of weather impacts on traffic flow in metropolitan Washington DC." Proceedings of the 19th International Conference on Interactive Information and Processing Systems (IIPS) for Meteorology. Oceanography. and Hydrology. 2003.

Stern. Nicholas (2007). “The Economics of Climate Change: The Stern Review”. Cambridge. United Kingdom: Cambridge University Press.

Stine S. (1994). “Extreme and oersistent drought in California and Patagonia during medieval time.” Naturem, vol 369, 546-549.

Susdrain. (2011) “Case Study: Lamb Drove, Residential SuDS scheme, Cambourne” <http://www.susdrain.org/case-studies/case_studies/lamb_drove_residential_suds_scheme_cambourne.html>

Syne, S. (2011) “Evolution of the Speyside Eco-Marine Park Rangers from a Community-Based Management Project: Contributions of the Global Environment Facility – Small Grants Programme in Tobago” International Conference on the Sustainable Development of Coastal Communities: Challenges and Solutions 1 – 3 June 2011, Port-of-Spain Trinidad

Taylor, et al. (2007). “Glimpses of the future: A Briefing from the PRECIS Caribbean Climate Change Project”. Caribbean Community Climate Change Centre, Belmopan, Belize.

Tasmanian Climate Change Office Department of Premier and Cabinet. “Helping farmers adapt to climate change: Information Sheet”

Tazmanian Institute of Agriculture. “Impact of climate change: overview: opportunities for Tasmanian agriculture”

The Interagency Working Group on Social Cost of Carbon (2013). “Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866”

Thomas. T.H. and Martinson. D.B. (2007). “Roofwater Harvesting: A Handbook for Practitioners”. Delft. The Netherlands. IRC International Water and Sanitation Centre. (Technical Paper Series; no. 49). 160 p.

The Caribbean Environmental Health Institute (2009). “Rainwater. Catch it While You Can - A Handbook on Rainwater Harvesting in the Caribbean”. The United Nations Environment Programme (UNEP).

The Cropper Foundation (2010). “Fourth National Report of Trinidad and Tobago to the Convention on Biological Diversity”.

The Cropper Foundation. "Port of Spain" Case Study. Trinidad and Tobago Housing Sub-Comittee Report. Available at: www.pnmtt.org/pdf/Housing/Housing_COMPLETED.pdf

The Texas Asphalt Pavement Association. (20??) "White paper on Permeable Friction Course Hot Mix Asphalt On Interstate Highways In Texas"

Titus, J. (1989) "Policy Implications Of Sea Level Rise: The Case Of The Maldives" <papers.risingsea.net/Maldives/Small_Island_States_3.html>

Tomalty,R. and Komorowski, B. (2010) "The Monetary Value of the Soft Benefits of Green Roofs Final Report" Canada Mortgage and Housing Corporation (CMHC)

Tompkins, E.L., et al. (2005). "Surviving Climate Change in Small Islands - A guidebook", The Tyndall Centre for Climate Change Research, United Kingdom

Torresan S., A. Critto, J. Rizzi, and A.Marcomini (2012). "Assesment of coastal vulnerability to climate change hazards at the regional scale: the case study of the North Adriatic Sea". Natural Hazards and Earth System Sciences, vol 12, 2347-2368.

UNEP (2004) "People and reefs: successes and challenges in the management of coral reef marine protected areas." UNEP Regional Seas Reports and Studies No. 176. UNEP 2004.

UN-Habitat. "Rainwater Harvesting and Utilisation". Blue Drop Skies Book 1: Policy Makers.

United Nations secretariat of the International Strategy for Disaster Reduction (UNISDR) (2010) "Local Governments and Disaster Risk Reduction Good Practices and Lessons Learned A contribution to the "Making Cities Resilient" Campaign"

US EPA (2009). "Synthesis of Adaptation Options for Coastal Areas." Washington, DC, U.S. Environmental Protection Agency

US EPA (2010) "Guidelines for preparing Economic Analysis" *National Center for Environmental EconomicsOffice of PolicyU.S. Environmental Protection Agency*

US EPA (2013) "Energy" Available at: <http://www.epa.gov/climatechange/impacts-adaptation/energy-adaptation.html#adaptenergy>

Van Beukering. P.. L. Brander. E. Tompkins. and E. McKenzie (2007). "Valuing the Environment in Small Islands: An Environmental Economics Toolkit". Available at: http://www.jncc.gov.uk/page-4065

Van Bochove (2012). "Final Report Results Of Community And Scientific Work." Tobago Coastal Ecosystems Mapping Project. Coral Cay Conservation Availbable at: <http://www.coralcay.org/app/download/5785462505/TCEMP+Report+2012.pdf>

Water Resources Agency (2001) "National Report On Integrating The Management Of Watersheds And Coastal Areas In Trinidad And Tobago"

WFP. "Disaster Risk Reduction" Available at: http://www.wfp.org/disaster-risk-reduction.

Whitaker, J. S., G. P. Compo, X. Wei, and T. M. Hamill (2004). “Reanalysis without radiosondes using ensemble data assimilation”. Mon. Weather Rev., 132, 1190–1200, doi:10.1175/1520-0493(2004)132.

Whitehead. J. (2001) “Cost-Benefit Analysis of Climate Change Adaption and Mitigation Projects in Trinidad and Tobago: Draft Final Report (Revised)”

Wilhite D.A., M.D. Svobova and M.J. Hayes. (2007). “Understanding the complex impacts of drought: Akey to enhancing drought mitigation and preparedness”. Water Resources Management, vol 21, 763-74.

World Bank. The (2010a). “The Costs to Developing Countries of Adapting to Climate Change. New Methods and Estimates”. Washington. D.C.: The World Bank Group.

The World Bank Group (2010b) “Economics of Adaptation to Climate Change: Vietnam”

World Bank (201?) ”A Pioneering Approach to Building Disaster Risk Management Capacity: Saving Lives in High-Risk Communities in Honduras” < http://web.worldbank.org/WBSITE/EXTERNAL/NEWS/0,,contentMDK:23170516~menuPK:141310~pagePK:34370~piPK:34424~theSitePK:4607,00.html>

World Bank. “Trinidad and Tobago Country Meta Data”.

World Travel and Tourism Council. (2005) “Trinidad and Tobago the impact of travel and tourism on jobs and the economy”.

World Resources Institute (2008) “Shoreline Protection by Coral Reefs - Tobago” Available at: http://www.wri.org/resources/maps/shoreline-protection-coral-reefs-tobago.

Yue Wang. David V. Rosowsky. “Joint distribution model for prediction of hurricane wind speed and size”. Structural Safety. Volume 35. March 2012. Pages 40-51. ISSN 0167-4730.

Zorrilla, G. Et al “10. Improving Rice Production Systems in Latin America and the Caribbean”

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