Antigua & Barbuda Climate Change Adaptation

Cost Effective Analysis

6 February 2020

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Version : V3

6 February 2020

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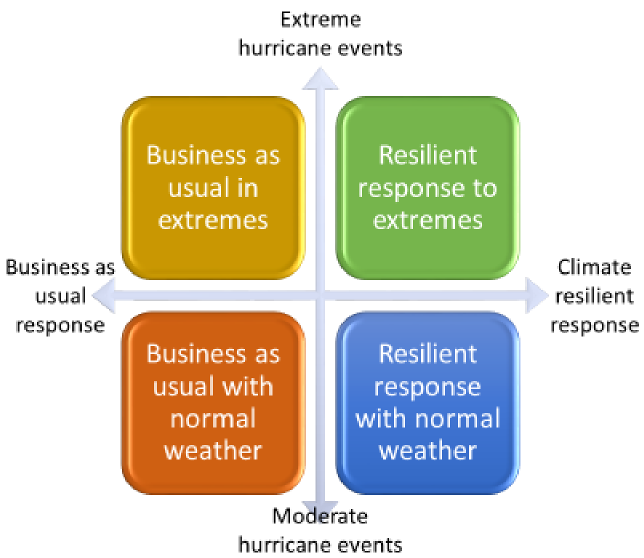
1 Executive Summary

In recent years several category 5 hurricanes have struck Antigua and Barbuda, resulting in serious damage levels. In order to take decisions regarding the type of climate change adaptation that the government should respond with, it is necessary to understand the adaptation expenditure options and their likely avoided hurricane impact costs. As the two options will have very different cost and impact implications, it is necessary to analyse the intervention expenditure and impact avoidance of the different adaptation options. A cost effectiveness analysis has been employed to inform the decision making. This analysis will identify which adaptation options will offer the greatest levels of cost avoidance or in other words, which option will be the most effective spend for Antigua and Barbuda society.

Antigua and Barbuda could experience different future climatic conditions, with different frequencies and intensities of hurricanes. Four plausible scenarios facing Antigua and Barbuda society were developed and are outlined in the graphic below.



Business as usual with 'normal' weather scenario - In this scenario government chooses to respond in a manner like the past, where infrastructure is repaired anticipating the past 'normal' weather. Buildings are repaired using conventional repairs, and the centralised water and energy supply system is maintained. To all intents, it is a business as usual response. In terms of the climatic conditions, hurricane phenomena are assumed to be similar to the past, with occasional category 3 hurricanes.

Business as usual with extreme weather scenario - In this scenario government also responds in the past manner, where infrastructure is repaired in a conventional manner anticipating 'normal' weather. Buildings are repaired using standard responses, and the centralised water and energy supply system is maintained. However, in terms of climatic conditions, the Antigua meteorological data from 1970 to 2013, and 2017 is adopted, which includes hurricanes of greater frequency and greater intensity (at category 4 and 5 levels).

Resilient response with 'normal' weather scenario - In this scenario government responds in a climate resilient manner, by anticipating future extreme weather. In terms of the response to infrastructure, 54 key government buildings are strengthened to resist category 5 hurricanes (that is, 25% of 200 key government buildings), and water and energy supply is decentralised to allow for multiple supply options (to reduce the risks associated with a single supply system). In terms of human and institutional capital, technical capacity is built in the public and private sector, building codes are regulated, innovative finance facilities to promote building adaptation is provided and an early warning system is established. In terms of the climatic conditions, hurricane phenomena and trends are assumed to be like the past (1900 to 1950).

Resilient response with extreme weather scenario - Here government responds in a climate resilient manner by strengthening 54 key government buildings to resist category 5 hurricanes, and water and energy supply is decentralised to allow for multiple supply options. Technical capacity is built in the public and private sector, building codes are regulated, innovative finance facilities to promote building adaptation is provided and an early warning system established. Climate change projections under both the RCP4.5 and 8.5 scenarios[1] indicate that, although the total number of storms is not expected to change significantly, there will be an increase in the frequency of high-intensity storms (Category 4 and 5 hurricanes) experienced by Antigua and Barbuda.

The expenditure on alternative intervention options were clustered into two broad packages, namely:

- A baseline package representing the conventional response to category 3 hurricane impacts and includes a total capital cost of USD 9.6 million and an annual operating expenditure of USD 64 800.
- A climate resilient package representing a retrofit of 54 buildings for category 5 hurricanes, capacity building interventions to lever climate resilient private sector responses and includes a total capital cost of USD 21 million and an annual operating expenditure of USD 717 910.

The Net Present Value (NPV) of the baseline or business as usual intervention package is USD 14 million, and the climate resilient retrofit is USD 37.3 million. The climate resilient option being 2.7 times greater than the baseline. However, to judge the whether the expenditure is justifiable, it is necessary to quantify the interventions' impacts in the four scenarios. The impacts of the scenarios were estimated by:

- Firstly, analysing the impacts of single hurricane events (both category 3 and 5 hurricanes) when combined with government intervention packages – either a business as usual response or a climate resilient response.
- Secondly, summing the costs of repeat hurricane events (category 3 or 5 or both) in either the 'normal' or extreme weather scenarios over the next 50 years.

The quantum of the impacts were estimated as **avoided losses** using i) direct market values with respect to manufactured capital as a proxy for the loss in infrastructure, ii) loss in income as a proxy for the impact on the economy and welfare of people, and iii) the human capital approach as a proxy for the impact on the productive capability of the population as well as pain and suffering.

The analysis then used 'normal' hurricane trends (i.e. more category 1,2 and 3 hurricanes) reflected in the period 1900–1950 and extreme hurricane trends (i.e. more category 4 and 5 hurricanes) reflected in the period 1970–2013 and in 2017 to count and sum the different hurricanes and to combine these with the impact costs over 50 years for each scenario. A comparison of the four scenarios' intervention costs and hurricane impacts is outlined in the table below. Note the following:

- In *a business as usual intervention with 'normal' weather*, the cost of the interventions is USD 14 million, with a USD 552 million impact cost. However, in a *business as usual response with extreme weather*, while the intervention costs are the same, the impact cost is USD 17.3 billion, orders of magnitude greater.
- On the other hand, in a *climate resilient response with 'normal' weather*, the cost of interventions is USD 37 million, some USD 23 million more than the *business as usual* costs. However, in this scenario the impact costs are USD 214 million, some USD 338 million less than in *a business as usual intervention with 'normal' weather*. The additional USD 23 million expenditure buys a cost avoidance of USD 338 million. **Therefore, even in a 'normal' weather scenario, the climate resilient intervention is a no-regret investment.** In terms of a *climate resilient response with extreme weather* scenario, the impacts costs are USD 8.1 billion, some USD 9.2 billion less than *business as usual response with extreme weather*. **In this case, the additional USD 23 million resilient intervention spend, buys a USD 9.2 billion cost avoidance. This is a highly cost effective spend.**

[1] These representative concentration pathways (RCPs) are based on the main forcing agents of climate change, including GHG emissions, GHG concentrations and land-use change. RCP4.5 represents the likely best-case scenario with a peak radiative forcing of 4.5 W/m2 (~650 ppm CO2 eq) at stabilisation after 2100. RCP8.5 represents a very high GHG emission scenario with a peak radiative forcing of 8.5 W/m2 (~1,370 ppm CO2 eq) and no expected stabilisation in emissions. RCP8.5 indicates a business as usual scenario where the rate of GHG emissions continues to increase with no mitigation measures.

	Net present value (NPV) of the expenditure on interventions (USD millions)	NPV of "Normal" hurricane impact costs (USD millions)	NPV of extreme hurricane impact costs (USD millions)
Baseline: BaU interventions	$ 13.8	$ 551.9	$ 17,253.0
Resilient interventions	$ 36.9	$ 214.0	$ 8,091.4
Differences between Business as usual and Resilient spend and cost avoidance	$ 23.1	$ -337.9	$ -9,161.7

Table 1: Comparison of intervention costs and associated hurricane impact costs in the four scenarios

The cost effectiveness analysis identifies which options provide the greatest magnitude of avoided losses to society per dollar spent on interventions. Note the following:

- The *'normal' hurricane exposure with a business as usual intervention*, constitutes the *baseline* or the standard by which the other interventions are evaluated. In the comparative ratio, the baseline becomes '1'. Furthermore, in this scenario, a USD 1 spend on interventions is associated with a hurricane impact cost of USD 39.9. On the other hand, a *climate resilient response with 'normal' weather*, is associated with a USD 5.8 hurricane impact cost to society per dollar spend, or some 15% of the baseline – a much lower impact.
- In the *business as usual response with extreme weather* scenario, the loss could be as high as USD 1,246 per dollar spend or 31 times greater than the baseline scenario. In terms of a *climate resilient response with extreme weather* scenario, the loss could be USD 219 per dollar spent, orders of magnitude lower than the baseline.
- **In both weather scenarios, the resilient interventions offer more cost effective responses than a business as usual response.**

2 Introduction

Futureworks was engaged to undertake a cost-effectiveness analysis of implementing a suite of climate change adaptation interventions in Antigua and Barbuda to respond to the increasing frequency of Category 4 and 5 hurricanes. Historically, Antigua and Barbuda have mostly experienced category 3 hurricane events and infrastructure has been designed accordingly. However, in recent years several category 5 hurricanes have struck Antigua and Barbuda, resulting in serious damage levels. Under future climate change conditions, these category 4 and 5 hurricanes are expected to more frequency. In order to take a decision regarding the type of adaptation that government should respond with, it is necessary to understand the costs and potential impacts of responding with a conventional, business as usual approach (as in the past), or with a new approach designed to cope with category 5 hurricanes. As the two options will have very different financial implications, it is necessary to analyse the costs and range of the potential impacts of the different adaptation options and/or set of interventions in different plausible futures.

This report outlines the cost effectiveness of two alternative responses to two hurricane incidence scenarios in Antigua and Barbuda.

An Excel model was developed to undertake the cost effectiveness analysis and is provided separately for use by the client for future applications or refinement of the current scenarios. Note that the tables in the report are extracted from the spreadsheet to allow for easy cross referencing, between the spreadsheet and this report.

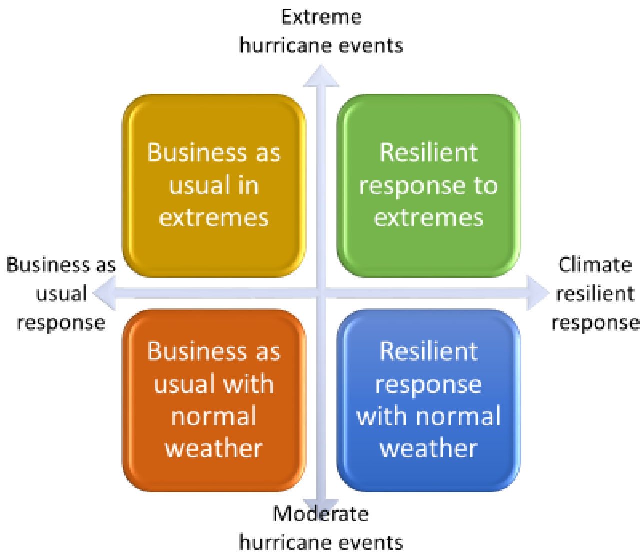
3 Cost Effectiveness Analysis Method

The terms of reference required a Cost Benefit Analysis (CBA) to be undertaken regarding two alternative approaches to repairing recent hurricane damage. A CBA is particularly useful when assessing private sector developments or the establishment of infrastructure that supports production, which provides a clear indication of how much revenue is generated for the money invested. However, in this case, where the money invested is intended to avoid the occurrence of future costs, a Cost Effectiveness Analysis is more appropriate. In simple terms, how much of a hurricane's impact costs are going to be avoided by spending on adaptation? This analysis will identify which adaptation options will offer the greatest levels of cost avoidance or in other words, which option will be the most effective spend for Antigua and Barbuda society.

The following chapters largely outline the inputs and outputs of the model. Note that this report is not a guide for using the model nor a guide to the algorithms in the spreadsheet. The data used in the spreadsheet was largely supplied by the Government of Antigua and Barbuda and public information.

4 The Adaptation Scenarios

The future hurricane scenarios are unknown. Antigua and Barbuda could experience different climatic conditions, with different frequencies and intensities of future hurricanes. Consequently, it is necessary to analyse different adaptation options in different climate futures. Four plausible scenarios facing Antigua and Barbuda society were developed and are outlined in the graphic below. The four scenarios are a matrix, combining two variables as continuums. The one continuum is the uncontrollable climate change future, where hurricane trends could be i) moderate through to ii) extreme. The other continuum represents a controllable variable, the nature of government response, which could be iii) business as usual response or iv) a climate resilience response. Combining both controllable and uncontrollable variables is a useful approach to avoid a simple either-or response to an assumed future and forces the analysis of several futures.



Business as usual with 'normal' weather scenario

In this scenario the government chooses to respond in a similar manner as the past, where infrastructure is repaired anticipating the past 'normal' weather, with occasional category 3 hurricanes. In this scenario buildings are repaired using conventional repairs, and the centralised water and energy supply system is maintained. To all intents, it is a business as usual response. In years 2039 and 2054 (20 and 35 years from 2019) infrastructure maintenance occurs, using business as usual costs.

In terms of climatic conditions, hurricane phenomena are assumed to be like the past. In this scenario (and the model), the Antigua meteorological data representing hurricane trends from 1900 to 1950, is used to describe the intensity and frequency of future hurricanes. Note that in years when more than one hurricane has occurred (1916 and 1950), the second hurricane was transferred to the next year for modelling purposes. In other words, 48 years data is spread over 50 years in the model. In addition, the model was built to make queries using two extremes, namely category 3 and category 5 hurricanes. Consequently, category 4 hurricanes were converted to category 3 hurricanes in this scenario.

Business as usual with extreme weather scenario

In this scenario the government responds in a manner similar to the past, where infrastructure is repaired in a conventional manner anticipating the 1900 to 1950 hurricane patterns. Buildings are repaired using standard responses, and the centralised water and energy supply system is maintained. It is a business as usual response. In years 2039 and 2054 (20 and 35 years from now) infrastructure maintenance occurs, using business as usual costs.

In terms of climatic conditions, hurricane incidence is assumed to respond to climate change with greater frequency and intensity, exhibiting extreme weather. The model used Antigua meteorological data from 1970 to 2013. However, 2017 data was inserted as the first three years of the data series in the model, thus representing current reality. If the 3 hurricanes of 2017 were modelled at the end of the data series (i.e. far into the future), then they would have minimal costs as Net Present Value (NPV) methodologies discount future values on an annual basis, so the more years involved the greater the degree of discounting. Consequently, the NPV of an event 50 years into the future will have a much smaller value than a current event. Category 4 hurricanes (of which there have been five occurrences since 1970) are converted alternatively as category 3 (three occurrences) and category 5 hurricanes (two occurrences) in the model.

Resilient response with 'normal' weather scenario

In this scenario government responds in a climate resilient manner, by anticipating extreme weather. In terms of a response to infrastructure, 54 key government buildings are strengthened to resist category 5 hurricanes (that is, 25% of 200 key government buildings), and water and energy supply is decentralised to allow for multiple supply options (to reduce the risks associated with a single supply system). In terms of human and institutional capital, technical capacity is built in the public and private sector, building codes are regulated, innovative finance facilities to promote building adaptation is provided and an early warning system is established. In years 2039 and 2054 (20 and 35 years from 2019) infrastructure maintenance occurs, using climate resilient response costs.

In terms of the climatic conditions, hurricane phenomena and trends are assumed to be like the past (1900 to 1950). In the scenario model, the Antigua meteorological data from 1900 to 1950 was used, using the same assumptions for 'normal' weather as in the *business as usual with 'normal' weather* scenario.

Resilient response with extreme weather scenario

In this scenario government responds in a climate resilient manner, by anticipating extreme future weather. In terms of a response to infrastructure, 54 key government buildings are strengthened to resist category 5 hurricanes (that is, 25% of 200 key government buildings), and water and energy supply is decentralised to allow for multiple supply options. In terms of human and institutional capital, technical capacity is built in the public and private sector, building codes are regulated, innovative finance facilities to promote building adaptation is provided and an early warning system is established. In years 2039 and 2054 (20 and 35 years from 2019) infrastructure maintenance occurs, using resilient response costs.

In terms of climatic conditions, hurricane phenomena are assumed to respond to climate change with greater frequency and intensity, exhibiting extreme weather. The scenario model used Antigua meteorological data from 2017 and 1970 to 2013, using the same assumptions as in the *business as usual with extreme weather* scenario. Category 4 hurricanes (of which there have been five occurrences since 1970) are converted alternatively as category 3 (three occurrences) and category 5 hurricanes (two occurrences) in the model.

5 The Expenditure on Interventions

The expenditure associated with alternative intervention options are outlined in Table 2 below. Note that the interventions have been clustered into two broad packages, namely:

- A baseline package representing a conventional response to category 3 hurricane impacts, and
- A climate resilient package representing a retrofit of 54 buildings for category 5 hurricanes, and capacity building interventions to lever climate resilient private sector responses.

The interventions have both capital costs and operating costs[2], with the capital costs being expended over 6 years from commencement, thus capital costs are divided linearly across years 1 – 6, but then repeated in years 20-25 and years 35-40, to account for depreciation and to ensure that the capital investment performs at an optimal level. In addition, there are annual operating costs incurred every year going forward. The total expenditure for the:

- Baseline or business as usual approach includes a total capital cost (expended over 6 years) of USD 9.7 million and an annual operating expenditure of USD 64 800.
- Climate resilient approach includes a total capital cost (expended over 6 years) of USD 22 million and an annual operating expenditure of USD 717 910.

[2] Stormwater drainage only has maintenance costs, as the capital costs are built into the water supply capital costs.

Interventions	Baseline: BaU level of intervention sufficient for max. category 3 hurricane impacts				Alternative: Resilient retrofit intervention sufficient for max. category 5 hurricane impacts			
	Capital sum (USD: 'million)	Implementation term	Start year	Operating and maintenance cost (USD/a: 'million)	Capital sum (USD: 'million)	Implementation term	Start year	Operating and maintenance cost (USD/a: 'million)
1 General structural repairs	$ 1.434717	6	2020	$ 0.01080				
2 General building repairs	$ 2.679475	6	2020	$ 0.02700				
3 Waste water treatment	$ 0.154751	6	2020	$ 0.01350				
4 General electric	$ 5.392323	6	2020	$ 0.01350				
8 Extreme weather resistance					$ 5.774616	6	2020	$ 0.05400
9 Solar PV + Batteries (on-site)					$ 7.950091	6	2020	$ 0.02160
10 Emergency RE stock (off-site)					$ 0.646212	6	2020	$ 0.03859
11Water supply					$ 3.540733	6	2020	$ 0.02160
12 Storm water drainage					$ -	6	2020	$ 0.02700
13 Climate change adaptation mainstreamed into the building sector and relevant financial mechanisms.					$ 3.055740	6	2020	$ 0.07204
14 Climate information services strengthened to facilitate early action within the building sector to respond to extreme climate events.					$ 0.846012	6	2020	$ 0.48307
Total	9.661266			0.06480	21.813404			0.71791

Table 2: Estimated expenditure per individual intervention and total expenditure per intervention package (in USD millions)

The Net Present Value of these two approaches are outlined in Table 3. Note the NPV uses a discount rate of 10% (the Antigua and Barbuda National Bank social discount rate) and the time period modelled is for 50 years (2020 to 2069). Importantly, the interventions' capital expenditure for both options is assumed to be incurred in the next six years, and then again in 2039 and 2055 to account for infrastructure maintenance.

In summary, the NPV for the baseline or business as usual intervention package is USD 13.8 million, and the climate resilient retrofit is USD 36.9 million. The climate resilient option is 2.6 times greater than the baseline. Note that the operating expenses for the climate resilient option is significantly higher than the baseline, in particular Intervention 14 (Climate information services), which aims to educate citizens and shape building standards which would then be climate resilient and avoid major damage costs. This single intervention, as it an annual cost, adds significantly to the NPV.

Interventions	Capital sum (USD$)	Implementation term	Start year	End year	Operating and maintenance cost (USD/a)	NPV
1 General structural repairs	1,434,717	6	2020	2025	10,800	2,068,198
2 General building repairs	2,679,475	6	2020	2025	27,000	3,930,280
3 Waste water treatment	154,751	6	2020	2025	13,500	345,379
4 General electric	5,392,323	6	2020	2025	13,500	7,504,627
5	-	-	0	0	-	-
6	-	-	0	0	-	-
7	-	-	0	0	-	-
						13,848,484
8 Extreme weather resistance	5,774,616	6	2020	2025	54,000	8,428,734
9 Solar PV + Batteries (on-site)	7,950,091	6	2020	2025	21,600	11,081,155
10 Emergency RE stock (off-site)	646,212	6	2020	2025	38,593	1,265,950
11Water supply	3,540,733	6	2020	2025	21,600	5,053,995
12 Storm water drainage	-	6	2020	2025	27,000	267,700
13 Climate change adaptation mainstreamed into the building sector and relevant financial mechanisms.	3,055,740	6	2020	2025	72,044	4,891,200
14 Climate information services strengthened to facilitate early action within the building sector to respond to extreme climate events.	846,012	6	2020	2025	483,070	5,945,965
0	-	-	0	0	-	-
0	-	-	0	0	-	-
0	-	-	0	0	-	-
						36,934,700

Table 3: The Net Present Value of the two approaches using a 10% discount rate

However, to judge the whether the expenditure is justifiable, it is necessary to quantify the impacts of the interventions in the four scenarios.

6 The Impacts of the Scenarios

The impacts of the scenarios were estimated by:

- Firstly, analysing the impacts of single hurricane events (both category 3 and 5 hurricanes) when combined with the government intervention packages – either a business as usual response or a climate resilient response.
- Secondly, summing the costs of repeat hurricane events (category 3 or 5 or both) in either the 'normal' or extreme weather scenarios over the 50-year time period.

Table 3 outlines the impacts on Antigua and Barbuda society of category 3 and 5 hurricane events (these impacts are single events and not for the 50-year scenario) when combined with two alternative intervention responses by government. The project team in Antigua and Barbuda deliberated and then estimated the average loss for category 3 and 5 hurricane events for each of the impact indicators listed below (see the Average line for each of the scenarios in Table 4). Note that the impacts for each hurricane event were considered in terms of several indicators and are outlined below[3]:

- The monetary value of hurricane damage to manufactured capital (such as buildings, and water and energy systems):
    - Moderately destroyed - indicator is a function of (average number of key government buildings damaged, the extent of damage to buildings (i.e. 40% of building damaged), Total Fixed Capital Stock of manufactured capital in Antigua and Barbuda); and
    - Irreparably destroyed – indicator is a function of (average number of key government buildings damaged, the extent of damage to buildings (i.e. 90% of building damaged), Total Fixed Capital Stock of manufactured capital in Antigua and Barbuda).
- The monetary value of citizens' productivity losses due to category 3 and 5 hurricane events in the two response options:
    - Numbers of productive days lost to society – indicator is function of (average number of workdays lost, number of possible workdays (i.e. 240), GDP per capita, population size);
    - Numbers of deaths – indicator is a function of (number of deaths, average age of affected persons, average life expectancy, population size, Gross National Product per capita);
    - Numbers of permanent disabilities - indicator is a function of (number of permanent disabilities, extent of productive potential lost (i.e. 50%), average age of affected persons, average life expectancy, population size, Gross National Product per capita); and
    - Number of serious injuries - indicator is a function of (number of permanent disabilities, extent of productive potential lost (i.e. 10%), average age of affected persons, average life expectancy, population size, Gross National Product per capita).

[3] The following data and references supported the estimation of losses: all values in USD

Social discount rate	10%		Provided by counterparts
GDP/capita	14,130	2017	http://documents.worldbank.org/curated/en/239271500275879803/The-little-green-data-book-2017 : page 22
Total fixed capital stock	13,417,950,000	2017	https://alfred.stlouisfed.org/series?seid=RKNANPAGA666NRUG&utm_source=series_page&utm_medium=related_content&utm_term=related_resources&utm_campaign=alfred
Gross national income per capita	13,270	2017	http://documents.worldbank.org/curated/en/239271500275879803/The-little-green-data-book-2017 ; page 22
Life expectancy (years)	77.5	2017	Provided by counterparts
Population	92,000	2017	http://documents.worldbank.org/curated/en/239271500275879803/The-little-green-data-book-2017 ; page 22

The quantum of the impacts avoided were based on i) direct market values with respect to manufactured capital as a proxy for the loss in infrastructure, ii) loss in income as a proxy for the impact on the economy and welfare of people, and iii) the human capital approach as a proxy for the impact on the productive capability of the population as well as pain and suffering. These proxies represent only a partial analysis of the impact of the costs avoided, but they are used consistently across all the scenarios. The results are representative of the comparative outcomes.

Cost1: Impact of Category 3 if intervention was business as usual

	% of manufactured (fixed) capital moderately destroyed	% of manufactured (fixed) capital irreparably destroyed	Number of productive work days lost	Number of deaths per 1000 of the population	Number of permanent disabilities per 1000 of the population	Number of serious injuries per 1000 of the population
Avg.	35%	15%	15.00	0.02	0.03	0.15
Weight	40%	90%	240	40	50%	10%
Value	1,878,513,000	1,811,423,250	81,250,000	915,630	686,723	686,723
Total	**3,773,475,325**					

Cost2: Impact of Category 5 if intervention was business as usual

	% of manufactured (fixed) capital moderately destroyed	% of manufactured (fixed) capital irreparably destroyed	Number of productive work days lost	Number of deaths per 1000 of the population	Number of permanent disabilities per 1000 of the population	Number of serious injuries per 1000 of the population
Avg.	50%	30%	50	0.50	0.20	1.50
Weight	40%	90%	240	40	50%	10%
Value	2,683,590,000	3,622,846,500	270,833,333	22,890,750	4,578,150	6,867,225
Total	**6,611,605,958**					

Cost3: Impact of Category 3 if intervention was climate resilient

	% of manufactured (fixed) capital moderately destroyed	% of manufactured (fixed) capital irreparably destroyed	Number of productive work days lost	Number of deaths per 1000 of the population	Number of permanent disabilities per 1000 of the population	Number of serious injuries per 1000 of the population
Avg.	15%	5%	10	0.000	0.000	0.010
Weight	40%	90%	240	40	50%	10%
Value	805,077,000	603,807,750	54,166,667	-	-	45,782
Total	**1,463,097,198**					

Cost4: Impact of Category 5 if intervention was climate resilient

	% of manufactured (fixed) capital moderately destroyed	% of manufactured (fixed) capital irreparably destroyed	Number of productive work days lost	Number of deaths per 1000 of the population	Number of permanent disabilities per 1000 of the population	Number of serious injuries per 1000 of the population
Avg.	25%	15%	20	0.005	0.000	0.020
Weight	40%	90%	240	40	50%	10%
Value	1,341,795,000	1,811,423,250	108,333,333	228,908	-	91,563
Total	**3,261,872,054**					

Table 4: The impacts of the two intervention options for individual category 3 and 5 hurricane events

The model then used an algorithm together with a look-up table for 'normal' hurricane trends (1900 to 1950) and extreme hurricane trends (2017, 1970 to 2013) (which included the number and intensify of hurricanes in a 50-year period) to count and sum the different hurricanes and to combine these with the impact costs over 50 years for each scenario. The monetary value of losses per scenario are outlined below:

- *Business as usual with 'normal' weather scenario* – Four category 3 hurricanes occur in 50 years (4 x USD 3.8 billion)
- *Business as usual with extreme weather scenario* – Seven category 3 and four category 5 hurricanes occur in 50 years (7 x USD 3.8 billion) & (4 x USD 6.6 billion)
- *Resilient response with 'normal' weather scenario* – Four category 3 hurricanes occur in 50 years (4 x USD 1.5 billion)
- *Resilient response with extreme weather scenario* – Seven category 3 and four category 5 hurricanes occur in 50 years (7 x USD 1.5 billion) & (4 x USD 3.3 billion)

The NPV for each of above scenarios was then calculated (see Table 5).

	NPV of "'normal'" hurricane impact costs (USD millions)	NPV of extreme hurricane impact costs (USD millions)
Baseline: BaU interventions	$ 551.9	$ 17,253.0
Resilient interventions	$ 214.0	$ 8,091.4

Table 5: The NPV of monetary losses for built capital and human capital in four scenarios

7 The Cost Effectiveness of the Four Scenarios

A comparison of the four scenarios' intervention costs and hurricane impacts is outlined in Table 6. Note the following:

- In *a business as usual with 'normal' weather*, the cost of the interventions is USD 13.8 million, with a USD 551.9 million impact cost. However, in a *business as usual with extreme weather*, while the intervention costs are the same, the impact cost is USD 17.2 billion, orders of magnitude greater.
- On the other hand, in a *climate resilient with 'normal' weather*, the intervention cost is USD 36.9 million, some USD 23 million more than the *business as usual* costs. However, in this scenario, the impact costs are USD 214, some USD 338 less than in *a business as usual with 'normal' weather*. The additional USD 23 million spend buys a cost avoidance of USD 337.9 million. Therefore, even in a 'normal' weather scenario, a climate resilient intervention is a no-regret investment. In terms of a *climate resilient with extreme weather* scenario, the impacts costs are USD 8 billion, some USD 9.1 billion less than *business as usual with extreme weather*. In this case, the additional USD 23 million resilient intervention buys a USD 9.1 billion cost avoidance. This is a highly cost effective spend.

	Net present value (NPV) of the expenditure on interventions (USD millions)	NPV of "'normal'" hurricane impact costs (USD millions)	NPV of extreme hurricane impact costs (USD millions)
Baseline: Business as usual interventions	$ 13.8	$ 551.9	$ 17,253.0
Resilient interventions	$ 36.9	$ 214.0	$ 8,091.4
Differences between Business as usual and Resilient spend and cost avoidance	$ 23.1	$ -337.9	$ -9,161.7

Table 6: Comparison of intervention costs and associated hurricane losses in the four scenarios

The cost effectiveness analysis identifies which options provide the greatest magnitude of avoided losses to society per dollar spent on interventions. See Table 7.
Note the following:

- The *'business as usual with 'normal' weather*, constitutes the baseline or the standard by which the other interventions are evaluated. In the comparative ratio, the baseline becomes '1'. Furthermore, in this scenario, a USD 1 spend on interventions is associated with a societal loss or impact of USD 39.9.
- On the other hand, the *climate resilient with 'normal' weather*, is associated with a USD 5.8 hurricane impact cost to society per dollar spend, or some 15% of the baseline impact loss.
- In the *business as usual with extreme weather* scenario, the loss could be as high as USD 1,246 per dollar spend or 31 times greater than the baseline scenario.
- In terms of a *climate resilient response with extreme weather* scenario, the loss could be USD 219 per dollar spend, or 5.5 times greater than the baseline.
- In both weather scenarios, the resilient interventions both offer more cost effective responses than business as usual responses.

		Baseline: BaU interventions	Resilient interventions
i)	*"'normal'" hurricane exposure*	39.9	5.8
	Extreme hurricane exposure	1,245.8	219.1

		Baseline: BaU interventions	Resilient interventions
ii)	*"'normal'" hurricane exposure*	1.00	0.15
	Extreme hurricane exposure	31.26	5.50

Table 7: The cost effectiveness of response options relative to 1 Dollar spent and the baseline impact costs