Resilience to hurricanes in the building sector in Antigua and Barbuda

Annex 2. Feasibility Study

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List of acronyms

AE	Accredited Entity
AO	Administrative Officer
APUA	Antigua Public Utilities Authority
CBDB	Caribbean Development Bank
CEP	UN Environment: The Caribbean Environment Programme
DCA	Development Control Authority
DoE	Department of Environment
DRR	Disaster risk reduction
EbA	Ecosystem-based Adaptation
EE	Executing Entity
EIMAS	Environmental Information Management and Advisory System
EMS	Environmental Management Systems
EPMA	Environmental Protection and Management Act
EU	European Union
EWS	Early Warning System
FPO	Financial and Procurement Officer
GCCA	Global Climate Change Alliance +
GCF	Green Climate Fund
GDP	Gross domestic product
GEF	Global Environment Facility
GHGs	Greenhouse gases
GoAB	Government of Antigua and Barbuda
IoM	Institute of Medicine
IRENA	International Renewable Energy Agency
IWCAM	Integrating Watershed and Coastal Area Management in Caribbean SIDS
IWEco	Integrating Water, Land, Resources and Ecosystems Management in Caribbean Small Islands Developing States Project
IWRM	Integrated Water Resource Management
IT	Information Technology
LDCF	Least Developed Countries Fund
M&E	Monitoring and Evaluation
MDGs	Millennium Development Goals
MoA	Ministry of Agriculture
MoE	Ministry of Energy
MoF	Ministry of Finance
MSJMC	Mount St John's Medical Centre
MTDS	Antigua and Barbuda's Medium-Term Development Strategy
NAP	National Action Plan for Antigua and Barbuda
NDC	Nationally Determined Contribution
NGOs	Non-governmental organisations
NODS	National Office of Disaster Services
NSWMA	National Solid Waste Management Authority
PC	Project Coordinator
PM	Project Manager
PMC	Project Management Committee
PMU	Project Management Unit
PO	Programme Officer
PWD	Public Works Department
RE	Renewable energy
RPFAB	Royal Police Force of Antigua and Barbuda
SCCF	Special Climate Change Fund
SDGs	Sustainable Development Goals
SIRF	Sustainable Island Resource Framework

SIRMM	Sustainable Island Resource Management Mechanism
SIRMZP	Sustainable Island Resource Management Zoning Plan for Antigua and Barbuda
SPP	Sustainable Public Procurement
SPPARE	Sustainable Pathways – Protected Areas and Renewable Energy Project
SSTs	Sea surface temperatures
TAC	Technical Advisory Committee (TAC) for The Environment Division, Ministry of Public Works and Environment
ToRs	Terms of Reference
UN	United Nations
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNDP	United Nations Development Programme
US	United States
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organisation

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1. Executive summary

This Feasibility Study supports the proposed GCF project entitled "*Resilience to hurricanes, floods and droughts in the building sector in Antigua and Barbuda"* which has the objective of establishing a standard of climate resilience across the country's building sector that can be scaled up and replicated nationally and across the Caribbean region. This approach is underpinned by a strengthened institutional framework that will create an enabling environment for the sustainable uptake and scaling up of climate change adaptation measures within Antigua and Barbuda's building sector. The Feasibility Study describes the baseline situation of the country context and provides technical analyses and support of the proposed project interventions presented in the GCF Funding Proposal.

1.1. Geography, demographics and socio-economic context

1.1.1. Geography

Antigua and Barbuda forms part of the Leeward Islands in the eastern Caribbean, located between the Caribbean Sea and the Atlantic Ocean. Consisting of two main inhabited islands, the country has a total land area of ~456 km^2 (Figure 1). Antigua is the larger of the two islands at 280 km^2, while Barbuda — which is 40 km north of Antigua — has a land area of 176 km^2. While the topography of the islands varies, both are low-lying with 70% of the land in Antigua less than 30 m above mean sea-level and most of Barbuda only 3 m above mean sea-level[1].

1.1.2. Population

In 2018, the total number of inhabitants of the country was ~96,000[2] and the population density was ~232 people/km^2. More than 60% of this population lives within the coastal zone of the two islands[3]. The majority of the country's inhabitants live on Antigua. The capital city of St John's alone is home to ~25,000 people[4]. In contrast, the number of permanent residents on Barbuda is only ~1,600[5]. This number has decreased from 1,800 in 2017 after the extensive damage caused by Hurricane Irma resulted in the evacuation of all inhabitants from Barbuda to Antigua[6].

1.1.3. Economy

The country's economy is currently based on the service sector[7], with tourism contributing: i) nearly 60% of the Gross Domestic Product (GDP); ii) 40% of investment; and iii) employment for 70% of the population[8]. In addition to tourism, other prominent economic sectors are agriculture and industry, which contributed 2% and 21% respectively to the national GDP in 2017[9]. Antigua and Barbuda is considered to be a high-income country because its gross national income (GNI) per capita is larger than US$12,376[10] (Table 1). However, despite the country's high per capita income, approximately 18% of the total population falls below the

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[1] James P. 2001. Antigua and Barbuda Country Paper on National Climate Change Issues. Component 4: Formulation of a Policy Framework for Integrated (Adaptation) Planning and Management, Caribbean Planning for Adaptation to Climate Change.
[2] United Nations. World Population Prospects. Available at: https://population.un.org/wpp/DataQuery/.
[3] United Nations Statistics Division. 2017. UN Data: Antigua and Barbuda. Available at: http://data.un.org/CountryProfile.aspx?crName=antigua%20and%20barbuda.
[4] City Population. 2016. Antigua and Barbuda: Parishes. Available at: https://www.citypopulation.de/Antigua.html.
[5] 2019 GoAB estimates.
[6] The Guardian. 2017. The night Barbuda died: how Hurricane Irma created a Caribbean ghost town. Available at: https://www.theguardian.com/global-development/2017/nov/20/the-night-barbuda-died-how-hurricane-irma-created-a-caribbean-ghost-town.
[7] Global Water Partnership Caribbean. 2013. The Post 2015 Water Thematic Consultation: Antigua and Barbuda.
[8] Antigua and Barbuda economy — overview. Available at: https://www.indexmundi.com/antigua_and_barbuda/economy_overview.html.
[9] Antigua and Barbuda economy — overview. Available at: https://www.indexmundi.com/antigua_and_barbuda/economy_overview.html.
[10] The World Bank. 2019. Data: World Bank Country and Lending Groups. Available at: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

poverty line[11] and 14% is unemployed[12]. When considering the proportion of the population that is at risk of falling into poverty if there is a shock to the economy[13], the percentage rises to 28%[14].

1.2. Climate profile

Antigua and Barbuda has a tropical savanna climate[15], with high and uniform average daily temperatures between 24°C–30°C (Figure 5)[16]. The climate regime is characterised by dry winters and wet summers, with the average annual rainfall on Antigua varying from 580–1,660 mm and on Barbuda from 620–2,100 mm[17] (Figure 5). Of this rainfall, 29% occurs during the dry season (between December and April) while the remaining 71% occurs during the wet season (between May and November)[18]. Despite the country's tropical climate, high seasonal variability in precipitation and a limited natural surface water storage capacity have resulted in Antigua and Barbuda becoming one of the most water scarce countries per person in the world[19]. The country's climate is influenced by several factors, namely the: i) migration of the north Atlantic sub-tropical high-pressure system; ii) eastward spreading of the tropical Atlantic warm pool; iii) easterly trade winds; and iv) tropical depressions, storms and hurricanes[20].

1.3. Climate rationale

As a small island developing state (SIDS), Antigua and Barbuda is among the most vulnerable countries to extreme climate events, particularly hurricanes[21,22] and tropical storms[23]. These storms form off the west coast of Africa and usually move through the Leeward island chain on a north-westerly course[24]. Historically, Antigua and Barbuda had only been hit by relatively low-intensity hurricanes, with those reaching hurricane status seldom strengthening above Category 3[25]. The return rate of Category 4 hurricanes in the first half of the 20th century was only 1 in 50 years, and until 2017, the country had never experienced a Category 5 hurricane. Consequently, building codes in Antigua and Barbuda did not prescribe the construction methods/technologies required to withstand the impacts of a hurricane stronger than a Category 3. While designing buildings to withstand up to a Category 3 hurricane was sufficient in the past, the increasing intensity of hurricanes hitting the country is having severe impacts on the country's built environment and population. Most of the damage to vegetation and buildings caused by hurricanes can be attributed to high winds, storm surges, flooding and landslides[26]. Moreover, access to emergency, public and electricity services is severely disrupted, often for several weeks immediately following an extreme climate event. This disruption of services has considerable negative impacts on health, livelihoods and well-being, as well as the economic security of the country. To determine the most appropriate sites to receive project interventions and ensure that maximum benefits are realised as a result of these interventions, a climate

[11] The poverty line is a monetary measure of the minimum amount of money a household would need to spend to meet its minimum food and non-food requirements. In Antigua and Barbuda, the poverty line is US$2,366 per annum, or an average of US$6.57 per day.
[12] The World Bank. 2017. Data: Antigua and Barbuda. Available at: https://data.worldbank.org/country/antigua-and-barbuda.
[13] For example, a shock to the economy brought about by an extreme weather event.
[14] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[15] Available at: https://en.climate-data.org/north-america/antigua-and-barbuda-165/.
[16] Antigua and Barbuda Meteorological Service. 2019. Government of Antigua and Barbuda. Available at: http://www.antiguamet.com/Climate/
[17] Antigua and Barbuda Meteorological Service. 2019. Government of Antigua and Barbuda. Available at: http://www.antiguamet.com/Climate/.
[18] Antigua and Barbuda Meteorological Service. 2019. Government of Antigua and Barbuda. Available at: http://www.antiguamet.com/Climate/
[19] Haites E. 2002. Assessment of the economic impact of climate change on CARICOM countries. Margaree Consultants, Toronto.
[20] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[21] A hurricane is defined as a hurricane with maximum sustained winds of 119 kph (64 knots) or above.
[22] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[23] A tropical storm is a hurricane with maximum sustained winds of 63–118 kph, or 34–63 knots.
[24] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[25] The following explanation clarifies the use of the terms 'hurricanes', 'tropical storms' and 'high-intensity storms' in this Feasibility Study: The Saffir-Simpson Hurricane Wind Scale defines a hurricane as having sustained wind speeds of more than 74 mph (119 km/h), while a tropical storm has sustained wind speeds of less than 38 mph (61 km/h). Hurricanes are therefore likely to result in more damage to infrastructure and loss of life than tropical storms. Additionally, Category 4 and 5 hurricanes are considered to be high-intensity storms because of the associated sustained wind speeds of these hurricanes. According to the Saffir-Simpson Hurricane Wind Scale, Category 4 hurricanes have sustained wind speeds of 130–156 mph (209–251 km/h) while Category 5 hurricanes have sustained wind speeds upwards of 157 mph (252 km/h).
[26] Nunez C. 2019. Hurricanes, cyclones and typhoons, explained. Available at: https://www.nationalgeographic.com/environment/natural-disasters/hurricanes/.

vulnerability analysis was conducted. This analysis included a hydraulic flood analysis as well as a walk-time analysis to determine the total coverage of project interventions and support justification for the project to primarily address the impacts of Category 4 and 5 hurricanes. The selection of these buildings was done in a manner which ensures that critical services provide maximum coverage to high-population areas, the poorest communities and those individuals living in areas outside of the main drainage channels. The distribution of project interventions therefore covers the majority of built-up areas in Antigua and Barbuda, with increased coverage in the more densely populated and exposed communities. Furthermore, the majority of the selected project intervention sites are located in areas of higher elevation, outside of the potential inundation areas from extreme downpours associated with hurricanes, as noted during Hurricane Irma. Nine sites are located within 10 m of the flood inundation zones, five are within 30 m, five within 50 m, 12 within 100 m and 16 sites are located further than 100 m away from these inundation zones. 60% of the project intervention sites are therefore located 50 m or more away from potential flood-inundation zones. For this reason, climate change adaptation measures to be implemented on target critical infrastructure will be designed and installed to primarily reduce the impacts of high wind speeds associated with Category 4 and 5 hurricanes, which is the main climate threat to these critical buildings in Antigua and Barbuda. Further details on the findings from vulnerability analysis conducted are presented in Section B.3 of the Funding Proposal, as well as in Section 10 of this Feasibility Study.

Given that Category 4 and 5 hurricanes are expected to occur more frequently under future climate conditions, the combined impacts of intense rainfall and strong winds will become increasingly severe in the absence of urgent adaptation interventions. This will have severe impacts on the lives and livelihoods of local communities as well as the economy as a whole[27]. Following a Category 5 hurricane, power and water supply can be disrupted for up to 24 months, while damage to communication and transport infrastructure disrupts associated services for up to 6 months. Furthermore, rough seas and inflated insurance premiums after a storm disrupt the import of vital food, medical and building supplies for several weeks after an extreme climate event. The capacity of the country to respond to such events is constrained by the vulnerability of critical public services, including healthcare, police, fire and rescue services as well as government coordination and response agencies. Disruption to these services caused by damages to critical infrastructure reduces the efficiency and effectiveness of emergency response and delays recovery. This vulnerability is further exacerbated by limited capacity within Antigua and Barbuda's Meteorological Services (ABMS) for early warning and preparatory action for an extreme climate event. The Government of Antigua and Barbuda is already investing in climate change adaptation, however, given the existing financial problems and high public debt, further external support is required to address the adaptation needs of the country's building sector.

1.4. Policies and governance

The Government of Antigua and Barbuda (GoAB) has established several policy frameworks, strategies and initiatives to increase the resilience of the country's population to the impacts of extreme climate events. These include *inter alia* the: i) Environmental Protection and Management Act (2019) — for undertaking and coordinating environmental management-related activities as well as incorporating international environmental treaty obligations into national law and best practice[28]; ii) Physical Planning Act (2003) — for the orderly and progressive development of land as well as the improvement of amenities; iii) Public Health Act[29] — which regulates all matters concerning public health in the country; and iv) Disaster Management

[27] A detailed cost-benefit analysis is presented in Annex 3 and summarised in Section D.6 of the Funding Proposal. This analysis describes what the projected costs of extreme climate events will be in Antigua and Barbuda with and without project interventions under baseline and projected climate change scenarios.
[28] AnB Environmental law and policy. Available at: http://www.eagantigua.org/page89.html.
[29] Government of Antigua and Barbuda. Public Health Act. No. 34 of 1965, amended in 1992.

Act (2002) — which provides a framework for the effective coordination of efforts to manage, mitigate, respond to, and recover from, natural as well as man-made disasters in the country[30].

The proposed project aligns with *inter alia*: i) Antigua and Barbuda's Nationally Determined Contributions (NDC; 2015) — which outlines the country's adaptation and mitigation targets[31]; and ii) Third National Communication to the UNFCCC. In addition, the GoAB has developed and implemented the institutional structures and legal frameworks necessary to access international climate finance[32]. Project interventions relating to the built environment — particularly those with the objective of climate-proofing priority public buildings — will closely follow the standards and guidelines set out in the national building code, which is currently under peer review to tailor the code to the technical requirements of Antigua and Barbuda[33]. This code provides administrative and enforcement requirements regarding building practices and specifications for improved construction practices which consider the high wind speeds and levels of rainfall associated with Category 4 and 5 hurricanes[34]. Further details on the current status of the Antigua and Barbuda's building code are presented in Section 5.1.7 of this Feasibility Study.

Best practices from the Organisation of Eastern Caribbean States (OECS) Building Code and the Caribbean Disaster Mitigation project were used to inform the design of climate proofing interventions to be implemented under the project. Lessons learned from numerous baseline investments into climate change adaptation in Antigua and Barbuda were also used to guide the design of all project interventions. Such lessons include appropriate mechanisms for ensuring that project activities are implemented in a participatory, gender-inclusive and sustainable way[35]. Specific details on all best practices and lessons learned relevant to the project are presented in Section 7 of this Feasibility Study.

1.5. Barriers to addressing climate change impacts on the building sector

Several technical, institutional and financial barriers to the preferred adaptation solution have been identified for Antigua and Barbuda. These are summarised below and explained in detail in Section 8 of this Feasibility Study.

Barrier 1: The government of Antigua and Barbuda has limited financial capacity to invest in climate proofing critical public service and community buildings to withstand Category 4 and 5 hurricanes. This includes not being able to install decentralised energy and water systems to maintain supply when centralised distribution lines are disrupted by a storm.

Barrier 2: The remote location of Antigua and Barbuda makes it difficult to access replacement solar PV panels to restore power after a storm to critical service buildings that are equipped with decentralised renewable energy systems. There is currently limited stock of renewable energy equipment available in the country and no secure location to store additional back-up equipment.

Barrier 3: During a major storm, critical information servers/computers at public institutions – including hospitals, police stations and other government institutions – are likely to be damaged resulting in the loss of vital information for public health and security. However, there is currently limited technical capacity to preserve this information, either through the safeguarding of physical infrastructure or the provision of reliable backup systems.

[30] Government of Antigua and Barbuda. Natural Disaster Management Act. No. 13 of 2002.
[31] Government of Antigua and Barbuda. Nationally Determined Contribution. 2015
[32] The Commonwealth. 2019. Antigua and Barbuda: Destined for climate finance success. Available at: http://thecommonwealth.org/media/news/antigua-and-barbuda-destined-climate-finance-success.
[33] OECS. 2016.OECS Building Code. 7th Edition.
[34] OECS. 2016.OECS Building Code. 7th Edition.
[35] Further details on the relevant baseline investments are presented in Section B.1 of the Funding Proposal.

Barrier 4: Climate change adaptation for the building sector has not been sufficiently mainstreamed into Antigua and Barbuda's regulatory frameworks. In particular, the Physical Planning Act (2003) does not make provision for the effective implementation of the newly revised national building code — which includes appropriate actions for reducing the risk of buildings to the impacts of Category 4 and 5 hurricanes. As a result, the guidelines established in the building code are not formalised into legislation, rendering them unenforceable. Given the costs associated with building to code, the unenforceability of the building code leads to inadequate implementation. There is also limited technical and institutional capacity within the Public Works Department (PWD) and Development Control Authority (DCA) to adequately apply the regulations stipulated in the building code, thereby exacerbating the risk of buildings to the impacts of Category 4 and 5 hurricanes.

Barrier 5: While there is a firm understanding of the need to climate proof buildings in Antigua and Barbuda, local communities and private sector property owners, as well as public sector decision makers and design engineers/architects, have limited knowledge of the adaptation options available for the building sector, in particular those aligned with the revised building code.

Barrier 6: There are currently limited financial mechanisms available to support ongoing investment into climate-resilient development in both the public and private sectors. This includes limited provision for adaptation finance through existing development funds, limited replenishment of such funds as well as limited consideration of climate change adaptation by the banking and insurance sectors.

Barrier 7: The long-term sustainability and upscaling potential of climate change adaptation interventions is constrained by limited technical capacity within the National Office of Disaster Services (NODS), Development Control Authority (DCA) and Public Works Department (PWD) for long-term monitoring, maintenance and planning for adaptation measures in the building sector. These capacity limitations extend to the local workforce who are ultimately responsible for the installation and maintenance of equipment.

Barrier 8: To effectively prepare for a storm – including the temporary removal of solar panels – requires adequate lead time on early warnings. However, there is currently limited technical capacity in the Antigua and Barbuda Meteorological Service (ABMS) and NODS to adequately disseminate early warnings to support early action, particularly with regards to preparing shelters and securing renewable energy equipment ahead of a storm.

1.6. Proposed project interventions to overcome existing barriers

The proposed project will shift the country's building sector away from reactive development — involving costly recovery actions after an extreme climate event — towards a proactive approach in which buildings are adapted to withstand the increased frequency of high-intensity hurricanes. This proactive approach will include direct investments into critical public service and community buildings to climate-proof them against Category 4 and 5 hurricanes, as well as mainstreaming climate resilience into the building sector and relevant financial mechanisms to facilitate the upscaling of such interventions across all buildings in the country. The effectiveness of climate-proofing interventions will be enhanced by formalising communication protocols between the ABMS and relevant government agencies to facilitate early action within the building sector to respond to extreme climate events. This will include strengthening the capacity of ABMS to collect, process and manage climate data, thereby improving the accuracy and reliability of early warnings. The combined transformative effect of project interventions will result in a standard of climate resilience for Antigua and Barbuda's building sector being established that can be readily scaled up and replicated nationally and regionally.

2. Context and baseline

2.1. *Physical and geographical situation*

Antigua and Barbuda forms part of the Leeward Islands in the eastern Caribbean, located between the Caribbean Sea and the Atlantic Ocean. Consisting of two main inhabited islands, the country has a total land area of ~450 km^2 (Figure 1). Antigua is the larger of the two islands at 280 km^2, while Barbuda — which is 40 km north of Antigua — has a land area of 176 km^2. While the topography of the islands varies, both are low-lying with 70% of the land in Antigua less than 30 m above mean sea-level and most of Barbuda only 3 m above mean sea-level[36].

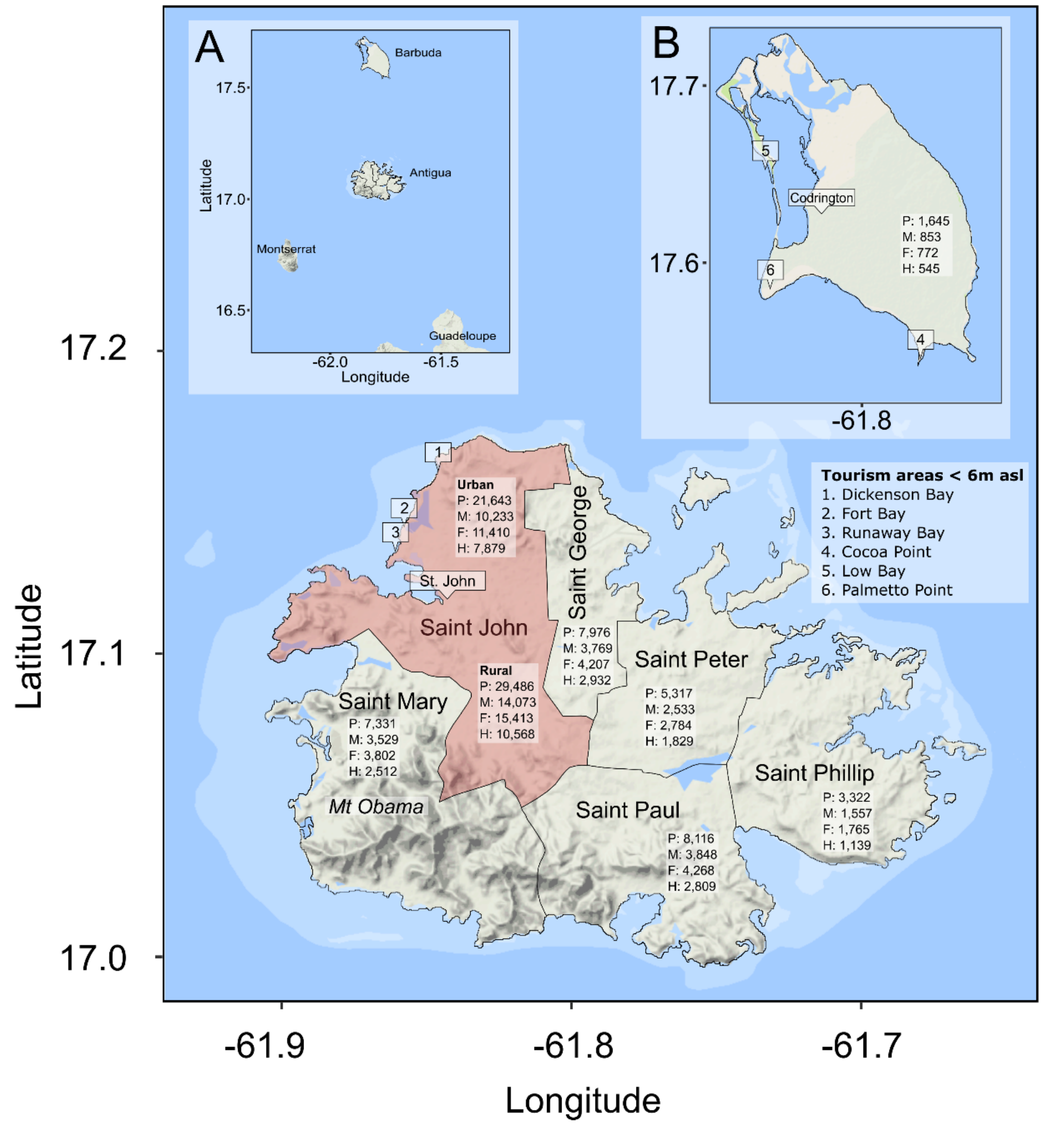

Figure 1. A map of the island of Antigua, indicating parishes, as well as the location of the capital city, St John. Inset A: Antigua and Barbuda in relation to the islands of Guadeloupe and Montserrat. Inset B: Barbuda with its capital city, Codrington. Tourism areas less than 6 m above mean sea-level are vulnerable to sea-level rise; these points are indicated as 1–6 on the map and Inset B. Population numbers according to the 2011 census are indicated for each

[36] James P. 2001. Antigua and Barbuda Country Paper on National Climate Change Issues. Component 4: Formulation of a Policy Framework for Integrated (Adaptation) Planning and Management, Caribbean Planning for Adaptation to Climate Change.

parish as the: i) total parish population (P); ii) male population (M); iii) female population (F); and iv) the number of households (H)[37].

Antigua comprises three distinct geological zones, namely: i) a mountainous region of igneous and sedimentary volcanic soils in the south-west; ii) central plains of hard clay soils across the south-east; and iii) productive limestone hills in the north[38]. The island's highest point is Mount Obama at 402 m, while Barbuda is mainly a level coral island consisting predominantly of limestone flats. Several smaller, uninhabited islands form part of Antigua and Barbuda, namely the Great Bird, Green, Guinea, Long, Maiden, Redonda and York islands. Both Antigua and Barbuda hold limited amounts of surface water, as neither island has running rivers, and both have only a few springs[39]. Watersheds on the islands, which tend to be small and close to the coast, feed into shallow aquifers that are vulnerable to saltwater intrusion[40].

The country's coastlines are protected from erosion by extensive areas of seagrass beds, mangroves and ~25 km^2 of coral reefs[41,42]. Seagrass beds are found in shallow waters surrounding both islands and, along with stabilising loose sand, provide shelter and food resources for numerous commercially relevant species[43]. Mangrove wetlands cover 3% of land area in Antigua and 22% in Barbuda. As well as functioning as a sediment trap and preventing erosion, mangroves provide important nurseries, breeding and feeding grounds for both marine and terrestrial species. Forming part of the Eastern Caribbean Seascape, coral reefs are most prominent on the windward, eastern side of the country[44]. Coral reefs contribute to both the formation and protection of beaches on the two islands, however, a large percentage of the islands' reefs are no longer ecologically viable. This loss of coral reef functionality, along with declines in the extend of mangrove wetlands and seagrass beds, is the result of *inter alia* frequent hurricanes, untreated sewage, sediment loading from erosion and damage from boats or dredging[45].

2.2. *Socio-economic context*

Antigua and Barbuda gained independence from British rule in 1981 and now form part of the British Commonwealth of Nations[46]. In 2018, the population density was ~232 people/km^2 and the total number of inhabitants was ~96,300[47]. More than 60% of this population lives within the coastal zone of the two islands[48]. Antigua holds most of the country's inhabitants, where the capital city of St John's alone is home to ~25,000[49] people. In contrast, the number of permanent residents on Barbuda is only ~1,600[50]. This number has decreased from 1,800 in 2017 after the extensive damage caused by Hurricane Irma resulted in the evacuation of all inhabitants from Barbuda to Antigua[51].

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[37] Adapted from: Statistics Division. 2014. Antigua and Barbuda 2011, population and housing census. Book of statistical tables I. Ministry of Finance, the Economy, Public Administration, Public Broadcasting and Information.
[38] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[39] Momsen JD, Tolson R, and Niddrie DL. 2019. Antigua and Barbuda. Encyclopaedia Britannica. Available at: https://www.britannica.com/place/Antigua-and-Barbuda#accordion-article-history.
[40] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[41] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[42] Antigua and Barbuda: Coral Reef Report Card. 2016. The Nature Conservancy, the Department of Environment and the Federal Ministry for the Environment, Nature Conservation, Buildings and Nuclear Safety.
[43] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[44] Antigua and Barbuda: Coral Reef Report Card. 2016. The Nature Conservancy, the Department of Environment and the Federal Ministry for the Environment, Nature Conservation, Buildings and Nuclear Safety.
[45] Antigua and Barbuda Third National Communication 2015.
[46] Nationally Determined Contribution (NDC). 2015. Government of Antigua and Barbuda.
[47] United Nations. World Population Prospects. Available at: https://population.un.org/wpp/DataQuery/.
[48] United Nations Statistics Division. 2017. UN Data: Antigua and Barbuda. Available at: http://data.un.org/CountryProfile.aspx?crName=antigua%20and%20barbuda.
[49] City Population. 2016. Antigua and Barbuda: Parishes. Available at: https://www.citypopulation.de/Antigua.html.
[50] Government of Antigua and Barbuda. 2011. Population and Housing census.
[51] The Guardian. 2017. The night Barbuda died: how Hurricane Irma created a Caribbean ghost town. Available at: https://www.theguardian.com/global-development/2017/nov/20/the-night-barbuda-died-how-hurricane-irma-created-a-caribbean-ghost-town.

2.2.1. Vulnerability of the population

Baseline information on population, socio-economic and vulnerability indicators is listed in Table 1. The Human Development Index (HDI) for the country has increased over the last decade from 0.766 in 2005 to 0.780 in 2017, indicating an improvement in overall human development[52,53]. Antigua and Barbuda is currently ranked 70 out of 189 countries, placing it within the 'high' human development category and giving the country the highest HDI rank within the Organisation of Eastern Caribbean States (OECS)[54].

Table 1. Baseline population, socio-economic and vulnerability indicators for Antigua and Barbuda[55].

Indicator		Value	Year
Population	Total population	~96,300 people	2018[56]
	Population growth (per 1,000 population)	~1%	2018[57]
	Age dependency ratio — elderly	~10%	2018[58]
	Age dependency ratio — youth and children	~34%	2018[59]
	Percentage of population with access to electricity	~98%	2016[60]
	Total net enrolment in primary education (men and women)	~88%	2017[61]
	Mean years of schooling (of adults)	~9 years	2017[62]
Five-year indicators	Life expectancy at birth	~76 years	2017[63]
	Average annual rate of population change	~1%	2018[64]
	Crude death rate	~6 deaths per 1,000 population	2017[65]
	Infant mortality rate	0.54%	2017[66]
	Under-five mortality	~12 deaths per year	2017[67]
	Deaths by major area, region and country for 1950–2010	~3,000 deaths	2015[68]
Economy	Gross Domestic Product (GDP) per capita; PPP	~US$ 21,000	2014[69]
	Gross National Income (GNI) per capita; PPP	~US$ 25,160	2018[70]
	Inflation; consumer prices	~2%	2017[71]
Capacity	Roads; total network	~1,160 km	2002[72]
Vulnerability	Proportion of the population using improved drinking water sources	~98%	2015[73]

[52] The Human Development Index considers three dimensions of human development, namely a long and healthy life, access to knowledge and a decent standard of living. Higher HDI values indicate higher overall human development.
[53] UNDP. 2018. Human Development Indices and Indicators: 2018 Statistical Update — Antigua and Barbuda. Available at: http://hdr.undp.org/sites/all/themes/hdr_theme/country-notes/ATG.pdf.
[54] UNDP. 2018. Human Development Indices and Indicators: 2018 Statistical Update — Antigua and Barbuda. Available at: http://hdr.undp.org/sites/all/themes/hdr_theme/country-notes/ATG.pdf.
[55] Humanitarian Data Exchange (HDX). 2017. Antigua and Barbuda Baseline Data. HDX V1.8.7. Available at: https://data.humdata.org/dataset/atg_baseline_data
[56] The World Bank. World Development Indicators. Available at: http://datatopics.worldbank.org/world-development-indicators/.
[57] The World Bank. World Development Indicators. Available at: http://datatopics.worldbank.org/world-development-indicators/.
[58] The World Bank. World Development Indicators. Available at: http://datatopics.worldbank.org/world-development-indicators/.
[59] The World Bank. World Development Indicators. Available at: http://datatopics.worldbank.org/world-development-indicators/.
[60] Available at: https://ourworldindata.org/country/antigua-and-barbuda.
[61] The World Bank. World Development Indicators. Available at: http://datatopics.worldbank.org/world-development-indicators/.
[62] Available at: https://ourworldindata.org/country/antigua-and-barbuda.
[63] Available at: https://ourworldindata.org/country/antigua-and-barbuda.
[64] The World Bank. World Development Indicators. Available at: http://datatopics.worldbank.org/world-development-indicators/.
[65] The World Bank. World Development Indicators. Available at: http://datatopics.worldbank.org/world-development-indicators/.
[66] Available at: https://ourworldindata.org/country/antigua-and-barbuda.
[67] Available at: https://ourworldindata.org/country/antigua-and-barbuda.
[68] United Nations. World Population Prospects. Available at: https://population.un.org/wpp/DataQuery/.
[69] Available at: https://ourworldindata.org/country/antigua-and-barbuda.
[70] The World Bank. World Development Indicators. Available at: http://datatopics.worldbank.org/world-development-indicators/.
[71] Available at: https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG?locations=AG.
[72] Humanitarian Data Exchange (HDX). 2017. Antigua and Barbuda Baseline Data. HDX V1.8.7. Available at: https://data.humdata.org/dataset/atg_baseline_data.
[73] Available at: https://ourworldindata.org/country/antigua-and-barbuda.

Indicator		Value	Year
	Global Needs Assessment (GNA) Crisis Index	0	2012[74]
	GNA Vulnerability Index	1	2012[75]
	Proportion of the population using improved sanitation facilities	~91%	2011[76]
	Per capita food supply	~2,417 kcal capita^{-1} day^{-1}	2013[77]

Antigua and Barbuda, along with seven other Caribbean Small Island Developing States (SIDS)[78], is considered to be a high-income country because its GNI per capita is larger than US$12,376[79] (Table 1). However, despite the country's high per capita income, approximately 18% of the total population falls below the poverty line[80] and 14% is unemployed[81]. When considering the proportion of the population that is at risk of falling into poverty if there is a shock to the economy[82], the percentage rises to 28%[83]. St John's is considered the poorest of the country's districts, with 22% of the city's urban population falling below the poverty line[84].

2.2.2. Major economic sectors in Antigua and Barbuda

Historically, Antigua and Barbuda relied on an agricultural economy based on the production of sugar. However, the current economy is based on the service sector[85], with tourism contributing: i) nearly 60% of the Gross Domestic Product (GDP); ii) 40% of investment; and iii) employment for 70% of the population[86]. Nearly one million tourists visit the country each year[87,88] and, as a result, the economy is largely reliant on the influx of foreign exchange. Major tourist attractions include the islands' numerous beaches and areas of high biodiversity. The country's offshore islands are particularly biodiverse, with the island of Redonda considered a Key Biodiversity Area[89]. Besides tourism, other prominent economic sectors are agriculture and industry, which contributed 2% and 21% respectively to the national GDP in 2017[90]. The greatest contributor to the agricultural sector is from fisheries exports, particularly on Barbuda[91]. Other agricultural products include sugar and its by-products, cotton, livestock as well as various fruits and vegetables[92]. Figure 2 shows land used on Antigua for agriculture, as well as other economic sectors. As a whole, the agricultural sector is hampered by limited surface water supply related to droughts, damage by hurricanes and labour shortages resulting from higher wage opportunities presented by tourism and construction[93,94].

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[74] Humanitarian Data Exchange (HDX). 2017. Antigua and Barbuda Baseline Data. HDX V1.8.7. Available at: https://data.humdata.org/dataset/atg_baseline_data
[75] Humanitarian Data Exchange (HDX). 2017. Antigua and Barbuda Baseline Data. HDX V1.8.7. Available at: https://data.humdata.org/dataset/atg_baseline_data
[76] Available at: https://ourworldindata.org/country/antigua-and-barbuda.
[77] Available at: https://ourworldindata.org/country/antigua-and-barbuda
[78] Including Aruba, the Bahamas, Barbados, British Virgin Islands, Puerto Rico, Saint Kitts and Nevis and Trinidad and Tobago.
[79] The World Bank. 2019. Data: World Bank Country and Lending Groups. Available at: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.
[80] The poverty line is a monetary measure of the minimum amount of money a household would need to spend to meet its minimum food and non-food requirements. In Antigua and Barbuda, the poverty line is US$2,366 per annum, or an average of US$6.57 per day.
[81] The World Bank. 2017. Data: Antigua and Barbuda. Available at: https://data.worldbank.org/country/antigua-and-barbuda.
[82] For example, a shock to the economy brought about by an extreme weather event.
[83] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[84] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[85] Global Water Partnership Caribbean. 2013. The Post 2015 Water Thematic Consultation: Antigua and Barbuda.
[86] Antigua and Barbuda economy — overview. Available at: https://www.indexmundi.com/antigua_and_barbuda/economy_overview.html.
[87] i.e. to both islands
[88] Caribbean Development Bank. 2018. Antigua and Barbuda: Country Economic Review. Available at: https://www.caribank.org/publications-and-resources/resource-library/economic-reviews/country-economic-review-2018-antigua-and-barbuda.
[89] Birdlife International. 2019. The World Database of Key Biodiversity Areas. Available at: http://www.keybiodiversityareas.org/site/factsheet/redonda-iba-antigua-and-barbuda.
[90] Antigua and Barbuda economy — overview. Available at: https://www.indexmundi.com/antigua_and_barbuda/economy_overview.html.
[91] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[92] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[93] Antigua and Barbuda economy — overview. Available at: https://www.indexmundi.com/antigua_and_barbuda/economy_overview.html.
[94] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.

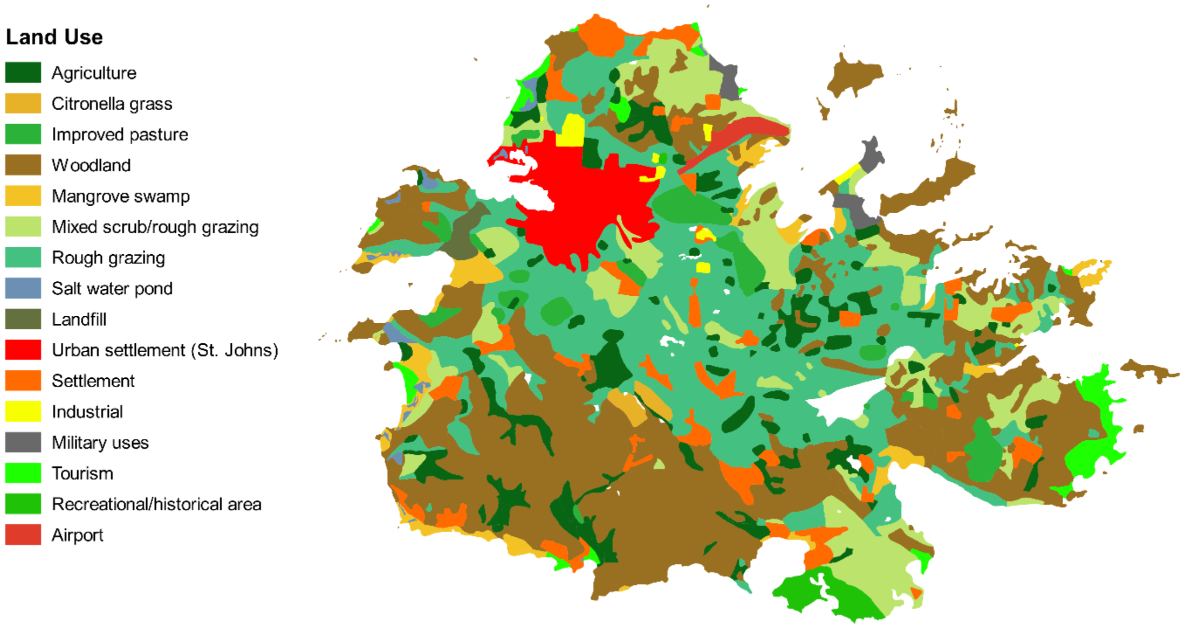


Figure 2. Map indicating land-use on Antigua[95].

Because of its dependence on tourism, Antigua and Barbuda is sensitive to changes in the global economy[96]. For example, in 2009, the country was severely affected by the global economic crisis[97], whereby the country experienced a steep decline in tourism from 2009–2011. As a result, there was a considerable decrease in GDP from ~US$1.36 billion in 2008 to ~US$1.14 billion in 2011[98], reaching an all-time low GDP growth rate of -12.04% in 2009[99]. More recently, competition from other destinations and uncertainty around the United Kingdom's withdrawal from the European Union (BREXIT) contributed to a drop in real GDP growth from 5.3% in 2016 to 2.7% in 2017 because of a decline in tourists from the United Kingdom[100]. Along with global economic volatility, the country's economy is vulnerable to the effects of extreme weather events. From 1982–2001, it was estimated that Antigua and Barbuda incurred a total of US$87.2 million in damages from hurricanes and tropical storms[101]. Between 2008 and 2017, the combined cost incurred to Antigua and Barbuda from named hurricanes was US$232 million. On average, hurricanes account for 8.4% of the annual loss in GDP for Antigua and Barbuda[102]. In terms of financial losses, the most destructive hurricane in recent history was Hurricane Georges, which resulted in almost US$11 billion in damages across the Caribbean in 1998, US$74 million of which was in Antigua and Barbuda[103]. The combined damages caused by hurricanes Irma and Maria in 2017 — which equated to US$136 million — lowered Antigua and Barbuda's GDP growth rate by 1.1% because of reduced tourism infrastructure and

[95] Sustainable Island Resource Management Zoning Plan (SIRMZP) for Antigua and Barbuda (including Redonda). 2011. GENIVAR Trinidad and Tobago, in association with Ivor Jackson and Associates and Kingdome Consultants Inc.
[96] Caribbean Development Bank. 2018. Antigua and Barbuda: Country Economic Review. Available at: https://www.caribank.org/publications-and-resources/resource-library/economic-reviews/country-economic-review-2018-antigua-and-barbuda.
[97] Central Intelligence Agency (CIA). 2017. The World Factbook – Central American and Caribbean: Antigua and Barbuda. Available at: https://www.cia.gov/library/publications/the-world-factbook/geos/ac.html.
[98] Trading Economics — Antigua and Barbuda GDP. Available at: https://tradingeconomics.com/antigua-and-barbuda/gdp
[99] The World Bank. 2017. Data: Antigua and Barbuda GDP growth (annual %). Available at: https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?locations=AG&view=chart
[100] Caribbean Development Bank. 2017. Antigua and Barbuda: Country Economic Review.
[101] Haites E. 2002. Assessment of the economic impact of climate change on CARICOM countries. Margaree Consultants, Toronto.
[102] Acevedo S. 2016. Gone with the wind: estimating hurricane climate change costs in the Caribbean. International Monetary Fund Working Paper.
[103] Acevedo S. 2016. Gone with the wind: estimating hurricane climate change costs in the Caribbean. International Monetary Fund Working Paper.

increased spending on relief efforts and repairs[104]. Although these financial impacts are already severe, climate change is predicted to exacerbate the impact of extreme climate events as they are projected to increase in intensity (see Section 3).

2.3. Gender considerations in Antigua and Barbuda

Women in Antigua and Barbuda continue to be adversely affected by socio-cultural, political and economic inequalities, despite being protected from a legal context[105]. As of the country's 2000 census, minimal gender disparity was observed amongst the economically active population[106,107], with 33% of men and 34% of women over the age of 15 being employed and economically active (Figure 3 and Figure 4)[108]. However, women usually occupy low-paying, insecure positions in the workplace that reinforce gender role stereotypes, including domestic work and provision of care[109]. Overall, women tend to maintain a higher unemployment rate and remain unemployed for longer periods compared to men.

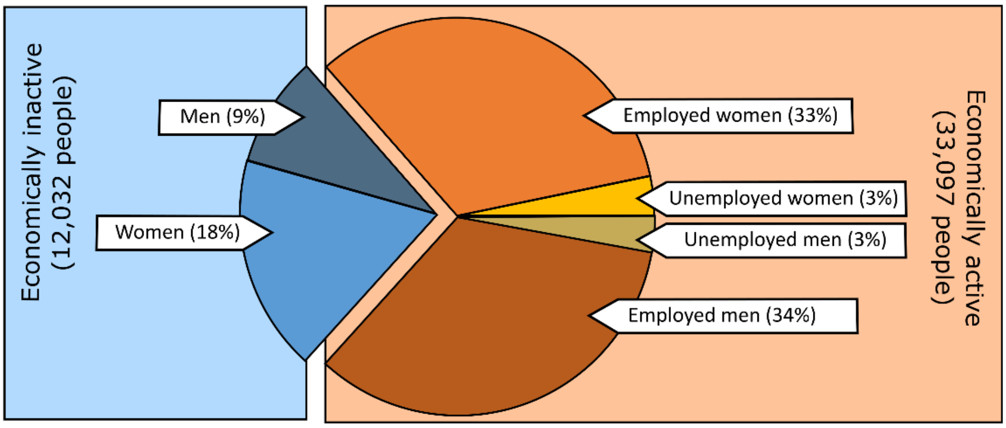


Figure 3. Economically active and inactive population disaggregated by gender from 45,810 people over the age of 15, recorded as part of the 2000 census[110].

[104] Government of Antigua and Barbuda. 2018. Hurricane Irma Needs Assessment. Available at: https://www.gfdrr.org/en/publication/hurricane-irma-and-maria-recovery-needs-assessment-antigua-and-barbuda.
[105] Huggins T. 2014. Country Gender Assessment (CGA): Antigua and Barbuda. Volume 1. Caribbean Development Bank, Rawwida Baksh and Associates.
[106] The 'economically active population' comprises all persons of either sex above a specified age who furnish the supply of labour for the production of economic goods and services.
[107] Caribbean Community Secretariat (CCS). 2010. Woman and men in the Caribbean community: Facts and figures 1998–2005. Statistics Sub-Programme.
[108] Caribbean Community Secretariat (CCS). 2010. Woman and men in the Caribbean community: Facts and figures 1998–2005. Statistics Sub-Programme.
[109] Huggins T. 2014. Country Gender Assessment (CGA): Antigua and Barbuda. Volume 1. Caribbean Development Bank, Rawwida Baksh and Associates.
[110] Caribbean Community Secretariat (CCS). 2010. Woman and men in the Caribbean community: Facts and figures 1998–2005. Statistics Sub-Programme.

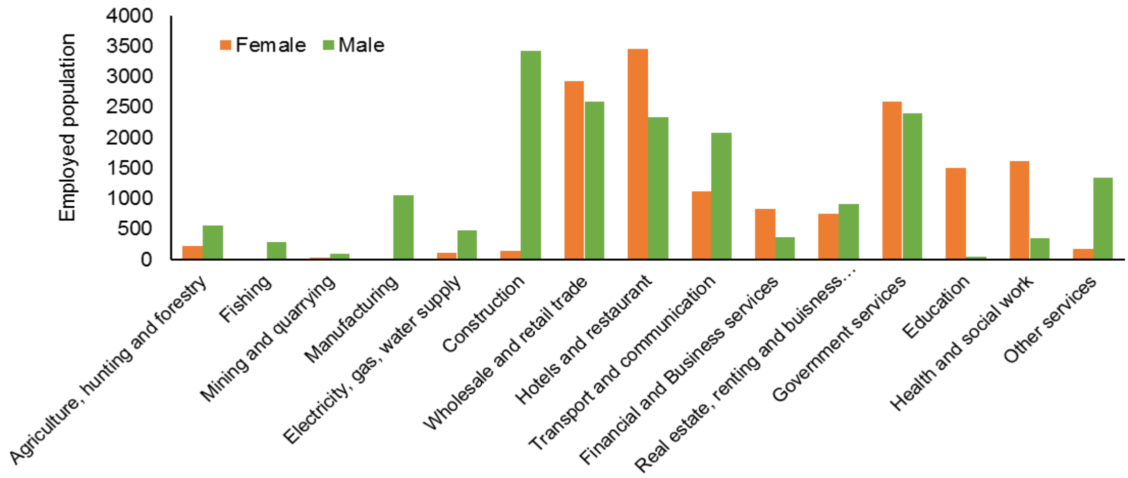
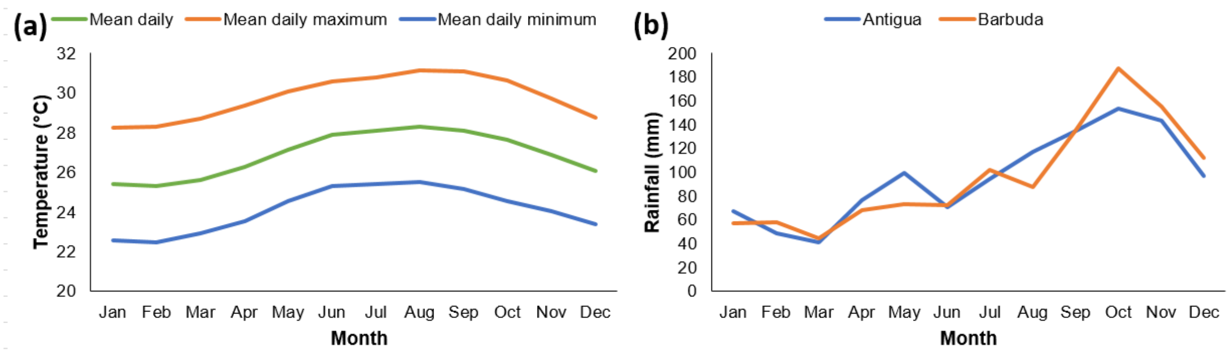


Figure 4. Employed population by economic sector disaggregated by gender[111].

2.4. *Climate and* natural resources

2.4.1. Climate baseline

Antigua and Barbuda has a tropical savanna climate[112] with high and uniform average daily temperatures between 24–30°C (Figure 5a) [113]. The climate regime is characterised by dry winters and wet summers, with the average annual rainfall on Antigua varying from 580–1,660 mm and on Barbuda from 620–2,100 mm (Figure 5b) [114]. Of this rainfall, 29% occurs during the dry season (between December and April) while the remaining 71% occurs during the wet season (between May and November)[115]. Despite the country's tropical climate, high seasonal variability in precipitation and a limited natural surface water storage capacity have resulted in Antigua and Barbuda becoming one of the most water scarce countries per capita in the world[116]. During wet seasons, reservoirs and dams often overflow, causing much of the freshwater to flow into the sea and not be utilised[117].



[111] Huggins T. 2014. Country Gender Assessment (CGA): Antigua and Barbuda. Volume 1. Caribbean Development Bank, Rawwida Baksh and Associates.
[112] Available at: https://en.climate-data.org/north-america/antigua-and-barbuda-165/.
[113] Antigua and Barbuda Meteorological Service. 2019. Government of Antigua and Barbuda. Available at: http://www.antiguamet.com/Climate/
[114] Antigua and Barbuda Meteorological Service. 2019. Government of Antigua and Barbuda. Available at: http://www.antiguamet.com/Climate/.
[115] Antigua and Barbuda Meteorological Service. 2019. Government of Antigua and Barbuda. Available at: http://www.antiguamet.com/Climate/
[116] Haites E. 2002. Assessment of the economic impact of climate change on CARICOM countries. Margaree Consultants, Toronto.
[117] Antigua and Barbuda: Environmental Management Strategy and Action Plan 2004–2009 (EMSAP). 2003. Government of Antigua and Barbuda.

Figure 5. Average daily temperatures recorded at VC Bird International Airport (VCBIA), Antigua for the period 1995–2018 (a); and total annual rainfall for Antigua and Barbuda from 1993–2018 (b)[118].

The country's annual climate cycle is influenced by several factors, namely the: i) migration of the north Atlantic sub-tropical high-pressure system; ii) eastward spreading of the tropical Atlantic warm pool; iii) easterly trade winds; and iv) tropical depressions, storms and hurricanes[119]. In addition, climate in Antigua and Barbuda is affected by the El Niño Southern Oscillation (ENSO), which is a periodic fluctuation in sea surface temperature (SST) and the overlying atmosphere, leading to cycles of warm and cold temperatures across the Pacific[120]. ENSO brings about two distinct changes in weather patterns known as El Niño and La Niña, which each typically last for 9–12 months but can persist for as long as two years[121]. Although El Niño and La Niña mostly affect areas surrounding the Pacific, they can affect the climate in other parts of the globe as well.

La Niña occurs when strong trade winds push warm ocean water to the western equatorial Pacific Ocean, causing an upwelling of cold water in the eastern Pacific off the coast of South America[122]. This phase is therefore characterised by SSTs that are below average in the central and eastern tropical Pacific Ocean[123]. Within the Caribbean, La Niña results in wetter and cooler conditions and weakens upper- and lower-level winds, reducing wind shear and increasing hurricane activity[124]. La Niña can also influence hurricane activity by interacting with other climatic patterns. The warm phase of the Atlantic Multi-Decadal Oscillation (AMO), for example, produces warm SSTs and weaker easterly trade winds in the Atlantic Ocean that together encourage hurricane development in the Caribbean[125]. In a warm AMO phase — otherwise known as an Atlantic high-activity era — the occurrence of a simultaneous La Niña phase can result in an above-normal season for hurricane activity.

In contrast to La Niña, El Niño is associated with the weakening of the easterly trade winds over the Pacific Ocean, leading to above-normal SSTs in the central and eastern Pacific[126]. In the Caribbean, this will cause warmer and drier conditions during the late wet season[127]. These weather patterns, along with greater vertical wind shear and a more stable atmosphere, mean that El Niño is usually associated with less frequent hurricanes[128]. However, El Niño can negatively impact countries in the Caribbean — including Antigua and Barbuda — by increasing the likelihood and severity of droughts[129]. Partly as a result of the ENSO cycle, Antigua and Barbuda experiences severe droughts approximately every five to seven years[130].

[118] Antigua and Barbuda Meteorological Service. 2019. Government of Antigua and Barbuda. Available at: http://www.antiguamet.com/Climate/.
[119] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[120] National Oceanic and Atmospheric Administration. 2019. El Niño/Southern Oscillation (ENSO) technical discussion. U.S. Department of Commerce. Available at: https://www.ncdc.noaa.gov/teleconnections/enso/enso-tech.php.
[121] National Oceanic and Atmospheric Administration. 2019. What are El Niño and La Niña? U.S. Department of Commerce. Available at: https://oceanservice.noaa.gov/facts/ninonina.html.
[122] National Oceanic and Atmospheric Administration. 2019. What are El Niño and La Niña? U.S. Department of Commerce. Available at: https://oceanservice.noaa.gov/facts/ninonina.html.
[123] National Oceanic and Atmospheric Administration. 2019. What are El Niño and La Niña? U.S. Department of Commerce. Available at: https://oceanservice.noaa.gov/facts/ninonina.html.
[124] National Oceanic and Atmospheric Administration. 2014. Impacts of El Niño and La Niña on the hurricane season. U.S. Department of Commerce. Available at: https://www.climate.gov/news-features/blogs/enso/impacts-el-ni%C3%B1o-and-la-ni%C3%B1a-hurricane-season.
[125] National Oceanic and Atmospheric Administration. 2014. Impacts of El Niño and La Niña on the hurricane season. U.S. Department of Commerce. Available at: https://www.climate.gov/news-features/blogs/enso/impacts-el-ni%C3%B1o-and-la-ni%C3%B1a-hurricane-season.
[126] National Oceanic and Atmospheric Administration. 2019. El Niño/Southern Oscillation (ENSO) technical discussion. U.S. Department of Commerce. Available at: https://www.ncdc.noaa.gov/teleconnections/enso/enso-tech.php..
[127] National Oceanic and Atmospheric Administration. 2016. Global impacts of El Niño and La Niña. U.S. Department of Commerce. Available at: https://www.climate.gov/news-features/featured-images/global-impacts-el-ni%C3%B1o-and-la-ni%C3%B1a.
[128] National Oceanic and Atmospheric Administration. 2014. Impacts of El Niño and La Niña on the hurricane season. U.S. Department of Commerce. Available at: https://www.climate.gov/news-features/blogs/enso/impacts-el-ni%C3%B1o-and-la-ni%C3%B1a-hurricane-season.
[129] National Drought Mitigation Center. 2019. ENSO and drought forecasting. Available at: https://drought.unl.edu/Education/DroughtIn-depth/ENSO.aspx
[130] Antigua and Barbuda Meteorological Service. 2019. Droughts. Available at: http://www.antiguamet.com/Climate/STATS/anu_drought.html.

2.4.2. Water resources

Currently, freshwater demand in Antigua is met by several sources, including: i) surface water storage in dams and multiple small ponds with a combined capacity of ~6 Mm^3; ii) groundwater aquifers; and iii) seawater desalination that provides ~75% of the national drinking water demand. During wet seasons, ~70% of Antigua's daily water supply is obtained through the desalination of seawater. This amount increases to nearly 100% during dry seasons[131]. However, while Antigua has access to seawater desalination for its supply of freshwater, the Barbuda population relies heavily on shallow groundwater aquifers that underlie 650 ha of sand in the Palmetto Point Area[132]. These groundwater reserves are extremely vulnerable to saltwater intrusion caused by over-extraction and rising sea-levels[133]. The contamination of freshwater aquifers with saltwater can lower the water quality and cause associated boreholes and well-points to become unusable, restricting the available water supply for both drinking and agricultural purposes[134]. In Barbuda, saltwater intrusion has already contaminated some shallow aquifers close to the coastline[135,136]. Added to this, sand mining in the Palmetto Point Area threatens Barbuda's main groundwater supply by raising the water table several feet and exposing portions of the aquifer, resulting in evaporation from portions of the aquifer[137]. The supply of freshwater in Antigua and Barbuda has been further stressed as a result of the country's population growth and economic development. This has rapidly increased water demand to the point where demand currently exceeds the available ground and surface water supply.

2.4.3. Energy resources

Antigua and Barbuda's reliance on desalinisation for its fresh water supply makes the country largely dependent on electricity to power the desalination plants. Despite fossil fuels being the main source of energy in the country, neither of the islands produce fossil fuels and consequently are reliant on imported oil and gas for electricity generation[138]. While there is considerable scope for the use of solar and wind power for renewable energy in Antigua and Barbuda[139], several barriers to implementing these energy alternatives exist. These barriers include: i) the relatively high costs as well as perceived risks of renewable energy and energy-efficient technologies; ii) insufficient access to affordable financing to implement these systems; and iii) low levels of awareness and understanding of the benefits, costs and applications of renewable energy/energy-efficient technologies. Assessments and action plans are therefore required to provide a framework for future action and development of necessary renewable energy infrastructure that is also climate-proof[140].

2.5. Ecosystem services

Antigua and Barbuda's natural environment provides a wide variety of ecosystem services, which many of the economic sectors depend on. These ecosystem services include *inter alia*: i) habitat provisioning for

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[131] Global Water Partnership Caribbean. 2013. The Post 2015 Water Thematic Consultation: Antigua and Barbuda.
[132] Simpson MC, et al., 2012. CARIBSAVE Climate Change Risk Atlas – Jamaica. DFID, AusAID and the CARIBSAVE Partnership, Barbados, West Indies.
[133] James P. 2001. Antigua and Barbuda Country Paper on National Climate Change Issues. Component 4: Formulation of a Policy Framework for Integrated (Adaptation) Planning and Management, Caribbean Planning for Adaptation to Climate Change.
[134] Alfarrah N & Walraevens K. 2018. Groundwater overexploitation and seawater intrusion in coastal areas of arid and semi-arid regions. *Water*. 10: 143. doi:10.3390/w10020143.
[135] Union of Concerned Scientists. 2011. "Climate hot map: global warming effects around the world — Antigua and Barbuda". Available at: http://www.climatehotmap.org/global-warming-locations/antigua-and-barbuda.html.
[136] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[137] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[138] Fuel currently comprises ~35% of all imports in Antigua and Barbuda.
[139] Economic Commission for Latin America and the Caribbean (ECLAC). 2013. An assessment of fiscal and regulatory barriers to deployment of energy efficiency and renewable energy technologies in Antigua and Barbuda.
[140] Sustainable Island Resource Management Zoning Plan (SIRMZP) for Antigua and Barbuda (including Redonda). 2011. GENIVAR Trinidad and Tobago, in association with Ivor Jackson and Associates and Kingdome Consultants Inc.

fisheries; ii) cultural, recreational and touristic benefits based on natural ecosystems; iii) regulatory services for flood protection, sediment retention and water purification; and iv) supporting services for primary production and nutrient cycling. Although much of the islands consists of sandy soil and shrub vegetation as a result of volcanic ash in the soil, some areas support tropical forested vegetation. These ecosystems are home to a number of endangered[141] and endemic species[142]. To protect these species and their habitat, seven national parks and wildlife reserves have been established in the country, covering ~19% of the islands' total surface area[143]. Codrington Lagoon on Barbuda, which covers most of the west coast of the island, has been listed as a Ramsar Wetland of International Importance and is a major tourist attraction[144]. In addition, there are 40 Marine Protected Areas (MPAs), that cover 624 km^2 of Antigua and Barbuda's territorial waters[145].

Insufficient land-use planning and management have resulted in the degradation of the environment and ecosystem functioning, which threatens the ecosystem services upon which the country's economic activities depend. Vast areas of watersheds have been cleared of native forest vegetation and large regions of productive agricultural land have been lost to urban expansion, while unsustainable agricultural practices[146] have further reduced land productivity. Residential and tourism development in the coastal zone is negatively affecting coastal ecosystems, with invasive alien species and limited management capacity further threatening terrestrial protected areas[147]. Consequently, land degradation and loss of ecosystem services have reduced the capacity of the country's natural resources to sustain livelihoods and provide basic needs — such as food security and water resources — to local communities. Increases in the frequency and intensity of extreme climate events — including tropical storms, hurricanes, droughts and extended dry periods, floods and rising air temperatures — are exacerbating the effects and impacts of deteriorating ecosystem functioning on vulnerable communities and the environment[148].

2.6. *Natural Hazards* in Antigua and Barbuda

2.6.1. Tropical storms and hurricanes

Tropical cyclones pass through the Lesser Antilles[149] during the hurricane season from June–November and can be categorised as tropical depressions[150], tropical storms[151] or hurricanes[152,153]. These storms generally form off the west coast of Africa and move through the Leeward Island chain on a north-westerly course[154]. Hurricanes that are described as Category 1 or 2 on the Saffir-Simpson Hurricane Wind Scale pass close enough to affect Antigua and Barbuda every 2–8 years, while major hurricanes[155] — those

[141] For example, the Antiguan racer snake (*Alsophis antiguae*) was listed as the world's rarest reptile before conservation efforts increased its numbers. However, the species remains 'Critically Endangered' on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. Available at: http://www.iucnredlist.org/details/939/0..
[142] For example, the Antiguan ground snake (*Alsophis antillensis antiguae*), dwarf woodslave (*Sphaerodactylus elegantulus*) and green lizard (*Anolis bimaculatus leachi*).
[143] The World Bank. 2019. Available at: https://data.worldbank.org/indicator/ER.LND.PTLD.ZS?locations=AG.
[144] Ramsar. 2014. Antigua and Barbuda. Available at: http://www.ramsar.org/wetland/antigua-and-barbuda.
[145] Marine Conservation Institute. 2019. Atlas of Marine Protection: Antigua and Barbuda. Available at: http://www.mpatlas.org/region/country/ATG/.
[146] Such as *inter alia* overgrazing, land clearing, uncontrolled fires and over-application of agro-chemicals.
[147] Action Plan for Implementing the Programme of Work on Protected Areas of the Convention on Biological Diversity. 2012. Submitted to the Secretariat of the Convention on Biological Diversity. Available at: https://www.cbd.int/doc/world/ag/ag-nbsap-powpa-en.pdf.
[148] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[149] The Lesser Antilles are a long arc of small islands, including Antigua and Barbuda, that run from the northern coast of Venezuela to east of Puerto Rico and form the eastern boundary of the Caribbean Sea.
[150] A tropical depression is a hurricane with maximum sustained winds of 62 kilometers per hour (kph), or 33 knots.
[151] A tropical storm is a hurricane with maximum sustained winds of 63–118 kph, or 34–63 knots.
[152] A hurricane is defined as a hurricane with maximum sustained winds of 119 kph (64 knots) or above.
[153] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[154] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[155] A major hurricane is a hurricane that has sustained maximum winds speeds of 178 kph (96 knots) or above.

defined as Category 3, 4 or 5 — partially or directly hit the country every 6–31 years[156]. This return period[157] has been shown to be shortening over time, resulting in more frequent occurrences of major hurricanes. Specifically, the return period for Category 4 hurricanes between the first and second halves of the 20th century has changed from 1 hurricane occurring every 50 years between 1900–1949 to 1 in every 10 years between 1950–1999[158]. Category 5 hurricanes — which are the most intense hurricanes with the fastest sustained winds — have historically only impacted Antigua and Barbuda very recently, with the only two recorded cases occurring in 2017. The return periods of named tropical storms, hurricanes and major hurricanes affecting Antigua and Barbuda are presented in Table 2. Since 1995, Antigua and Barbuda has experienced 4 tropical depressions, 14 tropical storms and 15 hurricanes (Figure 6).

Table 2. Return periods (in years) of tropical storms, hurricanes and major hurricanes within 15 nautical miles (nm)[159], 15–65 nm and 65–105 nm of Antigua and Barbuda[160].

Distance from island	Tropical storm return period (yrs)	Hurricane return period (yrs)	Major hurricane return period (yrs)
Antigua			
Up to 15 nm (28 km)	6–7	8	15–16
15–65 nm (28–120 km)	2	3	8
65–105 nm (120–194 km)	1–2	2–3	8
Barbuda			
Up to 15 nm (28 km)	6–7	8	30–31
15–65 nm (28–120 km)	3–4	4–5	15–16
65–105 nm (120–194 km)	2	3	6–7

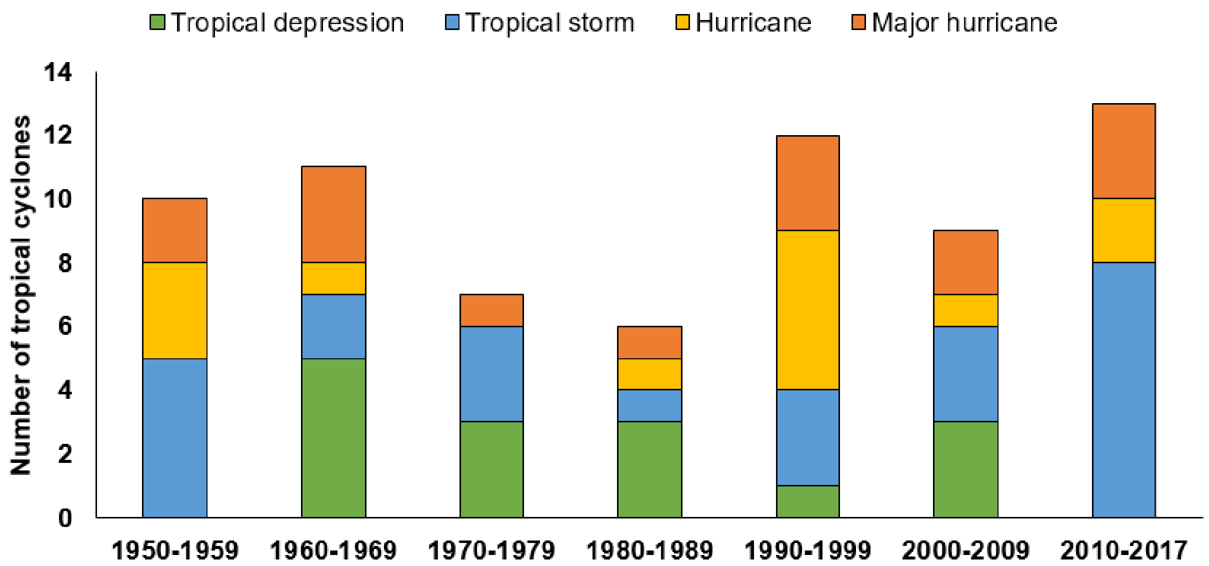


Figure 6. The number of hurricanes to either brush or directly hit Antigua and Barbuda per decade from 1950–2017[161].

[156] Destin DCS. 2019. Antigua and Barbuda hurricane climatology. Antigua and Barbuda Meteorological Service Climate Section. Available at: http://antiguamet.com/Climate/STATS/AntiguaBarbudaTCClimo.pdf.
[157] A return period can be described as the frequency in which a certain intensity hurricane can be expected within a given distance of a specific location.
[158] Antigua and Barbuda Meteorological Service. 2019. Government of Antigua and Barbuda. Available at: http://www.antiguamet.com/Climate/.
[159] A nautical mile (nm) is equivalent to 1.1508 statue or 'normal' miles.
[160] Destin DCS. 2019. Antigua and Barbuda hurricane climatology. Antigua and Barbuda Meteorological Service Climate Section. Available at: http://antiguamet.com/Climate/STATS/AntiguaBarbudaTCClimo.pdf.
[161] Antigua and Barbuda Meteorological Service. 2019. Government of Antigua and Barbuda. Available at: http://www.antiguamet.com/Climate/.

Most of the damage to vegetation and buildings caused by hurricanes can be attributed to strong winds, storm surges, flooding and landslides[162]. Water-related incidents pose the highest risk to human life, with most fatalities during hurricane events linked to drowning[163]. Such extreme events also result in severe damage to property, buildings, ecosystems and loss of life. Moreover, access to emergency, public and electricity services are often intermittent or not available for weeks immediately following extreme climate events. This disruption of services has considerable negative impacts on health, livelihoods and well-being, as well as the economic security of the Antigua and Barbuda.

The most recent hurricanes to affect Antigua and Barbuda — namely Irma, Jose and Maria — occurred in September 2017 and followed each other in close succession. Hurricane Irma affected a total of 14 SIDS, including Antigua and Barbuda, setting an Atlantic basin record by having sustained winds exceeding 290 kph for 36 consecutive hours[164]. Of Antigua and Barbuda, the latter was the worst affected by Hurricane Irma. In addition to three deaths, 95% of Barbuda's buildings were damaged or destroyed[165]. Because of the extensive damage and the additional threat posed by Hurricane Jose two days later, the entire population of Barbuda was evacuated to Antigua, leaving the former uninhabited for the first time in 300 years (Figure 7)[166]. Although Hurricane Jose did not reach Antigua and Barbuda, 12 days later Hurricane Maria impacted the island of Antigua, which experienced tropical storm-force winds and heavy rainfall as a result. Damages from the combined impact of Hurricanes Irma and Maria are estimated to be ~US$136 million, while economic losses amount to ~US$19 million[167]. Recovery needs following these two hurricane events were estimated to be US$222 million. The tourism sector was the worst affected, accounting for 44% of total damage costs and 76% of total losses[168] (Figure 8). The economic and social impacts of Hurricanes Irma and Maria, as well as other hurricanes that have affected Antigua and Barbuda since 1995, are summarised in Table 3.

[162] Nunez C. 2019. Hurricanes, cyclones and typhoons, explained. Available at: https://www.nationalgeographic.com/environment/natural-disasters/hurricanes/

[163] Shultz JM, Kossin JP, Shepherd JM, Ransdell JM, Walshe R, Kelman I & Galea S. 2018. Risks, health consequences, and response challenges for small-island-based populations: observations from the 2017 Atlantic hurricane season. Disaster Medicine and Public Health Preparedness.

[164] Shultz JM, Kossin JP, Shepherd JM, Ransdell JM, Walshe R, Kelman I & Galea S. 2018. Risks, health consequences, and response challenges for small-island-based populations: observations from the 2017 Atlantic hurricane season. Disaster Medicine and Public Health Preparedness.

[165] Blake ES. 2018. The 2017 Atlantic Hurricane Season: catastrophic losses and costs. Weatherwise. 71: 28–37.

[166] Cangialosi JP, Latto AS & Berg R. 2018. National Hurricane Centre Hurricane Report: Hurricane Irma. National Oceanic and Atmospheric Administration.

[167] Government of Antigua and Barbuda. 2018. Hurricane Irma Needs Assessment. Available at: https://www.gfdrr.org/en/publication/hurricane-irma-and-maria-recovery-needs-assessment-antigua-and-barbuda

[168] Government of Antigua and Barbuda. 2018. Hurricane Irma Needs Assessment. Available at: https://www.gfdrr.org/en/publication/hurricane-irma-and-maria-recovery-needs-assessment-antigua-and-barbuda

Figure 7. Natural colour satellite images of Barbuda before (left) and after (right) Hurricane Irma[169].

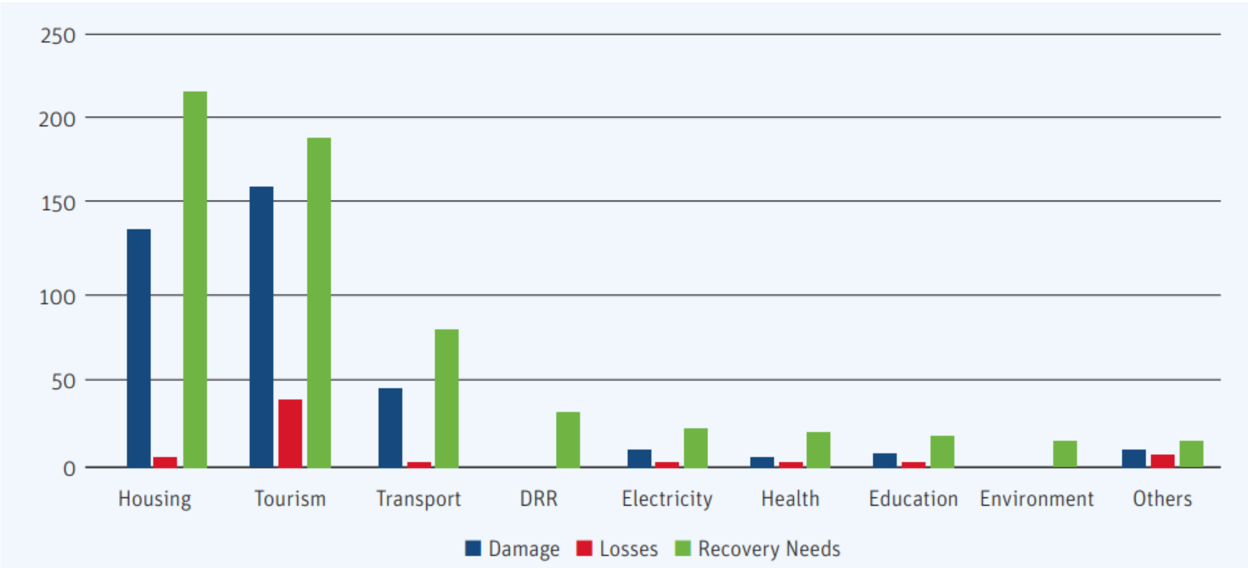


Figure 8. Damage, losses and recovery needs for Antigua and Barbuda following Hurricane Irma and Maria (million EC$, where 1EC$ = 0.37US$)[170][171].

[169] NASA Earth Observatory. 2017. Barbuda and Saint Barthelemy browned by Irma. Available at: https://earthobservatory.nasa.gov/images/90975/barbuda-and-saint-barthelemy-browned-by-irma.
[170] Government of Antigua and Barbuda. 2018. Hurricane Irma Needs Assessment. Available at: https://www.gfdrr.org/en/publication/hurricane-irma-and-maria-recovery-needs-assessment-antigua-and-barbuda
[171] Note: these costs are not considered exhaustive and several additional needs have been identified; for example the need for a new sanitary landfill for Barbuda after the existing one was pushed over capacity by Hurricane Irma.

Table 3 below, which shows the extensive infrastructural damage caused by hurricanes in Antigua and Barbuda, supports the rationale for the identification of hurricanes and their associated high wind speeds as the primary climate change threat to the country. This information is further supplemented by the findings from the vulnerability analysis conducted for the proposed project. These findings are presented in Section 10.3 of this Feasibility Study.

Table 3. Hurricanes and associated economic and social impacts in Antigua and Barbuda since 1995[172].

Year	Event	Economic loss/damages	Social impacts
1995	Hurricane Luis	• US$128 million • Damage amounted to ~30% of GDP • 17% decrease in tourist arrivals • 7,000 people left unemployed • 90% of buildings damaged	• Two reported fatalities[173] • Severe flooding and erosion • Damage to 70% of structures on Barbuda • Damage to 50% of private dwellings on Antigua
1998	Hurricane Georges[174]	• US$74 million • Numerous hospitals and airports damaged • 15% of businesses reported minor damages • Three schools damaged; one severely damaged • All Saints Police Station damaged	• Two reported fatalities; two injured[175] • 3,338 people left homeless • 1,650 private dwellings damaged • 150 private dwellings destroyed • Disrupted supply of water, power and telecommunications
1999	Hurricane Jose,[176]	• US$91 million (combined estimated cost with Lenny) • Two shelters damaged • 13 business places with major damage in St Paul's	• 1 fatality reported; 15 injured • 2,000 people affected or displaced • 8 homes destroyed and 16 damaged in St Paul's • 506 people residing in community shelters • Disrupted supply of water and power • Disruption of critical services
	Hurricane Lenny[177,178]	• Beach erosion • Flooding — 65% of Barbuda under water • Roads and bridges damaged or blocked by mudslides • 95% of agricultural industry affected on Barbuda • Several hotels flooded	• One confirmed fatality • 490 families affected/displaced • 20,000 people lacked access to drinking water on Antigua • Groundwater contamination on Barbuda • Mosquito and yellow belly black fly infestation
2008	Hurricane Omar[179,180]	• US$18 million	• Extensive flooding from strong storm surges[181]

[172] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[173] Lawrence MB. 1996. Preliminary report, Hurricane Luis, 28 August–12 September 1995. National Hurricane Centre.
[174] Caribbean Disaster Emergency Management Agency (CDEMA). 1998. CDEMA Impact Situation Report #4 – Hurricane Georges. Available at: http://reliefweb.int/report/anguilla/impact-situation-report-4-hurricane-georges
[175] US Agency for International Development (USAID). 1998. Hurricane Georges Fact Sheet #9: Caribbean, Dominican Republic, Haiti. 1998. Available at: http://reliefweb.int/report/antigua-and-barbuda/caribbean-dominican-republic-haiti-hurricane-georges-fact-sheet-9
[176] Caribbean Disaster Emergency Management Agency (CDEMA). 1999. CDEMA Hurricane Jose Post-Impact Situation Report #2. 1999. Available at: http://reliefweb.int/report/anguilla/hurricane-jose-post-impact-situation-report-2
[177] UN Office for the Coordination of Humanitarian Affairs. 1999. Hurricane Lenny OCHA Situation Report No. 7. Available at: http://reliefweb.int/report/anguilla/hurricane-lenny-ocha-situation-report-no-7
[178] US Agency for International Development (USAID). 2000. North-eastern Caribbean – Hurricane Lenny Fact Sheet #1, Fiscal Year (FY). Available at: http://reliefweb.int/report/antigua-and-barbuda/northeastern-caribbean-hurricane-lenny-fact-sheet-1-fiscal-year-fy-2000
[179] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[180] Kentish A. 2008. Omar floods homes, damages crops in Antigua. The Associated Press. Available at: http://www.webcitation.org/5dEpN92IK?url=http://www.antiguasun.com/paper/?as%3Dview%26sun%3D281935077507132005%26an%3D451823067811282008%26ac%3DOpinion
[181] Destin D. 2008. The Atlantic hurricane season summary — 2008: special focus on Antigua and Barbuda. Antigua and Barbuda Meteorological Service Climate Section. Available at: http://www.antiguamet.com/Climate/HURRICANE_SEASONS/HurricaneSeason2008.pdf

Year	Event	Economic loss/damages	Social impacts
		• Extensive damage to agricultural land and loss of crops • Damage to road infrastructure	• Landslides and mudslides • 75 people residing in community shelters • 30 people evacuated from flooded dwellings
2010	Hurricane Earl[182, 183]	• US$19 million • Damage to road, drainage and power infrastructures • Damage to crops and livestock — almost half of Antigua's crops were destroyed • Damage to fisheries	• 259–350 people residing in community shelters • 250 families displaced • Disrupted power supply
2014	Hurricane Gonzalo[184]	• US$40 million[185] • Damage to infrastructure	• Disrupted power supply • Minor flooding and coastal erosion
2017	Hurricane Irma[186, 187]	• US$19 million in economic losses and US$136 million in damages (both values combined with impact from Maria) • Loss in GDP of 1.1% • Losses in tourism, agricultural and fisheries sectors • 95% of buildings damaged or destroyed on Barbuda • Barbuda airport destroyed • Considerable damage to Hanna Thomas and Codrington hospitals[188] • Damage to Barbuda fire station • Four educational facilities damaged • Damage to road, harbour and airport infrastructure	• Considerable storm surge of 2.4 m in parts of Barbuda • Three fatalities on Barbuda • Evacuation of entire population of Barbuda (~1,800 people) • 45% of houses uninhabitable and 28% requiring complete reconstruction • Widespread psychological stress over incident and long recovery phase • 178 Barbudan students placed in schools in Antigua • Disruption in critical services, impacts still felt one year after the incident • Disruption of water supply, resulting in no town water for months. The desalination station was severely damaged • Contamination of groundwater • Disruption of power supply (distribution grid 100% destroyed) • Landfill exhausted beyond capacity (Illegal dumpsites for construction debris now being used)
	Hurricane Maria[189]	• Damage to road and harbour infrastructure on Antigua	• Some damage to homes on Antigua

[182] Caribbean Disaster Emergency Management Agency (CDEMA). 2010. CDEMA Situation Report #2 – Hurricane Earl. Available at: http://reliefweb.int/report/antigua-and-barbuda/cdema-situation-report-2-hurricane-earl
[183] Disaster Relief Emergency Fund (DREF). 2010. Antigua and Barbuda: Hurricane Earl. Available at: https://www.ifrc.org/docs/appeals/rpts10/mdrag002.pdf
[184] Caribbean Disaster Emergency Management Agency (CDEMA). 2014. CDEMA Situation Report #2 – Hurricane Gonzalo. Available at: http://www.cdema.org/index.php?view=article&catid=39%3Asituation-reports&id=1393%3Asituation-report-2-hurricane-gonzalo-as-of-500-pm-october-15-2014&format=pdf&option=com_content&Itemid=347
[185] Destin D. 2014. The Atlantic hurricane season summary — 2014: special focus on Antigua and Barbuda. Antigua and Barbuda Meteorological Service Climate Section. Available at: http://www.antiguamet.com/Climate/HURRICANE_SEASONS/HurricaneSeason2014.pdf
[186] Cangialosi JP, Latto AS & Berg R. 2018. National Hurricane Centre Hurricane Report: Hurricane Irma. National Oceanic and Atmospheric Administration.
[187] Government of Antigua and Barbuda. 2018. Hurricane Irma Needs Assessment. Available at: https://www.gfdrr.org/en/publication/hurricane-irma-and-maria-recovery-needs-assessment-antigua-and-barbuda
[188] International Federation of Red Cross (IFRC). 2018. Antigua and Barbuda and Saint Kitts and Nevis: Hurricane Irma (MDR49009): 12-month operations update. Available at: https://reliefweb.int/sites/reliefweb.int/files/resources/MDR49009eu12M.pdf
[189] Government of Antigua and Barbuda. 2018. Hurricane Irma Needs Assessment. Available at: https://www.gfdrr.org/en/publication/hurricane-irma-and-maria-recovery-needs-assessment-antigua-and-barbuda

2.6.2. Droughts

The islands of Antigua and Barbuda are two of the driest in the Caribbean region[190]. This is largely attributable to the relatively low amounts of rainfall received compared to other islands in the area, as well as the porous limestone geology and small, shallow watersheds. These factors contribute significantly to water insecurity across the Antigua and Barbuda[191]. Droughts can be defined according their cause and impact on the environment and society. A meteorological drought is a prolonged period where precipitation falls below the average for a particular area, resulting in a natural shortage of water[192]. The Department of Marine Services using a three month rain total to define drought, with the following categories: i) Slight: rainfall ranges from less than 30th percentile to the 20 percentile; ii) Moderate: rainfall ranges from less than the 20th percentile to the 10th percentile; iii) Serious: rainfall ranges from less than the 10th percentile to the 5th percentile; iv) Severe: rainfall less than the 5th percentile[193]. Inadequate water resource management during periods of meteorological drought can increase the vulnerability of a population to two other types of drought, namely agricultural and hydrological drought. An agricultural drought refers to a period of extended dryness where crops are adversely affected, while hydrological drought occurs when a reduction in available water severely affects livestock, households or other sectors[194].

Figure 9 presents a drought risk map of watersheds within Antigua and Barbuda, taking both environmental and land use factors that will influence the severity of droughts into account[195]. On Antigua, the areas at the highest risk of drought are in the north, east and southeast of the island. The area in the extreme southeast is particularly at risk because of: i) low rainfall; ii) shallow soils; iii) exposed soils vulnerable to drying and crusting which leads to erosion and reduced infiltration; and iv) overgrazing from a large population of goats. On Barbuda, the flat lands surrounding and to the south of the western town of Codrington are at the greatest risk of droughts.

[190] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[191] Government of Antigua and Barbuda. 2015. Third National Communication on Climate Change.
[192] National Office of Disaster Service (NODS). Drought. Available at: http://nods.gov.ag/hazzards/drought/
[193] DMS. 2015. Drought and Precipitation Statement for Antigua.
[194] Jackson I. 2001. Antigua and Barbuda drought hazard assessment and mapping summary report. Post-Georges Disaster Mitigation Project in Antigua and Barbuda and St. Kitts and Nevis. Available at: http://www.oas.org/pgdm/hazmap/drought/abdrtsum.htm
[195] Jackson I. 2001. Antigua and Barbuda drought hazard assessment and mapping summary report. Post-Georges Disaster Mitigation Project in Antigua and Barbuda and St. Kitts and Nevis. Available at: http://www.oas.org/pgdm/hazmap/drought/abdrtsum.htm

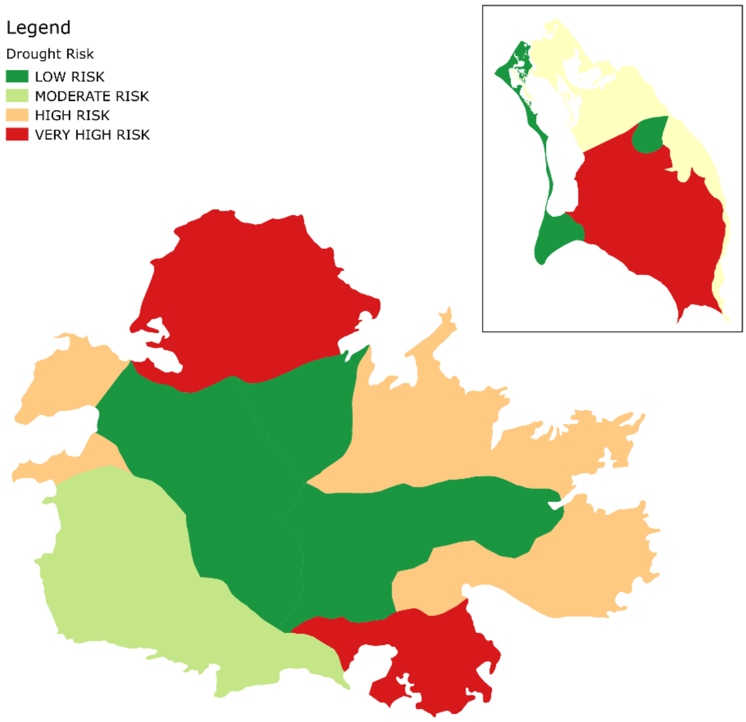


Figure 9. Drought hazard mapping in watersheds across Antigua and Barbuda[196].

Drought events have a return period of 2 years on Antigua and Barbuda and an average duration of 11 months[197]. The longest period between drought events affecting the country is two years and six months[198]. Drought events can be further categorised by severity, namely slight, moderate, serious and severe[199]. The return period and duration of each of these drought levels on Antigua and Barbuda are given in Table 4.

Table 4. The return periods (years) and average, minimum and maximum duration (months) of slight, moderate, serious and severe droughts in Antigua and Barbuda from 1928–2018[200].

Drought level	Return period (yrs)	Average duration (months)	Minimum duration (months)	Maximum duration (months)
Slight	6	7	2	19
Moderate	4	8	2	15
Serious	6	12	3	24
Severe	7	17	3	27

Past droughts have had numerous negative impacts on the inhabitants of Antigua and Barbuda, depending on the severity, duration and extent of the drought in question. These negative impacts include, but are not limited to, dehydration, increased occurrence of diseases from limited and poorly managed water resources, lowered food security and income losses from both the tourism and agricultural sectors[201]. The country's

[196] Jackson I. 2001. Antigua and Barbuda drought hazard assessment and mapping summary report. Post-Georges Disaster Mitigation Project in Antigua and Barbuda and St. Kitts and Nevis. Available at: http://www.oas.org/pgdm/hazmap/drought/abdrtsum.htm
[197] Antigua and Barbuda Meteorological Service. 2019. Droughts. Available at: http://www.antiguamet.com/Climate/STATS/anu_drought.html
[198] Antigua and Barbuda Meteorological Service. 2019. Droughts. Available at: http://www.antiguamet.com/Climate/STATS/anu_drought.html
[199] Drought levels are defined as: i) slight — rainfall ranges from the 20–30th percentile; ii) moderate — rainfall ranges from the 10–20th percentile; iii) serious — rainfall ranges from the 5–10th percentile; and iv) severe — rainfall is lower than the 5th percentile.
[200] Antigua and Barbuda Meteorological Service. 2019. Droughts. Available at: http://www.antiguamet.com/Climate/STATS/anu_drought.html
[201] Jackson I. 2001. Antigua and Barbuda drought hazard assessment and mapping summary report. Post-Georges Disaster Mitigation Project in Antigua and Barbuda and St. Kitts and Nevis. Available at: http://www.oas.org/pgdm/hazmap/drought/abdrtsum.htm

worst drought recorded in recent times occurred between 1983–1984. During this drought, farmers experienced major income losses, households had no access to piped water for months and hotels were required to import water tankers[202]. Water desalination facilities were introduced to Antigua after this event and the vulnerability of its inhabitants to further droughts has since been reduced[203]. Despite this increase in water security, the country is still negatively impacted by droughts. For example, inadequate rainfall over the 2014–2015 period resulted in water shortages on both islands, which led to scheduled water rationing and left many households without a reliable water supply[204].

2.6.3. Earthquakes

The Eastern Caribbean is influenced by earthquakes originating primarily from a subduction zone at the junction of two tectonic plates, namely the Caribbean and North American Plates[205]. The North-eastern Leeward Islands is one of the most seismically active zones within the Caribbean and frequently experiences minor earthquakes[206]. For the period between 1998–2018, 398 magnitude 3, 139 magnitude 4 and 22 magnitude 5 earthquakes were recorded within a 150 km radius around Antigua and Barbuda[207]. Earthquakes at these scales can cause minor damage to buildings and structures[208]. Greater magnitude earthquakes of 6–7 or 7 and above have return periods of 15 and 75 years respectively[209]. Earthquakes at these magnitudes can cause moderate or considerable damage and loss of life. The most recent high magnitude earthquake to affect Antigua and Barbuda occurred in 1974 and had a magnitude of 7.5. This earthquake caused extensive damage to Antigua's Cathedral of St. John, as well as the Deep Water Harbour facility and West Indies oil refinery[210].

3. Climate change in Antigua and Barbuda

Currently, Antigua and Barbuda is influenced by several climatic hazards, including tropical storms, hurricanes and droughts (see Section 2). In 2017, the country had a Climate Risk Index (CRI)[211] score of 20.67, ranking it as the 20th country most affected by extreme climate events[212]. This score has decreased from an average CRI score of 56.33 and rank of 43 between 1998–2017 — suggesting that the country's degree of exposure and vulnerability to extreme weather events has increased over the past few decades. Climate change trends indicate that the frequency and intensity of extreme climate events affecting Antigua and Barbuda will be exacerbated in the future, leading to increased impacts on the country's ecosystems and vulnerable communities.

Datasets for the analysis of current climate trends will focus on temperature, precipitation, Standardized Precipitation Evapotranspiration Index (SPEI) and hourly maximum wind gusts. Special focus will be given to hurricane activity within 100 km of Antigua and Barbuda. The assessment of climate changes will

[202] Jackson I. 2001. Antigua and Barbuda drought hazard assessment and mapping summary report. Post-Georges Disaster Mitigation Project in Antigua and Barbuda and St. Kitts and Nevis. Available at: http://www.oas.org/pgdm/hazmap/drought/abdrtsum.htm
[203] National Office of Disaster Service (NODS). Drought. Available at: http://nods.gov.ag/hazzards/drought/
[204] United Nations Development Programme (UNDP). 2012. Stock Taking Report: Rio +20 – Antigua and Barbuda.
[205] Gibbs T. 1998. Vulnerability assessment of selected buildings designed as shelters: Antigua and Barbuda. Organisation of American States General Secretariat, Unit for Sustainable Development and Environment.
[206] National Office for Disaster Services (NODS). 2017. Country Document for Disaster Risk Reduction: Antigua and Barbuda, 2016.
[207] Northern California Earthquake Data Centre (NCEDC). 2014. Historic ANSS Composite Catalogue Search. UC Berkeley Seismological Laboratory. Available at: http://www.ncedc.org/anss/catalog-search.html.
[208] Encyclopedia Britannica, Inc. 2019. Earthquake magnitude. Available at: https://www.britannica.com/science/earthquake-geology/Earthquake-magnitude
[209] Caribbean Catastrophe Risk Insurance Facility. Country Risk Profile: Antigua and Barbuda. Available at: https://www.ccrif.org/sites/default/files/publications/antigua_barbuda.pdf
[210] Public Seismic Network, Inc. The Leeward Islands earthquake of October 1974. Available at: http://www.dpsninc.org/index.php/stories/34-the-leeward-islands-earthquake-of-october-1974
[211] The Climate Risk Index quantifies impacts of extreme weather events on individual countries by considering fatalities and economic losses relating to these events over a specific timeframe.
[212] Ecktein D, Hutfils M-L & Winges M. 2019. Global Climate Risk Index 2019: Who suffers most from extreme weather events? Weather-related loss events in 2017 and 1998 to 2017. Germanwatch e.V. Berlin.

consider these same variables. Direct projection of hurricane activity into the future remains an area of much variability. Analyses used for the proposed project therefore focus on parameters known to influence hurricane activity and infers change in the environments conducive to the development and intensification of hurricanes. These parameters are: i) atmospheric vertical wind shear (VWS) in the major development region; and ii) sea surface temperature (SST).

The future global climate is dependent on anthropogenic mitigation of greenhouse gas (GHG) emissions. To accommodate for uncertainties around future GHG emissions and the success of mitigation measures, a scenario set of four possible future trajectories is commonly used for climate modelling. These four representative concentration pathways (RCPs) are based on the main forcing agents of climate change — namely GHG emissions, GHG concentrations and land-use change[213]. The different RCPs, described below, are based on the relative radiative forcing (in W/m^2)[214] target level for 2100[215,216].

- RCP2.6 represents the best-case mitigation scenario, with a global focus on environmentally sustainable practices. Peak radiative forcing is ~3 W/m^2 (~490 ppm CO_2 equivalent) before 2100 followed by a decline to 2.6 W/m^2 by 2100.
- RCP4.5 represents the likely best-case scenario with a peak radiative forcing of 4.5 W/m^2 (~650 ppm CO_2 equivalent) at stabilisation after 2100.
- RCP6.0 represents the likely worst-case scenario with a peak radiative forcing of 6 W/m^2 (~850 ppm CO_2 equivalent) at stabilisation after 2100.
- RCP8.5 represents a very high GHG emission scenario with a peak radiative forcing of 8.5 W/m^2 (~1,370 ppm CO_2 equivalent) 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.

Temporal assessment temperature, maximum wind gusts and precipitation trends for the RCP8.5 emission scenario used downscaled daily CORDEX data for the Eastern Caribbean, comprising the following models:

- MIROC5
- HadGEM2-ES
- MPI-ESM-LR
- NorESM1-M
- GFDL-ESM2M
- CanESM2
- CNRM-CM5
- CSIRO-Mk3-6-0
- CM5A-MR

Vertical wind shear is assessed through the CMIP5 HadGEM2-CC RCP4.5 and RCP8.5 model simulations as this dataset provided the required temporal and vertical pressure-level resolution outputs in the troposphere for zonal and meridional wind. SST was assessed using RCP4.5 and RCP8.5 from model ensembles of:

- GISS-E2
- HadGEM2
- MIROC
- CanESM2
- CSIRO-Mk3
- GFDL

[213] Van Vuuren DP, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K et al. 2011. The representative concentration pathways: an overview. Climate Change. 109: 5–31.
[214] Radiative forcing refers to how much an external factor adds to the radiative energy budget of the Earth's system.
[215] Van Vuuren DP, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K et al. 2011. The representative concentration pathways: an overview. Climate Change. 109: 5–31.
[216] IPCC. 2014. Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer OR].

Precipitation, wind and temperature was not available for RCP4.5 for the CORDEX dataset. These parameters were assessed spatially using the WorldClim[217] data, which has RCP4.5 and RCP8.5.

3.1. Temperature

Temperatures from the ERA5[218] dataset shows clear increases in average temperatures for both Antigua and Barbuda (Figure 10). From 1980 to the present day, average temperatures have risen ~0.15°C per decade — despite the occurrence of interannual variability in the data. This represents an average increase of more than 0.3°C above the baseline period of 1980–2000 — a trend that is supported by the review of the CRU data[219]. The average annual temperature in Antigua and Barbuda has shown a linear increase of 1.6°C, changing from ~25°C in 1981 to ~26.6°C in 2010 (Figure 10). For the period 1970–2000, the Caribbean as a whole has experienced a mean warming of 0.3°C compared to pre-industrial conditions — at a rate of 0.015°C per year[220]. For the following decade from 2001–2010, the mean warming increased to 0.7°C across the Caribbean.

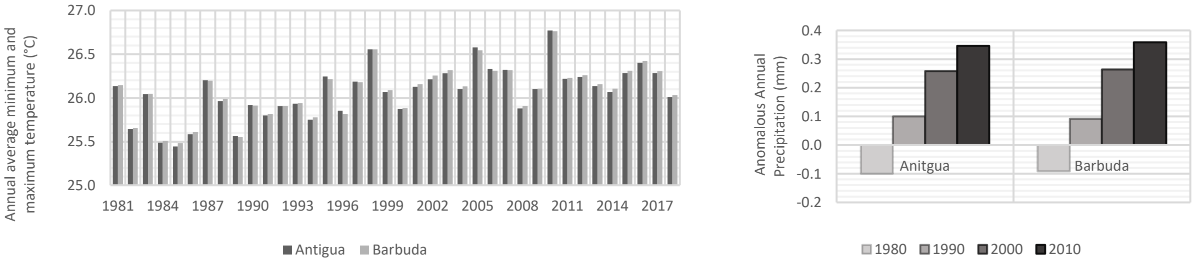


Figure 100. ERA5 annual average temperatures from 1980 to present (left), decadal anomaly (right).

Each subsequent decade from 1980 has been on average warmer than the previous in each month. The warmest months in Antigua and Barbuda occur from July to December (Figure 11). The largest increase in temperatures have occurred later in that period with October, November and December at ~0.4°C above the same months in the baseline period.

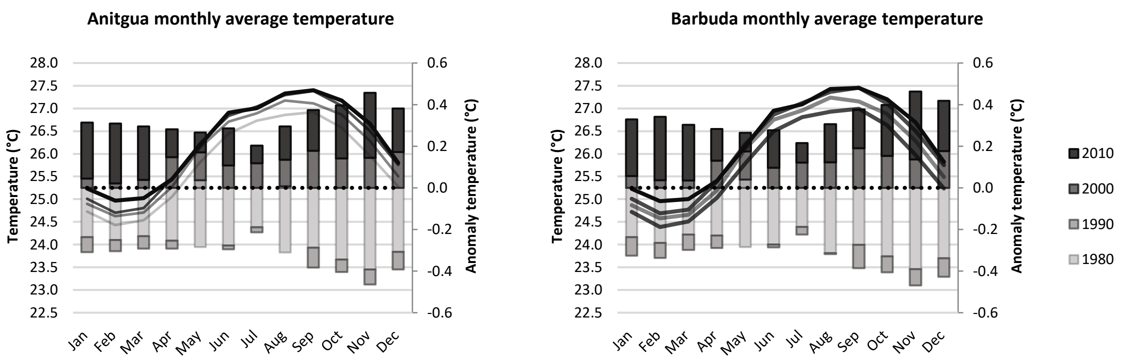


Figure 11. Monthly average and anomalous temperatures. Antigua (left), Barbuda (right).

This general increase has resulted in a shift in the average temperature profile, with the anomalous occurrence of a greater number of warmer days in the latter decades (Figure 12).

[217] WorldClim is a set of gridded climate data used for mapping and spatial modelling
[218] A reanalysis dataset which combines historical observations into global estimates using modelling and data assimilation systems. Available at: https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5
[219] Harris I, Jones PD, Osborn TJ & Lister DH. 2014. Updated high-resolution grids of monthly climatic observations — the CRU TS3.10 Dataset. International Journal of Climatology. 34: 623–642.
[220] Taylor MA, Clarke LA, Centella A, Bezanilla A, Stephenson TS, Jones JJ et al. 2018. Future Caribbean Climates in a world of rising temperatures: the 1.5 vs 2.0 dilemma. Journal of Climate. 31: 2907–2926.

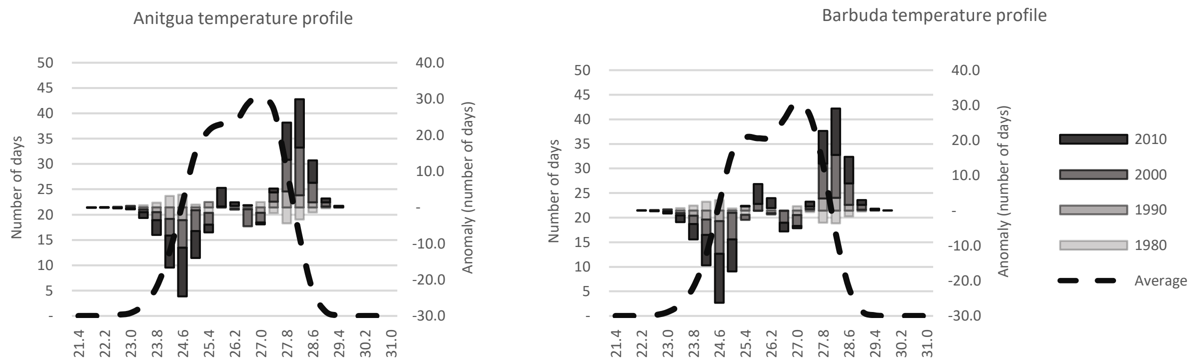


Figure 12. Average and anomalous temperature profiles over time. Antigua (left), Barbuda (right).

These increases will be greater when assessing the more extreme and heat wave conditions in the urbanised areas of Antigua particularly. In urban environments, the urban heat island (UHI) effect is estimated to increase ambient diurnal temperature by ~4.4°C.

Table 5. Urban heat island effects for Antigua and Barbuda.

	Average diurnal temperature
Urban	32.3°C
Rural	27.9°C
UHI	4.4°C

Based on future climate predictions, the current trend of increasing temperatures is expected to continue. Multi-model predictions under the RCP4.5 scenario suggest that the Paris Agreement global warming target of 1.5°C[221] will be reached between 2028–2031, at which point average annual temperatures within the Caribbean will be 1.2°C hotter than pre-industrial levels[222]. If global temperatures exceed the 1.5°C threshold and reach 2°C or 2.5°C — predicted to be reached between 2046–2055 and 2070–2100, respectively — average annual temperatures in the Caribbean could be 1.6°C and 2°C warmer than pre-industrial levels, respectively[223].

These increases are projected to shift not only the average and upper temperatures, but the full temperature profile will shift under the RCP8.5 scenario (Figure 13). This shift will cause the occurrence of present cooler days to become less frequent. The projected new average temperatures will be of a magnitude equivalent to historical higher or extreme temperatures. Historically simulated 60th percentile temperatures in September, October and November (SON) was in the range of 28°C. In the projected future scenario, the 28°C is simulated to occur at the 10th percentile range, with the new 60th percentile occurrence being ~30°C. The temperature profile will also cover a larger range of temperatures as maximum temperatures exceed historical records.

[221] The Paris Agreement pledged 195 nation signatories to rally toward a global target of keeping the global average temperature well below 2°C above pre-industrial levels, aiming to limit temperature increase to 1.5°C.
[222] Taylor MA, Clarke LA, Centella A, Bezanilla A, Stephenson TS, Jones JJ et al. 2018. Future Caribbean Climates in a world of rising temperatures: the 1.5 vs 2.0 dilemma. Journal of Climate. 31: 2907–2926.
[223] Taylor MA, Clarke LA, Centella A, Bezanilla A, Stephenson TS, Jones JJ et al. 2018. Future Caribbean Climates in a world of rising temperatures: the 1.5 vs 2.0 dilemma. Journal of Climate. 31: 2907–2926.

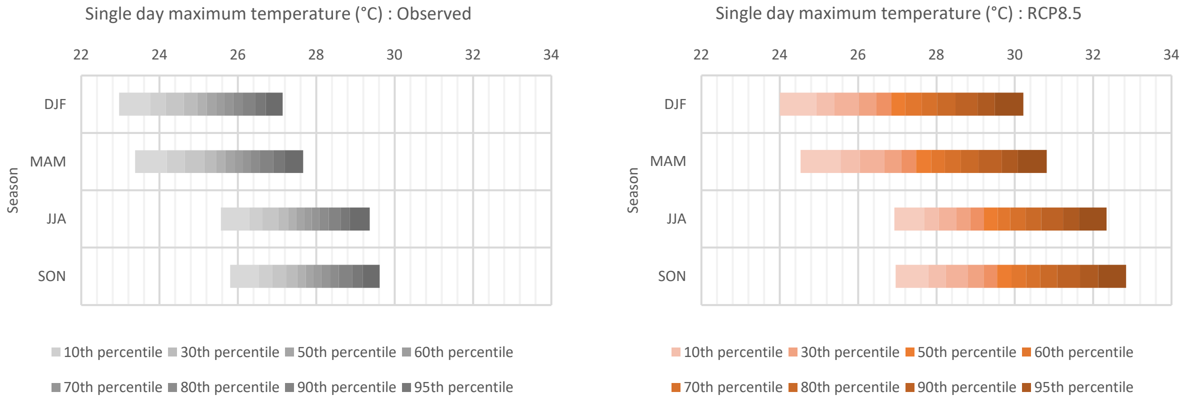


Figure 13. Seasonal temperature profile. Observed 1985–2005 (left), RCP8.5 2005–2099 (right). DJF (December January February), MAM (March April May), JJA (June July August), SON (September October November)[224].

For Antigua and Barbuda specifically (under the RCP8.5 scenario), monthly temperatures are expected to be consistently higher than current observed values over the next few decades (Figure 14). Compared to current observed values, temperatures are predicted to rise by 0.5°C–1°C in the 2030th decade, 1.4°C–1.6°C in the 2050th decade, 2.2°C–2.5°C in the 2070th decade and 2.8°C–3.2°C in the 2090th decade.

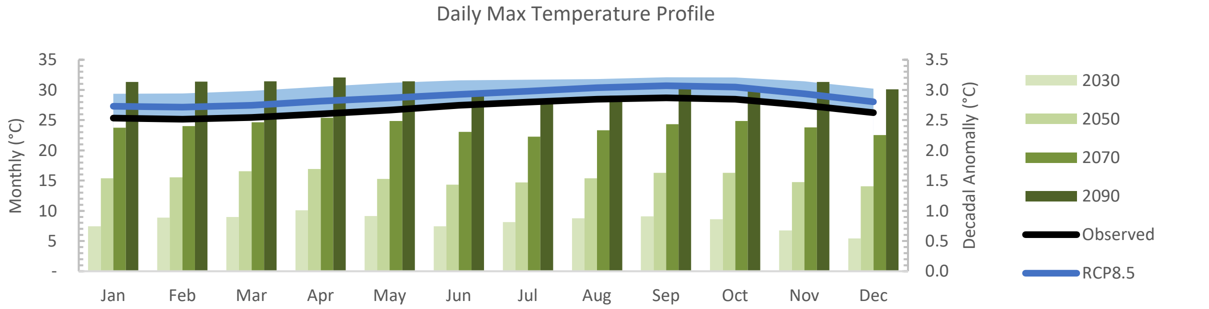


Figure 14. Observed (1985–2005) and predicted RCP8.5 scenario (2005–2100) average monthly temperatures (°C) for Antigua and Barbuda, as well as the decadal temperature anomaly (°C) between the observed and future predicted values under RCP8.5[225].

Extreme 90th percentile temperature days have been increasing steadily since the 1980s (Figure 15). This trend is expected to continue over the following decades, reaching maximum temperatures approximately 3–4°C hotter than current observed values by the 2090th decade. Figure 14 shows that, across four seasons, the lowest maximum daily temperatures will increase by 1°C by 2100, while the highest maximum daily temperatures may increase by as much as 3°C–5°C. Maximum daily temperature variability will also increase by 1°C–3.5°C.

[224] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012.
[225] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012.

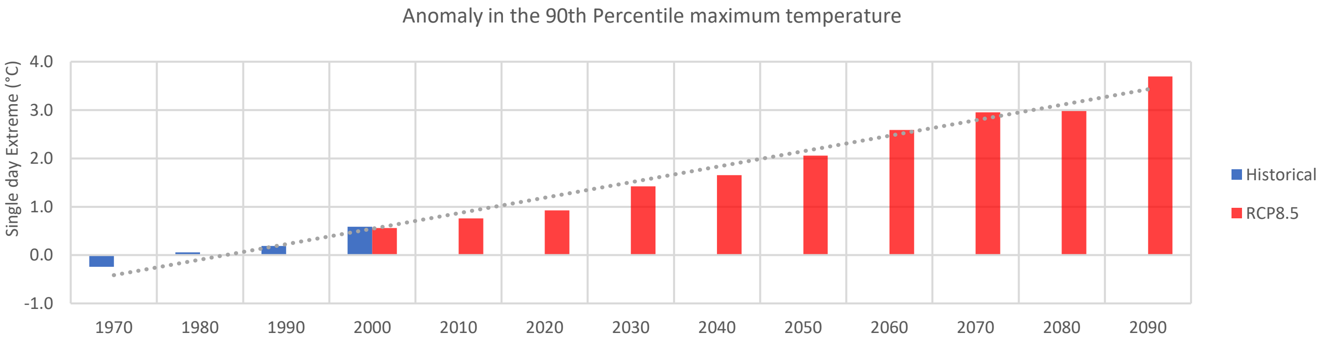


Figure 15. Daily extreme maximum (90th percentile) temperature anomalies for historical (1970–2005) and predicted RCP8.5 scenario (2005–2100) values in Antigua and Barbuda[226].

Spatially, the temperatures of the hottest month in Antigua and Barbuda tend to follow the topological profile with decreased average temperature in the areas of higher relief (Figure 16). Barbuda has a similar observed average temperature, with a range between 30°C and 31°C. Antigua is more varied with ~28°C in the higher altitude areas and ~31°C in the lower-lying western areas. The projected changes show near uniform spatial characteristics and anomaly ranges for Antigua as well as Barbuda. RCP4.5 anomalies are ~1.5°C (2050) and 1.7°C (2070), and RCP8.5 anomalies are 1.9°C (2050) and 2.6–2.9°C (2070).

[226] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012.

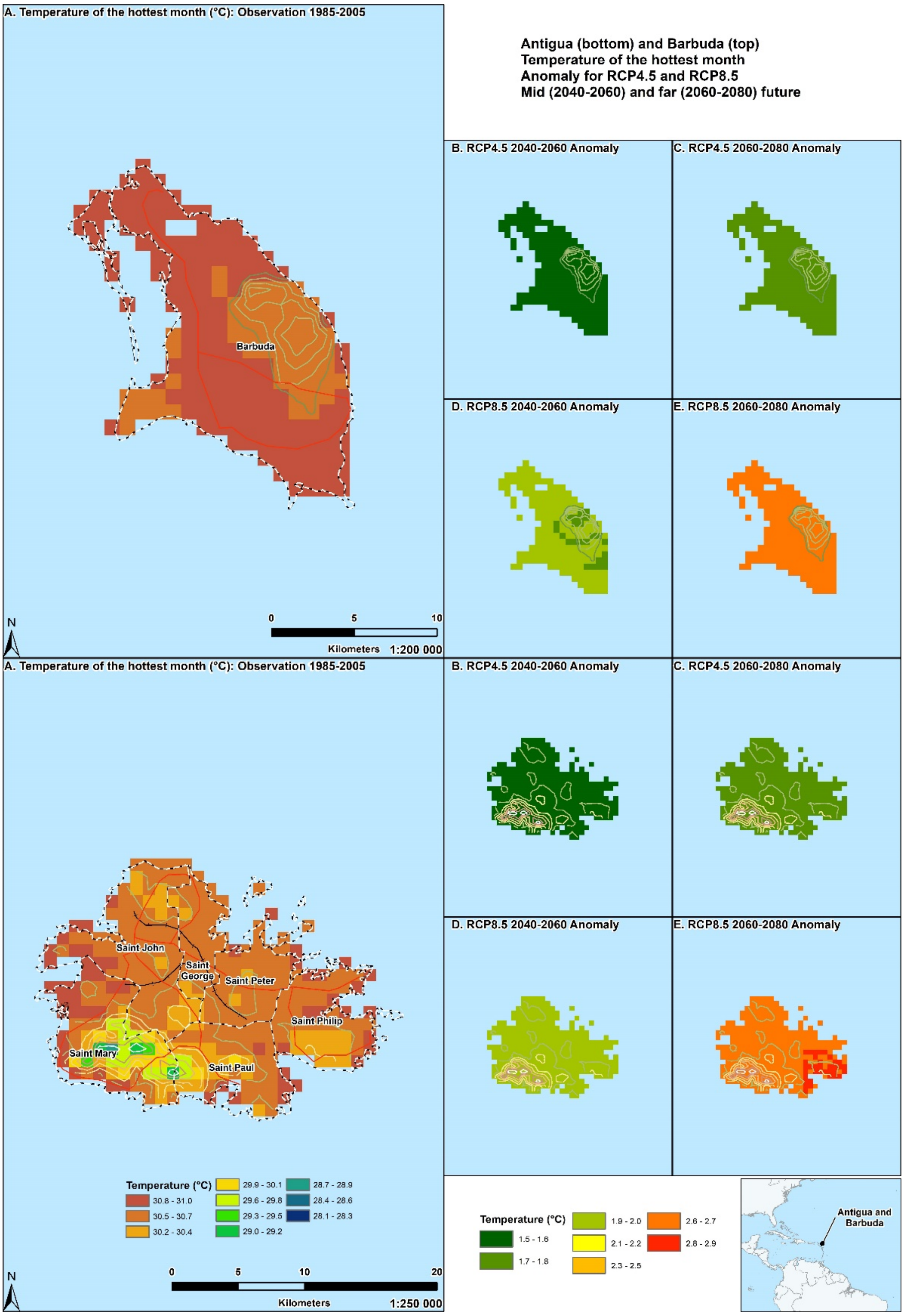


Figure 16. Observed temperature of the hottest month and projected anomalies for Antigua (bottom) and Barbuda (top) under RCP4.5 (B,C) and RCP8.5 (D,E).

3.2. Rainfall

Precipitation in Antigua and Barbuda ranges from 580–1,660 mm (Antigua) and 620–2,100 mm (Barbuda). The large year-on-year variability is influenced by *inter alia* the interception of hurricanes, with standard deviation ranges peaking at 300 mm per year in the mid-1990s. During this period, two reduced precipitation years (< 1,000 mm annually) occurred among years that experienced greater than 1,400 mm rainfall events. However, long-term decadal trends from 1981 to 2018 depict a decrease in annual precipitation (Figure 17, top).

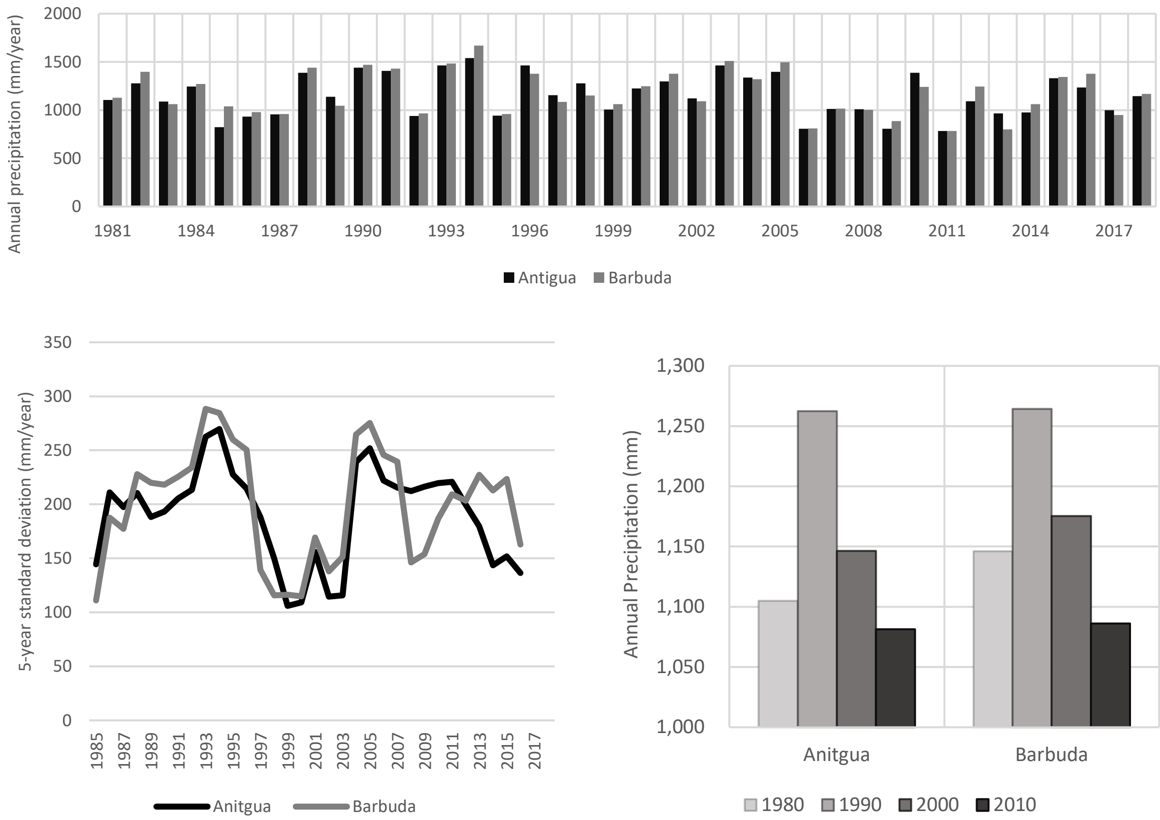


Figure 17. Long-term annual precipitation (top), standard deviation (bottom left), annual precipitation averaged per decade (bottom right).

The trend reflected in the annual precipitation decreases is noted through the analysis of the Standardized Precipitation Evapotranspiration Index (SPEI) reflecting a greater number of months each year with a SPEI value between -1 and -1.49 (moderately dry), -1.5 and 1.99 (severely dry), and less than -2 (extremely dry) (Figure 18).

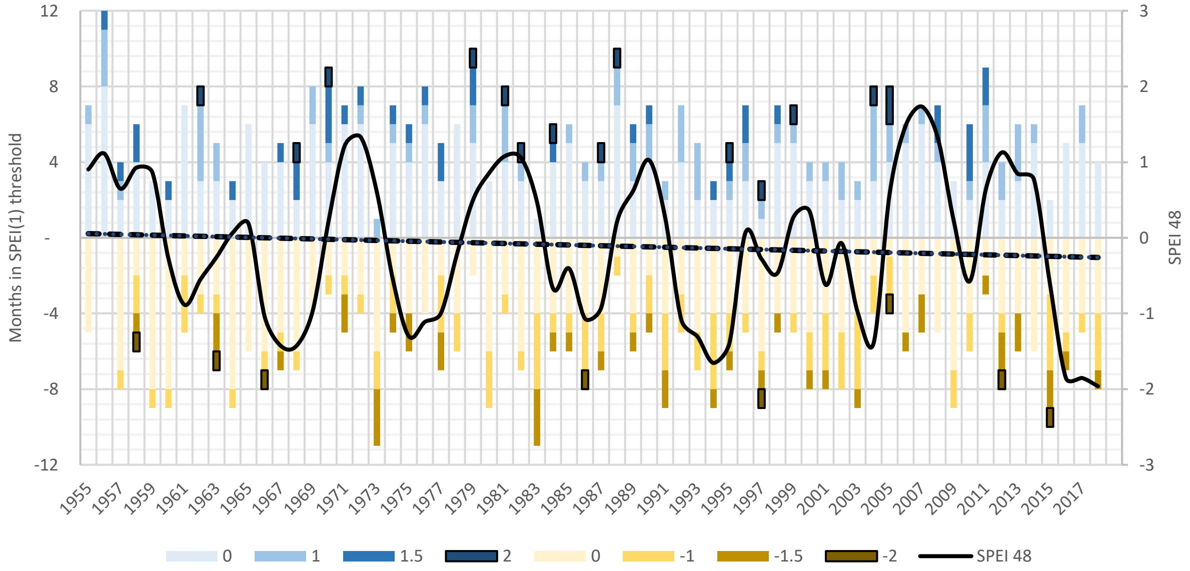


Figure 18. Standardized Precipitation Evapotranspiration Index (SPEI). 2.0+ is extremely wet, 1.5 to 1.99 is very wet, 1.0 to 1.49 is moderately wet, -0.99 to 0.99 is near normal, -1.0 to -1.49 is moderately dry, -1.5 to -1.99 is severely dry and -2 or less is extremely dry.

There is a wide disparity between the climate models both within the historical and project time frames (Figure 19). The largest model simulates 171% annual precipitation of the model means, while the lowest simulates 65%. This disparity is not unusual in climate model outputs, as each model simulates with varying parameterisations and convection schemes. Avoiding the biasing outputs based on these outliers, projected precipitation assesses the models representing 25th, 50th and 75th percentile anomalies.

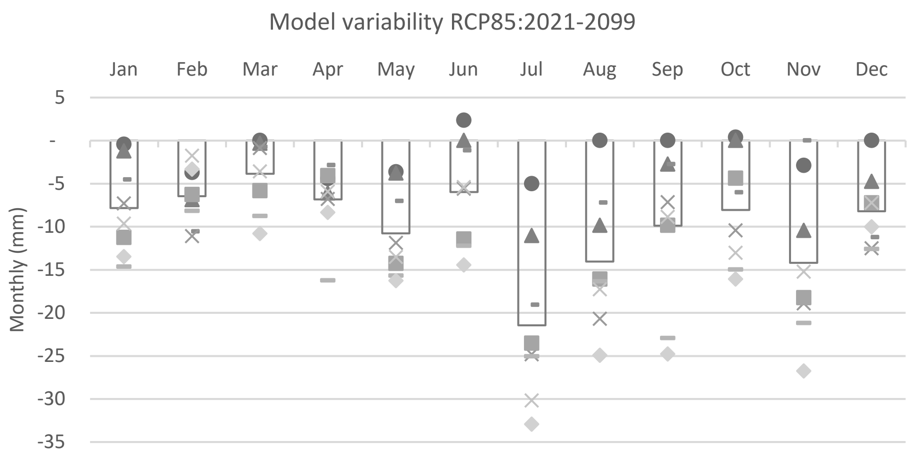


Figure 19. 2021–2099 RCP8.5 Cordex models anomaly from historical period 1985–2005.

This decreasing precipitation trend is anticipated to continue, with 2021–2099 annual volumes accounting for ~-26% from historical volumes (Figure 20). This decrease is at a rate of ~23mm per decade with 21.5mm at the 95% confidence interval. The majority of this decrease occurs in the months from July to November with the peak decrease occurring in July near the onset of the rainy season (Figure 21). These decreases are projected to be intensified over the course of the century. The high variability in monthly and annual volumes will remain within the wide monthly precipitation envelopes.

Figure 20. Change in annual precipitation from observed (1985–2005) and projected RCP8.5 scenario (2005–2099) for Antigua and Barbuda

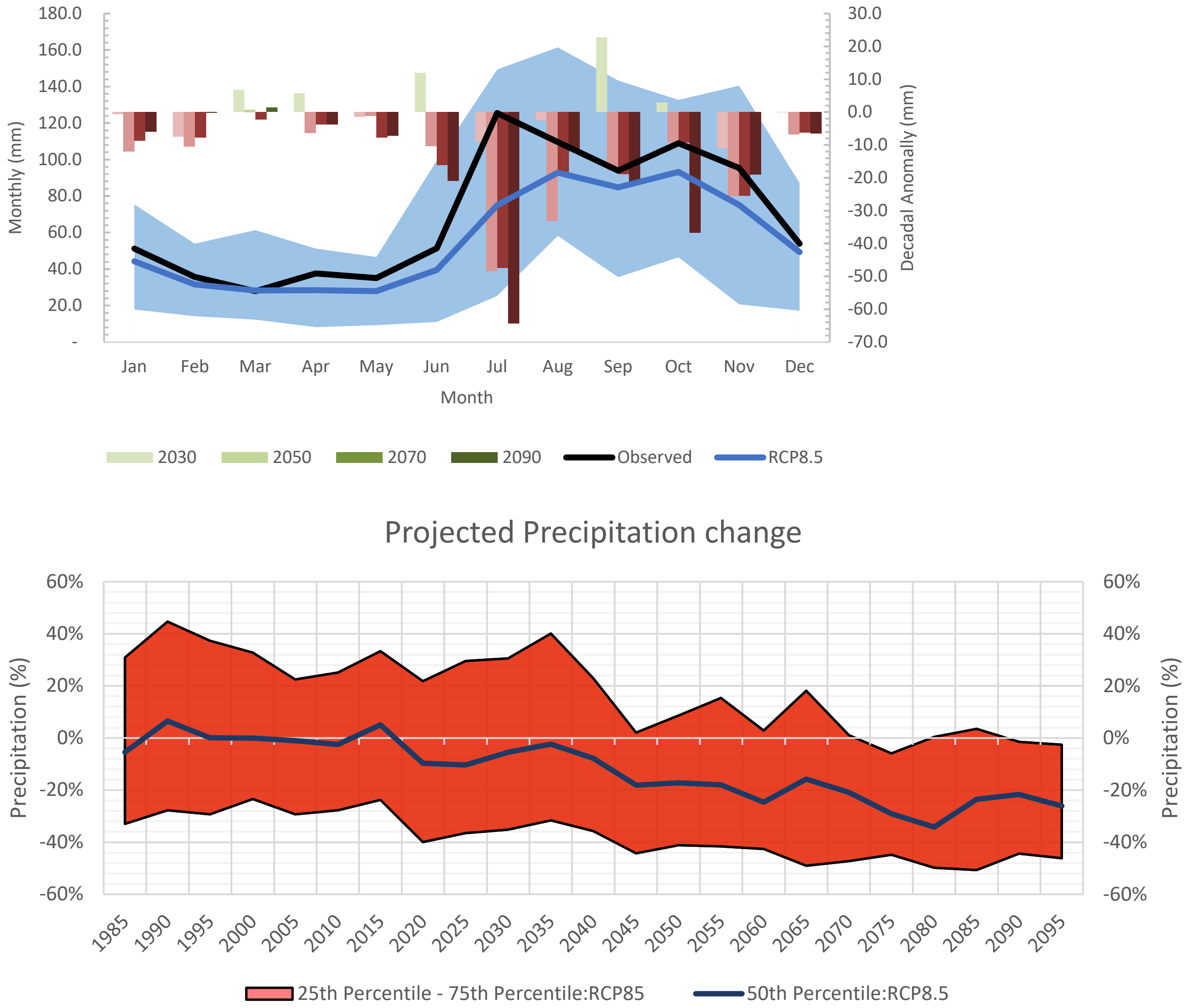


Figure 21. Observed (1985–2005) and projected RCP8.5 scenario (2005–2099) average monthly precipitation (mm), as well as the decadal precipitation anomaly (mm) between observed and future predicted values under RCP8.5 for Antigua and Barbuda[227].

Precipitation spatial variably on Antigua focuses precipitation maximum to the southwest over the higher relief areas and decreases to the northwest. Both RCP4.5 and RCP8.5 anomalies show the majority of decreased precipitation occurs in the areas of the main precipitation in the high topography areas of Antigua. Projections show reductions of ~10–20 mm (RCP4.5–2050), ~30mm–40 mm (RCP4.5–2070), ~70–90 mm (RCP8.5–2050), and ~90–130 mm (RCP8.5–2070) per year (Figure 22). Barbuda, with limited topographical influence sees a near spatially uniform reduction in each scenario. Reductions of ~10 mm (RCP4.5 — 2050), ~40 mm (RCP4.5 — 2070), ~75 mm (RCP8.5 — 2050) and ~80 mm (RCP8.5 — 2070) per year are noted.

[227] Christensen OB, Gutowski B & Nikulin G. 2012. CORDEX Archive Design, version 20/7/2012.

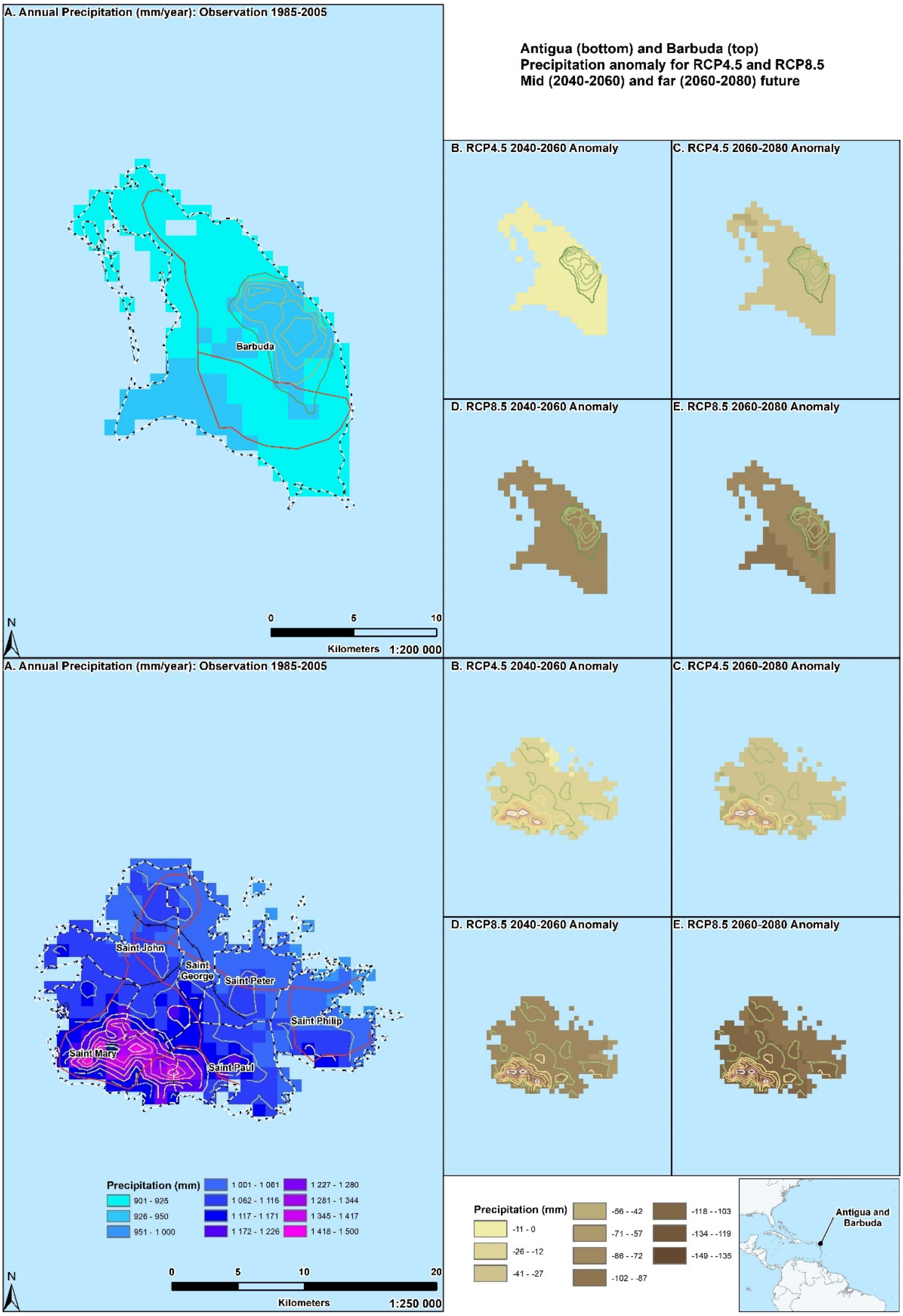


Figure 22. Observed precipitation and projected precipitation anomalies. Antigua (bottom), Barbuda (top).

When looking at the Caribbean as a whole, different areas are predicted to experience either wetter or drier conditions over the coming decades. The Lesser Antilles — including Antigua and Barbuda — are expected to receive less rainfall compared to other parts of the Caribbean. If global temperatures reach the 1.5°C threshold, Antigua and Barbuda could receive 5% less annual rainfall than it currently does[228]. If temperatures exceed this threshold and rise by 2.0–2.5°C, annual rainfall for the country is predicted to experience a considerable drop of ~10% compared to current values[229].

3.3. Hurricanes

As highly dynamic systems with development influenced by various atmospheric and oceanic factors, there is some uncertainty regarding changes in hurricane frequency and intensity. Factors influencing hurricane formation include *inter alia* sea surface temperature, vertical wind shear, ENSO state and moisture availability. Projecting the relative contribution of these factors and their forcings — both natural and anthropogenic — into the future is challenging. However emerging analyses indicate that there will likely be a higher frequency of more intense hurricane events (Category 4 and 5), but this is contrasted by an overall decrease in the total number of these events occurring each season.

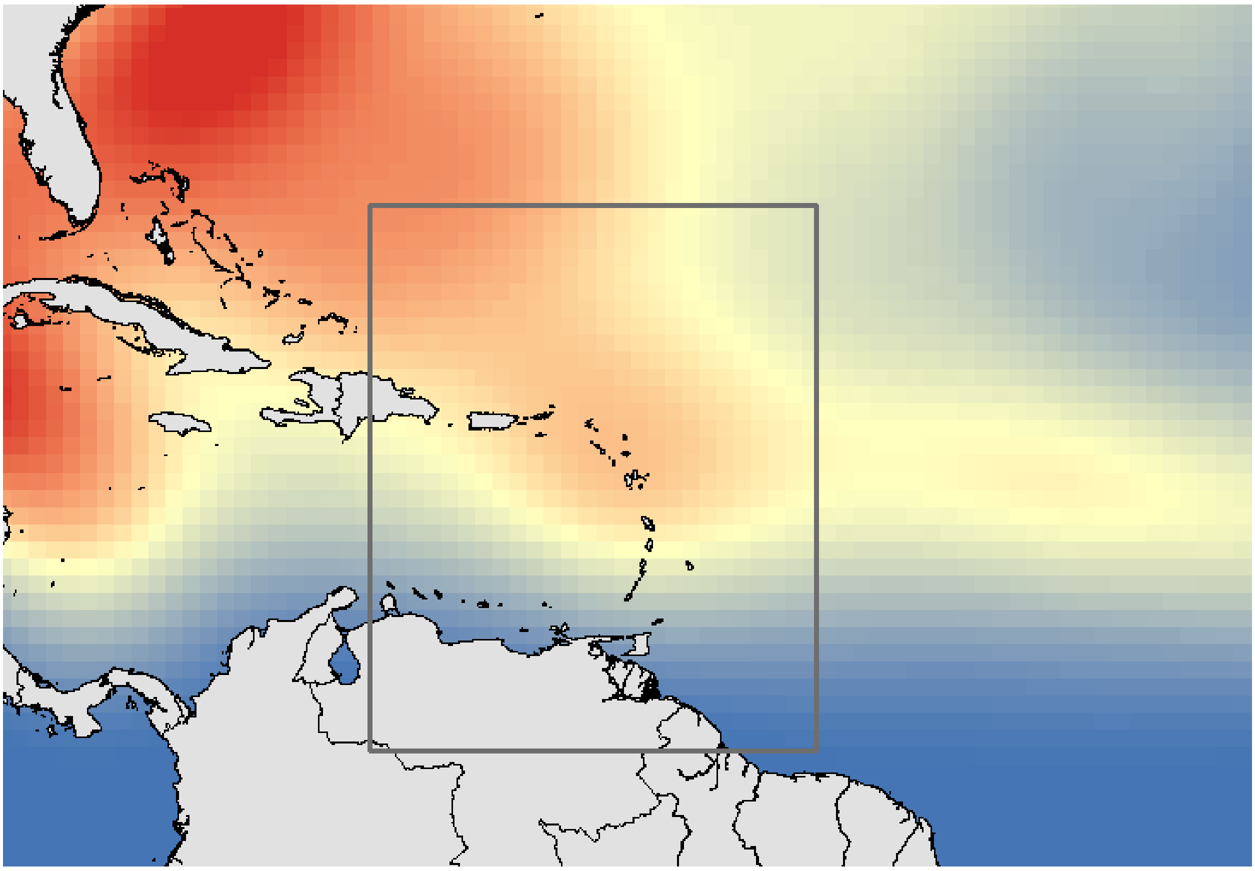


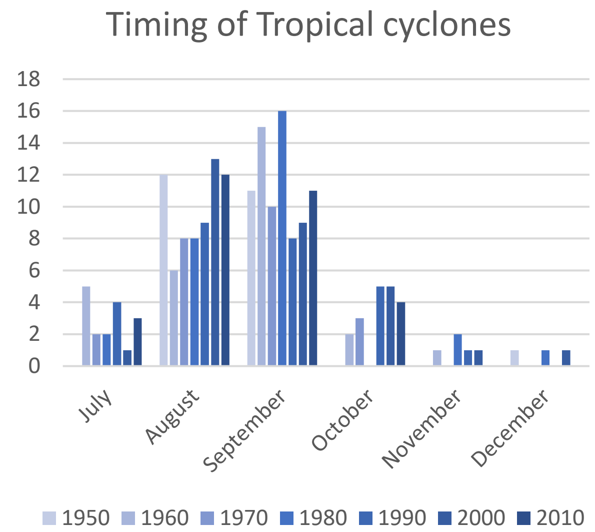
Figure 23. Assessment domain for historical hurricane events with increasing hurricane path density (blue to red).

The majority of hurricanes that affect the Caribbean region travel though the assessment domain (Figure 23). Given the large zonal shifts possible in the hurricane track — as was observed during the passage of Hurricane Irma — assessment of the characteristics of the domain is more prudent than focusing on events that have directly impacted Antigua and Barbuda.

[228] Taylor MA et al. 2018. Future Caribbean Climates in a world of rising temperatures: the 1.5 vs 2.0 dilemma. Journal of Climate. 31: 2907–2926.
[229] Taylor MA et al. 2018. Future Caribbean Climates in a world of rising temperatures: the 1.5 vs 2.0 dilemma. Journal of Climate. 31: 2907–2926.

Hurricanes entering this domain do so mostly in August and September, with a few both early and late season events either side of these focus months (Figure 24, left). The number of these events per year varies between the past decades, with no clearly defined trend. However, recent decades show a decrease in the number of events in August, though this may be a result of anomalously high event occurrence in the 1950s and 1990s. The September events appear to be increasing in frequency, though again this is likely a result of a low event count in the 1970s. Months outside of these two focus months do not show any clear trends over time.

While there are no discernible trends in the overall number of hurricane events, there is a notable increase in the number of more intense (Category 4 and 5) hurricanes in more recent decades (Figure 24, right). On average, there have been an increased number of Category 4 events occurring in the domain from the 1990s and 2000s, while the number of Category 5 events is highest in the 2010s. A decrease in number of lower-intensity events such as Category 1 has been observed between the 2000s and 2010s, while Category 2 sees fewer events in the 2010's.



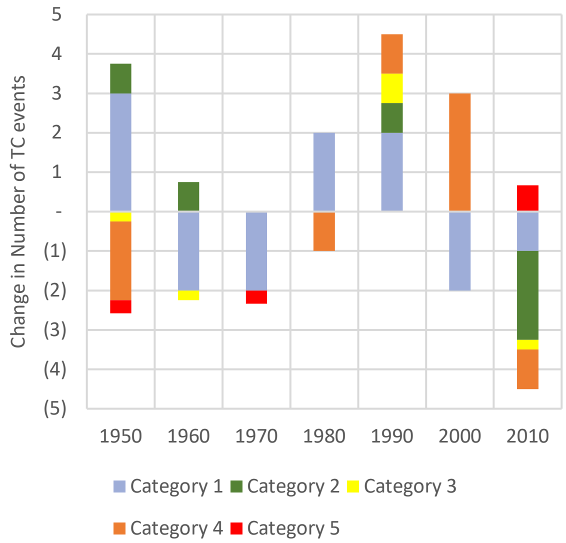


Figure 24. Monthly timing of hurricane events per decade (left), change in the occurrence of different category events per decade (right).

The average maximum sustained wind speeds of hurricane events do, however, show an increasing trend over time — particularly in September and October. The number of events may not be increasing, but the number of more intense events (Category 4 and 5) has increased in recent decades (Figure 25, left) — leading to the increase in the average maximum sustained wind speeds. The average maximum sustained wind speed per category does show variation between the decades. For the lower categories (1–3) the average maximum wind speeds have slightly decreased in more recent decades. Categories 4 and 5 show an increase in the maximum sustained wind speeds over time. For Category 4 events, wind speeds have increased to 135 km/h from the 1980s to 2010s. Category 5 events, though few in number, have seen an increase in average maximum sustained wind speeds from 140 km/h to 155 km/h in more recent decades (Figure 25, right).

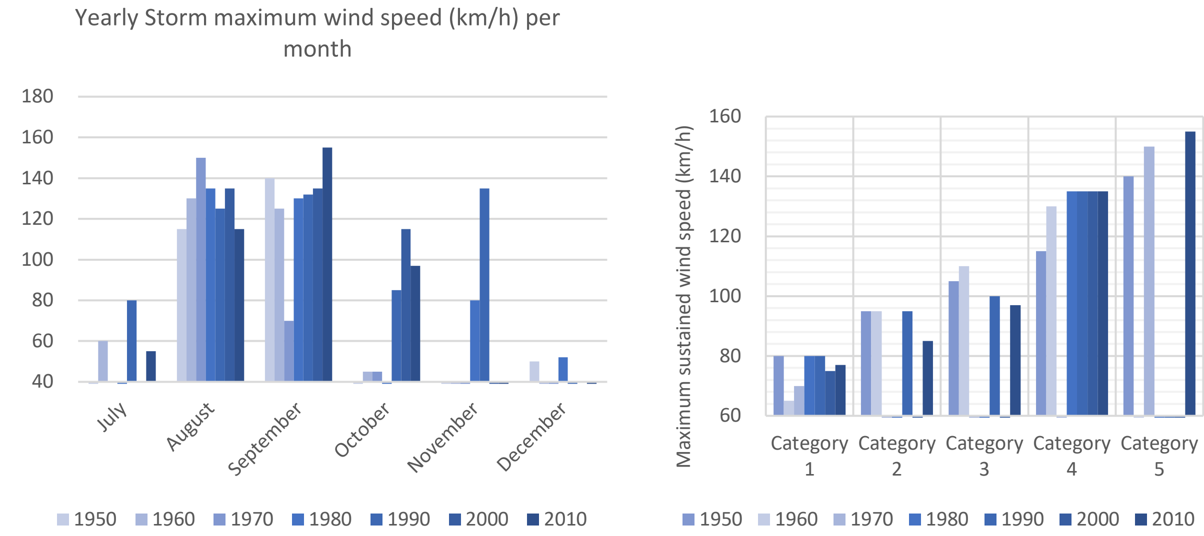


Figure 25. Maximum wind speed of hurricane events per decade (left), maximum sustained wind speed per category type (right).

The IPCC in the most recent AR5 report supports these key findings. Figure 26 highlights the projected changes:

- All hurricane activity being highly variable into the future with a likely (67% confidence) ~50% to -50% range either side of current occurrence. There is however an expected decrease change overall in the number of events;
- There is a likely frequency range of more intense Category 4 and 5 hurricanes being +200% to -100%. The wide disparity in these projected events is due to the infrequency of these events in the observed record. The likely expected change is an increase of 50% of these larger events.
- There will be a slight increase in the maximum intensity achieved in a hurricane event. The wind profiles of hurricanes are already extreme in nature, changes in atmospheric and oceanic conditions under projected climate changes will affect the development of hurricane events more so than the already extreme wind character.
- There is projected to be an increase in the precipitation rate associated with these hurricane events.

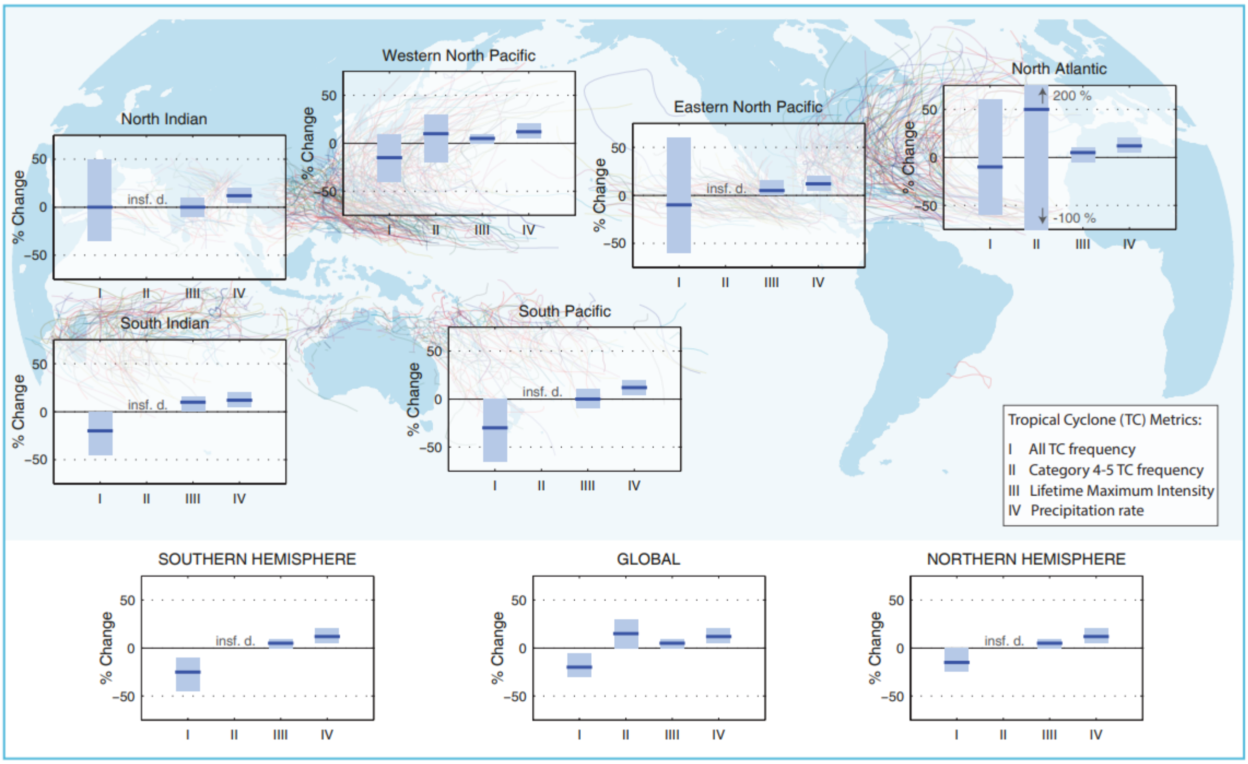


Figure 26. IPCC changes in hurricane characteristics[230].

The CSSR[231] findings support these conclusions:

- Anthropogenic activity has contributed to the upward trend of North Atlantic hurricane activity in the observed record (medium confidence).
- Model output suggests an increase in hurricane intensity and number of very intense events under future RCP scenarios. For the Atlantic region, this is projected to result in an increase in precipitation intensity (medium confidence).

This study is intended to assess changes in factors corelated to Atlantic hurricane development, to infer potential changes more relevant to Antigua and Barbuda. These factors are assessed relative to Hurricane Irma (2017) to provide additional context.

<u>Factors influencing hurricane development</u>

Uncertainly will remain in the assessment of hurricane development as a result of many inter-related influencing factors. Models do, however, suggest that there is a correlation between certain factors and hurricane formation. Hurricane frequency and intensity is strongly correlated to anomalous sea surface temperature (SST) in the main development region, the weakening of vertical wind shear (VWS) in the mid troposphere during depression development and the La Niña phase of El-Niño Southern Oscillation (ENSO). Each of these factors may be altered under future climate change conditions which may influence the hurricane characteristics. ENSO and wind-shear characteristics are highly dynamic and will be variable on synoptic and annual time scales around currently experienced conditions. SST changes, however, will

[230] Christensen, J.H., Kumar, K. Krishna, et al., "Climate Phenomena and Their Relevance for Future Regional Climate Change," in *Climate Change 2013 - The Physical Science Basis*, ed. Intergovernmental Panel on Climate Change (Cambridge: Cambridge University Press, 2013), 1217–1308, https://doi.org/10.1017/CBO9781107415324.028.

[231] USGCRP, 2017: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA.

be more linear in nature and while exhibiting a seasonal cycle, the baseline trend will likely not revert to oscillations about current SST means. These influencing factors are discussed in more detail below.

Assessment domain

The domains for assessment are the locations most aligned to observed hurricane activity. Two factors are assessed. Firstly, the vertical wind shear (VWS) in three 4°x 4° locations in the main development region (MDR) from 10°N to 20°N between West Africa and the Caribbean. Secondly, the sea surface temperature (SST) over the oceans in the lead up pathway (18°N, 60°W and 13°N, 48°W) for most hurricanes affecting Antigua and Barbuda.

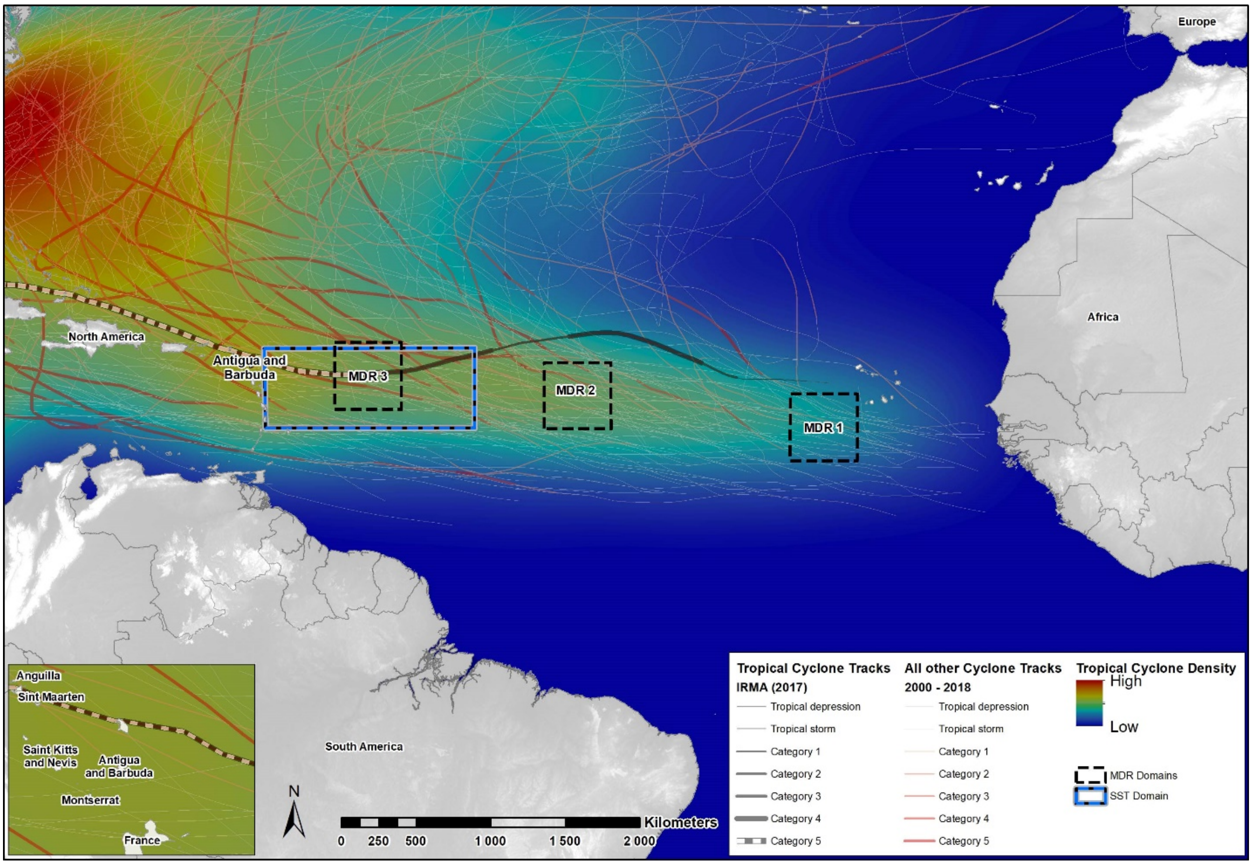


Figure 27. VWS and SST domains in the major hurricane region.

3.3.1. Vertical wind shear

Vertical wind shear (VWS) is the vector difference in wind speed and direction between air masses vertically through the troposphere. This is important because VWS is a key indicator in the development of hurricanes. The effects of VWS on storm development result from the deformation of a rotating system in the presence of higher VWS. Increased VWS results in the eyewall of a storm to become asymmetric[232]. This asymmetry may lead to tilting of the storm causing a weakening from the top down. In the upper troposphere, VWS may overcome vorticity and result in air being dispersed rather than concentrated and descending into the eye. Higher VWS, therefore, compromises hurricane sustained vorticity and will either lead to a weakening or dissipation of the system.

[232] Frank, W.M. and Ritchie, E.A., 2001. Effects of vertical wind shear on the intensity and structure of numerically simulated hurricanes. *Monthly weather review*, *129*(9).

Atmospheric favourability of the development for hurricanes would therefore see a reduction of the VWS in the development areas. Assessing the changes in VWS in the major development regions will give an indication as to the change in potential of atmospheric favourability for hurricane development. Assessment is undertaken in three regions along the higher density development track (Figure 27). Tropospheric levels considered were the vector difference between 850–700 kPa, 700–500 kPa and 500–250 kPa. These pressure levels equate to approximately 1 500m (850 kPa), 3 000m (700 kPa), 5 500m (500 kPa) and 10 000m (250 kPa). It should be noted that Hurricane Irma (2017) increased in intensity from Category 4 to 5 in VWS domain 3. Hurricanes that affect Antigua and Barbuda occur between July and October and then move from east to west through VWS domain 1 to VWS domain 3. The assessment considers VWS in the three development regions for these four months.

Anomalies are summarised into three decadal averages for RCP4.5 and RCP8.5. Full decadal and pressure level (lower, mid and upper troposphere) results are presented in Appendix 1. Atmospheric winds are more largely forced by daily synoptic variability than can be effectively attributed to changes in large-scale climate shifts, resulting in VWS anomaly heterogeneity. An underlying signal is however present in the data presenting a tendency for decreased VWS in future for each of the monthly domains, though there is sizeable noise in the outputs.

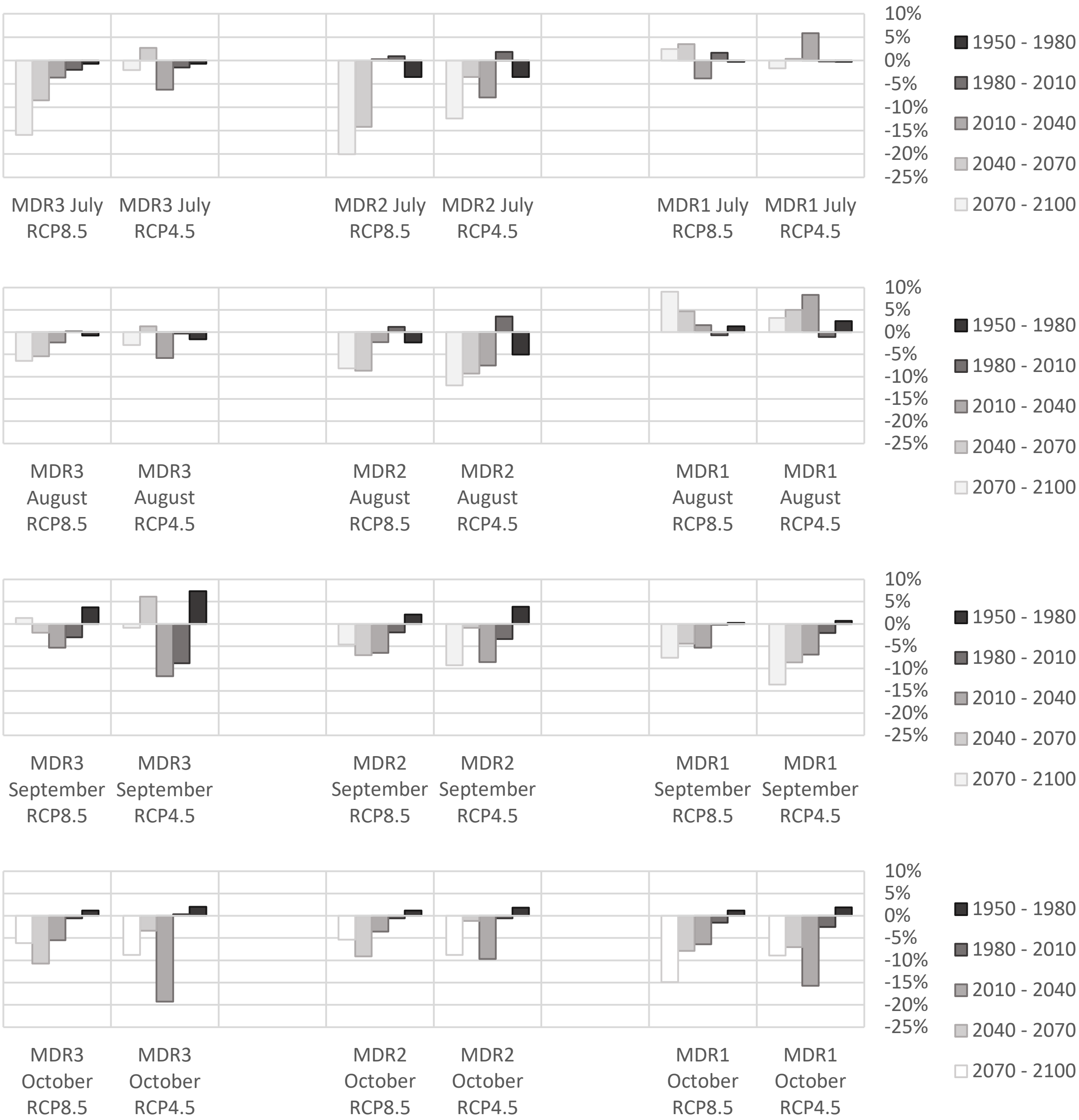


Figure 28. Change in VWS from July (top) to October (bottom) for MDR1-3 and under RCP4.5 and RCP8.5 scenarios.

Future projected changes of VWS are expressed as percent increase or deduction from the average vector of the full tropospheric column in the observed time frame of 1950–2005 for each month (Figure 28).

MDR1, the east most domain, sees potential increases in VWS — and potential weakening of hurricanes — in July and August. This situation is reversed in September and October with 10%–15% average reduction in VWS in the latter part of the century.

Assessing the decadal and multi-level changes shows additional detail in the nature of the change into the future. The months July and August show decreased VWS in the upper troposphere but an increase in the lower and mid troposphere. These anomalies are projected to increase in magnitude further into the century. Disruption in the lower- and mid-atmosphere may result in decreased hurricane formation during this time. However, the decrease in VWS in the upper troposphere may also compensate to overcome this disruption, but this is not clear. The months of September and October present a shift in the lower troposphere VWS anomaly to now be decreased from baseline climatology, the mid-troposphere varies between increases and decrease but is of lower magnitude than the anomaly noted in July and August. Both RCP4.5 and RCP8.5 show similar shape in the VWS anomalies, however, the magnitude of the anomaly is generally larger under the RCP8.5 scenario. For example, July 2090 VWS varies between -2 m/s and +2 m/s (RCP4.5) and -5 m/s and +5 m/s (RCP8.5).

This assessment does not suggest that there will not be cumulating circumstances that may lead to the development of tropical storms or hurricanes in MDR1. Instead, it identifies that it is likely that there will be more days in MDR1 where conditions will be unfavourable for tropical storm and hurricane development than days where conditions will be favourable for this development. This is particularly the case early in the hurricane season — in July and August; September and October.

MDR2, the central VWS domain shows general agreement in the direction of VWS change going forward in each month. Each of the 30-year periods going forward from 2010–2100 show a trend of decreasing VWS of 5–10%. VWS in MDR2, therefore, does seem likely to enhance or at least not disrupt the development of any tropical storm or hurricane in the area.

The decadal multi-level assessment shows the largest anomalies in the upper troposphere, which depict a reduced VWS overall, with very few exceptions. The upper troposphere reduction will constitute the larger part of the average VWS decreases. Mid-troposphere VWS anomalies are comparable to upper levels in the magnitude of July and August; these are reduced in September and October. VWS magnitude anomalies are reduced in the lower troposphere. RCP4.5 and RCP8.5 again show a bias in magnitude toward RCP8.5 toward to mid- to end-century (2050–2100).

The general reduction in VWS in MDR2 through the troposphere on all months, with a few exceptions, would certainly not reduce hurricane activity or intensity and may in fact lead to an atmosphere that is conducive to further enhancement of already-developed tropical storms and hurricanes moving westwards from MDR1. However, factors such as SST and ENSO would need to be accounted for.

MDR3, the western-most domain — the one closest to Antigua and Barbuda — projects large discrepancies in VWS anomalies between RCP4.5 and RCP8.5 as well as between each month. Average VWS changes do not depict notable trends for MDR3 going forward into the century, this is additionally the case under the RCP4.5 scenario with the largest VWS decreases present in 2010–2040 in all months, but with direction of change varying beyond that time frame. RCP8.5 exhibits a clearer trend with decreases growing in magnitude later in the century, in all months but September.

The RCP8.5 multi-level assessment is consistent with decreased VWS present going forward from the lower to upper troposphere, with September being the only notable exception showing more variability. RCP4.5 shows several decades with an increased VWS, particularly in the upper troposphere from July–September. The lower tropospheric character tends to mirror the direction of the upper troposphere but with reduced magnitude. The mid troposphere is showing a tendency for decreased VWS over most months into the future. The month of October is more variable through the whole atmospheric column with no clear trend for VWS.

MDR3 does not have the same clear trends noted in MDR2 and is subject to large variation between months, between decades into the future and between the RCP scenarios. No assessment for the change of atmospheric suitability, hurricane development or enhancement over time can be given for this dataset.

3.3.2. <u>Sea Surface Temperature</u>

Hurricanes use warmer ocean waters as an easily extracted moisture source for continued development while moving over the ocean. When hurricanes move over land or ocean with lower surface temperature, they start to weaken and lose intensity, which can result in their dissipation as they are overwhelmed by the larger synoptic dynamics. However, the complete atmospheric connection between SST and hurricane development and propagation are not fully understood. However, the IPCC AR5 and several other studies note that increases in SST have resulted in increased hurricane activity[233].

Using this premise, the projected future SSTs are assessed to show the potential anomalous state under which hurricanes may develop and move later in the century. Assuming stationarity in hurricane forcing, an increased SST would be indicative of increased hurricane activity.

Using 1985–2005 as the baseline temperature, the CMIP5 models show an increase under both the RCP4.5 and RCP8.5 scenarios in the SST domain. There is large variability expressed in the different models but the mean value reaches ~+2°C under RCP4.5 (Figure 29, left) and ~+5°C under RCP8.5 (Figure 29, right). It should be noted however that oceans have, and will continue to, absorb the majority of the global temperature increases that would otherwise be resident in the atmosphere currently and into the future. These increases are captured and cycled through the ocean systems only to be expressed with a longer lag time than is noted in the atmosphere. The increases will therefore likely be manifest beyond 2100 regardless of global mitigation actions. Monthly changes in SST are presented in Appendix 2. The monthly signal is similar between each of these months, with a median increase being just above 2°C for RCP4.5 and 4-5°C for RCP8.5. These changes in SST contribute to creating favourable conditions for the development of high-intensity (Category 4 and 5 hurricanes).

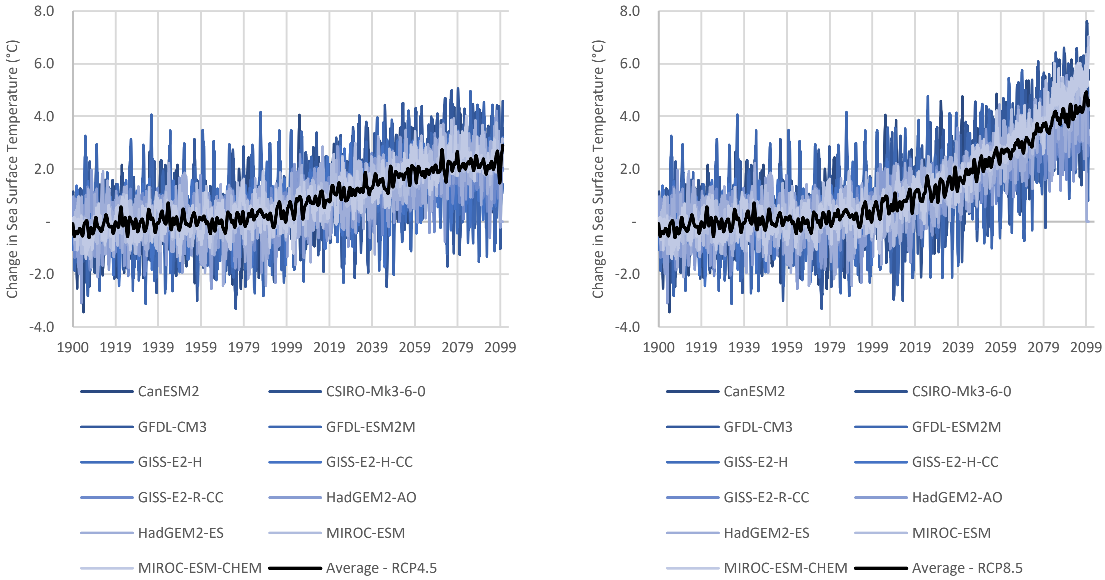


Figure 29. Sea Surface Temperature (SST) changes in the domain leading up to Antigua and Barbuda under RCP4.5 (left) and RCP8.5 (right).

3.3.3. Context of the assessment

The precise factors and the degree to which they influence hurricane intensity remain unclear, however, using hurricane Irma (2017) as an example illustrates an environment that is more favourable to hurricane

[233] Christensen, J.H., et al., 2013: Climate Phenomena and their Relevance for Future Regional Climate Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

development and intensification. Irma started as a tropical wave on 27 August but became a tropical depression after creating a well-defined circulation. It strengthened rapidly from a tropical depression to a hurricane in 30 hours because of favourable conditions of low vertical wind shear and having access to a moist lower troposphere, but also as a result of being over an ocean with a marginally warmer sea surface temperature. Irma's intensification stagnated between Category 2 and 3 as a result of intrusion of drier air masses in the eye, as well as from drifting further north, away from the warmer ocean surface. A strong high-pressure system forced Irma 2.5° south by 4 September 2017, back over the warmer sea surface. Irma reach its maximum intensity of 155 kt (Category 5) in the evening of 5 September located about 70 nautical miles southeast of Barbuda, before making landfall 11 hours later. Over the duration of Irma's propagation, intensification occurred under conditions of enhanced organisation of the eye wall resulting from a decrease in vertical wind shear and being forced over warmer ocean surfaces. Decreases in moisture availability or moving over land, disruption of the eye wall and cooler ocean surfaces resulted in weakening of the system.

Accurately predicting future hurricane activity, both global and regional, will depend critically on reliable projections of the behaviour of these modes of variability (including ENSO) under climate change, as well as an adequate understanding of their physical links with hurricanes. At present there is still uncertainty in their projected behaviours, though there is additional research being undertaken to evaluate the physical influences of a changed climate on hurricane development and intensification[234].

The analysis conducted for the proposed project utilises the Saffir-Simpson Hurricane Wind Scale (SSHWS) as the currently accepted, applied and projected academic and operational meteorology measure. There are, however, potential limitations with the SSHWS as a robust and granular measure of a tropical cyclone's potential impact, both in observed records and for projecting future tropical cyclone activity. This deficiency is based on the wide variety of noted on-the-ground impacts within a given hurricane category, as a result of being classified primarily by maximum sustained windspeed. Other factors that may contribute to the impact potential of a tropical cyclone would be the radius of high velocity winds from the centre of the hurricane, duration of high velocity wind, translation of energy between ocean and atmosphere, sea surface temperature (SST) and sea-level. Alternative methodologies that seek to address deficiencies in the SSHWS as a granular measure of a hurricane's potential impact are investigated below.

The Hurricane Severity Index (HSI) seeks to provide a greater degree of resolution to the destructive potential of a TC though a 50-point scale incorporating both storm size and intensity.		
Methodology	The assessment of the maximum sustained windspeed is scored on a 1–25 scale using the logic of a doubling of the wind speed, which equates to a four times greater wind force. The assessment of the radii of different windspeed thresholds, namely the distance from the centre, where winds of 35, 50, 65 and 87 kt are measured. Higher scores are given to larger radii. This assumes the larger the tropical cyclone, the greater the potential damage and economic cost that occurs as a result.	
	Observational	**Projected**
Pros	This provides greater granularity to potential impacts based on more observational parameters.	This would give greater resolution in the potential impacts beyond the current Category 1–5 and would allow for further disaster management interventions.

[234] Emanuel, K., 2017. Assessing the present and future probability of Hurricane Harvey's rainfall. *Proceedings of the National Academy of Sciences*, *114*(48), pp.12681-12684.

Cons	This is currently proprietary and has poor uptake in academic and operational analysis.	Atmospheric models have realistically simulated tracks and counts of tropical cyclones, however, the models still fail to properly simulate many of the tropical cyclone physical dynamics, including the radii of different windspeed thresholds.

Cyclone Damage Potential (CDP) index evolved from the Willis Hurricane Index with CDP being developed for more general societal applications		
Methodology	Damage is driven by maximum surface wind speed, the radii of hurricane force winds and the translation speed. The damage depends on the duration of these destructive winds and not just their value in terms of hurricane intensity.	
	Observational	**Projected**
Pros	This allows for improved understanding of climate variability and change impacts and real-time impact assessment before, and immediately following, a hurricane strike.	This would be useful for assessing the projected impacts on economic sectors.
Cons	There is a large data commitment for tropical cyclone dynamics and this may require further data observation.	The large data requirements rely on accurate assessment of tropical cyclone dynamics. Resolving these dynamics is still problematic in current high-resolution climate models.

Accumulated Cyclone Energy (ACE) and Storm Integrated Kinetic Energy (IKE) focus on ocean implications for damages		
Methodology	This assesses potential energy dissipation implications of storm surge and sea-level rise and the implications for coastal populations.	
	Observational	**Projected**
Pros	This will help scientists detect trends in storm size, which may be related to warming sea and air temperatures.	This would directly incorporate SLR and SST changes over time to provide more practical implications for coastal development planning.
Cons	It incorporates ocean and atmospheric dynamics and is more complex to calculate.	It relies on both ocean and atmospheric dynamics to be simulated accurately and is more complex to calculate.

Hurricane Hazard Index (HHI) focuses more on implications for population, density and value of structures for utilisation in hurricane relief operations		
Methodology	This uses hurricane radius, translation speed and maximum vorticity speed.	
	Observational	**Projected**
Pros	This would provide greater damage resolution and relies on simple data inputs for the index.	The simplicity of the data inputs for this index mean that it would be easier to assess the

		projected potential tropical cyclone characteristics.
Cons	This methodology is simpler than other indices and may not be able to provide as much resolution in damage classifications.	Currently, the propagation of simulated tropical cyclones has zonal bias, which will alter the propagation speed and thereby incorporate increased uncertainty into the projected characteristics.

Seeking to follow the other methodologies would provide further granularity and more practical potential outputs for tropical cyclone activity. However, given the unknowns over the physical dynamics and estimates that would need to go into the wind radii, propagations, and ocean interactions, undertaking the analysis using these various inputs would serve to increase uncertainties. Given this output deficiency — and that these methodologies are yet to gain significant traction with academic and applied meteorology to rival the use of the Saffir-Simpson Hurricane Wind Scale (SSHWS) —it does not seem feasible undertake these analyses using these different methodologies.

In the future, the enhanced simulation of tropical cyclones may make these methodologies more appropriate but given the acknowledged low confidence in modelling tropical cyclone dynamics under future climate conditions by the IPCC, the utilisation of the standard SSHWS method is more viable.

3.4. Climate impacts

Climate change is expected to result in increases in sea surface temperature and decreases in vertical wind shear. Changes in the La Niña phase of El-Niño Southern Oscillation (ENSO) however remain uncertain[235]. As a result of these changes, increases in the frequency of high-intensity storms (Category 4 and 5 hurricanes) will likely be observed. Given that most buildings in Antigua and Barbuda are not currently designed to withstand these storm events, an increase in frequency will lead to more severe impacts on critical infrastructure, basic services and the national economy under future climate change conditions. By quantifying damage to infrastructure, the economy and vulnerable communities, recent extreme climate events — including Hurricane Irma — can act as baselines for predicting future impacts. In addition to an increased likelihood of individual storms causing more damage, if these events become more frequent, SIDS such as Antigua and Barbuda will not have adequate time or resources to recover between hurricanes.

3.4.1. Impact of increased frequency of high-intensity storms on infrastructure

According to the current Organisation of Eastern Caribbean States (OECS) Building Code, critical public buildings are constructed to withstand maximum wind speeds of up to 270 km/h, which means that these buildings can withstand Category 1 to 3 hurricane events[236]. However, the extensive damage caused by Hurricane Irma in 2017 — with 95% of buildings on Barbuda damaged or destroyed[237] — demonstrated that most public and private buildings built under this code are not practically equipped to withstand a Category 5 hurricane[238]. Buildings in Antigua and Barbuda are impacted by hurricanes through a combination of high winds, flooding and landslides[239]. Strong hurricane winds cause damage to buildings primarily through roofing, window or door failures. During Hurricane Irma, extensive damage to buildings

[235] IPCC. 2018. Climate phenomena and their relevance for future regional climate change. Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter14_FINAL.pdf
[236] Organisation of Eastern Caribbean States. 2016. OECS Building Code: Seventh Edition.
[237] Government of Antigua and Barbuda. 2018. Hurricane Irma Needs Assessment. Available at: https://www.gfdrr.org/en/publication/hurricane-irma-and-maria-recovery-needs-assessment-antigua-and-barbuda
[238] Antigua and Barbuda public building climate adaptation upgrade programme. Feasibility study final report 2 July 2019.
[239] Antigua and Barbuda public building climate adaptation upgrade programme. Feasibility study final report 2 July 2019.

also resulted from flying or shifting debris, including large objects such as fallen trees or empty shipping containers[240]. In addition to strong winds, Irma resulted in storm surges that reached 600 m inland on Barbuda[241], subjecting buildings to short-term flooding which damaged their contents. Amongst the buildings adversely impacted by Hurricane Irma on Barbuda were critical service buildings, including hospitals, the fire station, the water desalination plant, power stations and the distribution grid[242]. The projected increase in the frequency of storm events of a similar magnitude to Irma as a result of climate change is expected to lead to higher occurrences of similar damages in the future.

Flooding from storm surges or heavy rainfall can impact not only buildings, but also critical transport infrastructure such as roads and ports. In 2017, flooding from Hurricanes Irma and Maria damaged 117 km of roadway in Antigua, 8 km of roads in Barbuda, the airport on Barbuda and major seaports on both islands[243]. As a result of this flooding, sand sedimentation in Barbuda's main cargo and ferry port restricted the size of vessels able to use the facility[244]. Climate change is expected to exacerbate the impact of flooding caused by Category 5 hurricanes, both by increasing the intensity of single rainfall events and by leading to greater storm surges, which will be capable of reaching further inland[245].

Within the Caribbean, Category 4 or 5 hurricanes result in greater cost from damages to buildings and infrastructure than Category 1, 2 or 3 hurricanes (on average US$394 million and US$747 million per decade compared to US$306 million, US$340 million and US$665 million, respectively)[246]. In addition, decades with more occurrences of Category 5 hurricanes tend to have more costly individual storms compared to decades with fewer high magnitude events. This could be a result of countries not having the time or resources to make the necessary repairs and upgrades to infrastructure between major storm events. Therefore, an increase in the frequency of high intensity hurricanes as a result of climate change is expected to increase the cost from damages to infrastructure in the future. Under the RCP8.5 scenario (mean SST increase of 4.3°C in the Caribbean), it is expected that the Caribbean will experience an increase in mean damages of 12% from hurricanes that do not make landfall[247] and 20% from hurricanes that make landfall by 2050, compared to current values[248]. For 2100, this number rises to a 32% increase for hurricanes that do not make landfall and 56% for hurricanes that make landfall. For Antigua and Barbuda specifically, by 2100 an RCP8.5 scenario could lead to damages from hurricanes accounting for 11.7% of GDP compared to 8.2% of GDP without climate change[249].

3.4.2. Impact of increased high-intensity storm events on disaster recovery

Along with an increase in damages and losses caused by individual Category 4 or 5 hurricanes, a shortening of return periods would mean that SIDS such as Antigua and Barbuda will not have adequate time to recover between high-intensity storm events. Because of their small geographical area, utilities on SIDS are typically

[240] Antigua and Barbuda public building climate adaptation upgrade programme. Feasibility study final report 2 July 2019.
[241] Government of Antigua and Barbuda. 2018. Hurricane Irma Needs Assessment. Available at: https://www.gfdrr.org/en/publication/hurricane-irma-and-maria-recovery-needs-assessment-antigua-and-barbuda
[242] Government of Antigua and Barbuda. 2018. Hurricane Irma Needs Assessment. Available at: https://www.gfdrr.org/en/publication/hurricane-irma-and-maria-recovery-needs-assessment-antigua-and-barbuda
[243] Government of Antigua and Barbuda. 2018. Hurricane Irma Needs Assessment. Available at: https://www.gfdrr.org/en/publication/hurricane-irma-and-maria-recovery-needs-assessment-antigua-and-barbuda
[244] Government of Antigua and Barbuda. 2018. Hurricane Irma Needs Assessment. Available at: https://www.gfdrr.org/en/publication/hurricane-irma-and-maria-recovery-needs-assessment-antigua-and-barbuda
[245] Cashman A & Nagdee MR. 2017. Impacts of climate change on settlements and infrastructure in the coastal and marine environments of Caribbean Small Island Developing States (SIDS). Caribbean Marine Climate Change Report Card: Science Review 2017.
[246] Acevedo S. 2016. Gone with the wind: estimating hurricane and climate change costs in the Caribbean. IMF Working Paper, WP/16/199.
[247] Because hurricane systems can extend for hundreds of kilometers, they do not have to make landfall (defined as the centre of the storm moving over the coast) to cause extensive damage. Countries or islands that are exposed to the outer edges of a hurricane that does not make landfall can still be impacted by strong winds, heavy rainfall and storm surges.
[248] Acevedo S. 2016. Gone with the wind: estimating hurricane and climate change costs in the Caribbean. IMF Working Paper, WP/16/199.
[249] Acevedo S. 2016. Gone with the wind: estimating hurricane and climate change costs in the Caribbean. IMF Working Paper, WP/16/199.

centralised with limited or no backup replacement systems[250]. After Hurricane Irma, Barbuda was without water for several months because of damages incurred to the pumping and desalination stations[251]. The island's power stations and distribution grid were also damaged, with the latter taking six months to repair[252]. The loss of critical water and electrical infrastructure contributed to the delayed recovery of Barbuda, which saw the full return of its population two years later.

An increase in the frequency of hurricanes such as Irma — particularly during the same season — reduces the time available for preparation between consecutive events from several years to months. The effective recovery of impacted communities would require critical utilities — including water, electricity and telecommunications — to be functional in less time than they currently are. Additional resources and funding will be necessary to reduce recovery time in preparation for consecutive hurricane events, placing a larger financial burden on individual SIDS[253].

Damage to critical infrastructure — including utilities buildings, roads and shelters — can have knock-on effects to evacuation efforts during subsequent hurricane events within the same season. For example, a simulation model of multiple hurricane strikes in Dominica demonstrated that the use of roads between two hurricane events differed considerably as a result of road damages caused by the first hurricane[254]. Damage to commonly used roads can lead to changes in which shelters are primarily utilised[255]. An inability of individual shelters to accommodate impacted communities because of damage from previous hurricanes would also limit shelter options for evacuees in the event of a second hurricane. Added to this, impacted roads, shelters, utilities and other critical infrastructure could considerably hamper efforts of emergency personnel — including fire services, law enforcement and medical response units — to assist local communities in the event of multiple hurricane strikes.

Even when storms from increasingly active hurricane seasons do not impact the same country multiple times in a season, increased hurricane frequency in the Caribbean will have a negative impact on the recovery of individual countries. This was observed for the 2017 Caribbean hurricane season, whereby widely dispersed populations from multiple countries were affected by separate hurricane events and required international aid[256]. For example, after dedicating personnel, funding and resources to recovery efforts in the US states of Texas and Florida following Hurricanes Harvey and Irma respectively, the Federal Emergency Management Agency (FEMA) displayed a comparatively weakened response to the later impact of Hurricane Maria on Puerto Rico[257]. This delayed response, along with other contributing factors, added to the country's slow recovery time and high number of deaths resulting from poor post-hurricane conditions[258]. In a similar way, multiple extreme hurricane events within the same season could result in

[250] Shultz JM, Kossin JP, Shepherd JM, Ransdell JM, Walshe R, Kelman I & Galea S. 2018. Risks, health consequences, and response challenges for small-island-based populations: observations from the 2017 Atlantic hurricane season. Society for Disaster Medicine and Public Health, Inc.
[251] Antigua and Barbuda public building climate adaptation upgrade programme. Feasibility study final report 2 July 2019.
[252] Antigua and Barbuda public building climate adaptation upgrade programme. Feasibility study final report 2 July 2019.
[253] Cashman A & Nagdee MR. 2017. Impacts of climate change on settlements and infrastructure in the coastal and marine environments of Caribbean Small Island Developing States (SIDS). Caribbean Marine Climate Change Report Card: Science Review 2017.
[254] Hilljegerdes M & Augustijn-Beckers. 2019. Evaluating the effects of consecutive hurricane hits on evacuation patterns in Dominica. Geospatial Technologies and Geographic Information Science or Crisis Management (GIS) — Proceedings of the 16th ISCRAM Conference. Valencia, Spain.
[255] Hilljegerdes M & Augustijn-Beckers. 2019. Evaluating the effects of consecutive hurricane hits on evacuation patterns in Dominica. Geospatial Technologies and Geographic Information Science or Crisis Management (GIS) — Proceedings of the 16th ISCRAM Conference. Valencia, Spain.
[256] Shultz JM, Kossin JP, Shepherd JM, Ransdell JM, Walshe R, Kelman I & Galea S. 2018. Risks, health consequences, and response challenges for small-island-based populations: observations from the 2017 Atlantic hurricane season. Society for Disaster Medicine and Public Health, Inc.
[257] Shultz JM, Kossin JP, Shepherd JM, Ransdell JM, Walshe R, Kelman I & Galea S. 2018. Risks, health consequences, and response challenges for small-island-based populations: observations from the 2017 Atlantic hurricane season. Society for Disaster Medicine and Public Health, Inc.
[258] Shultz JM, Kossin JP, Shepherd JM, Ransdell JM, Walshe R, Kelman I & Galea S. 2018. Risks, health consequences, and response challenges for small-island-based populations: observations from the 2017 Atlantic hurricane season. Society for Disaster Medicine and Public Health, Inc.

international aid institutions becoming overwhelmed, negatively affecting recovery efforts of countries like Antigua and Barbuda.

3.4.3. Impact of increased high intensity storm events on the economy

Increased recovery times and damages to infrastructure and ecosystems, as a result of more frequent high intensity hurricanes, are expected to negatively impact Antigua and Barbuda's economy. Agriculture, fisheries and tourism are the sectors expected to be most impacted. Potential negative impacts on agriculture include lowering of agricultural yields and worsening of already difficult working conditions for labourers through exposure to high temperatures and extreme climate events[259]. More frequent high-intensity hurricanes can directly contribute to agricultural losses though crop damage — particularly tree crops — and flooding[260]. Similarly, the fisheries sector is dependent on the health of ecosystems such as coral reefs, seagrasses and mangroves, all of which could be weakened by increasingly frequent Category 4 and 5 hurricanes, as well as rising temperatures and sea-levels related to climate change[261].

Damage to beaches and tourism infrastructure by hurricanes also lowers the tourism potential of a Caribbean country such as Antigua and Barbuda and can be costly to repair. In addition to repair expenditures, business interruption costs and higher insurance rates contribute to the overall financial burden placed on the tourism sector from increased hurricane-related damages[262]. The deterioration of ecosystems resulting from extreme storm events will also contribute to impacts on the tourism sector, as they provide aesthetic benefits as well as opportunities for recreational activities. Losses within the tourism sector because of climate change will have considerable ramifications for the country's economy, with the combined costs from hurricane damages and loss of tourism predicted to account for 8–24% of GDP[263] by 2050 and 11–49% of GDP by 2100[264]. This could amount to losses of US$2–8 million per year by 2050 and US$3–15 million per year by 2100[265,266].

4. Climate change impact pathways, options analysis and preferred solution

Climate projections indicate that Antigua and Barbuda is likely to experience an increase in the frequency of Category 4 and 5 hurricanes.[267]. In addition, two other major changes are occurring in the region as a result of climate change, namely shifting patterns of precipitation and increasing average terrestrial surface temperature. The associated impacts of these events are likely to increase considerably under future climate change conditions, as described in Sections 2 and 3 of this Feasibility Study. Figure 30 below presents the potential climate change impact pathways (IPs) affecting Antigua and Barbuda's economy as well as the health and well-being of the population. In this Feasibility Study, the focus is primarily on the addressing the impact of increasingly frequent Category 4 and 5 hurricanes on critical infrastructure and services, with specific focus on the impacts of strong winds and heavy rainfall. Options for disrupting these climate impact pathways are presented below, along with justification for the selection of project interventions.

[259] International Labour Organisation. 2014. Climate change and employment: challenges and opportunities in the Caribbean.
[260] UN Economic Commission for Latin America and the Caribbean. 2011. Caribbean Development Report Volume III: The economics of climate change in the Caribbean.
[261] International Labour Organisation. 2014. Climate change and employment: challenges and opportunities in the Caribbean.
[262] Simpson M, Scott D & Trotz U. 2011. Climate change's impact on the Caribbean's ability to sustain tourism, natural assets, and livelihoods. Inter-American Development Bank Environmental Safeguards Unit Technical Notes, No. IDB-TN-238.
[263] Estimates are based on the GDP in 2004.
[264] Bueno R, Herzfeld C, Stanton EA & Ackerman F. 2008. The Caribbean and climate change: the costs of inaction. Stockholm Environment Institute — US Center.
[265] Amounts are in 2007 United States Dollars.
[266] Bueno R, Herzfeld C, Stanton EA & Ackerman F. 2008. The Caribbean and climate change: the costs of inaction. Stockholm Environment Institute — US Center.
[267] Further details on climate projections and the associated impacts are presented in Section 3 of this Feasibility Study.

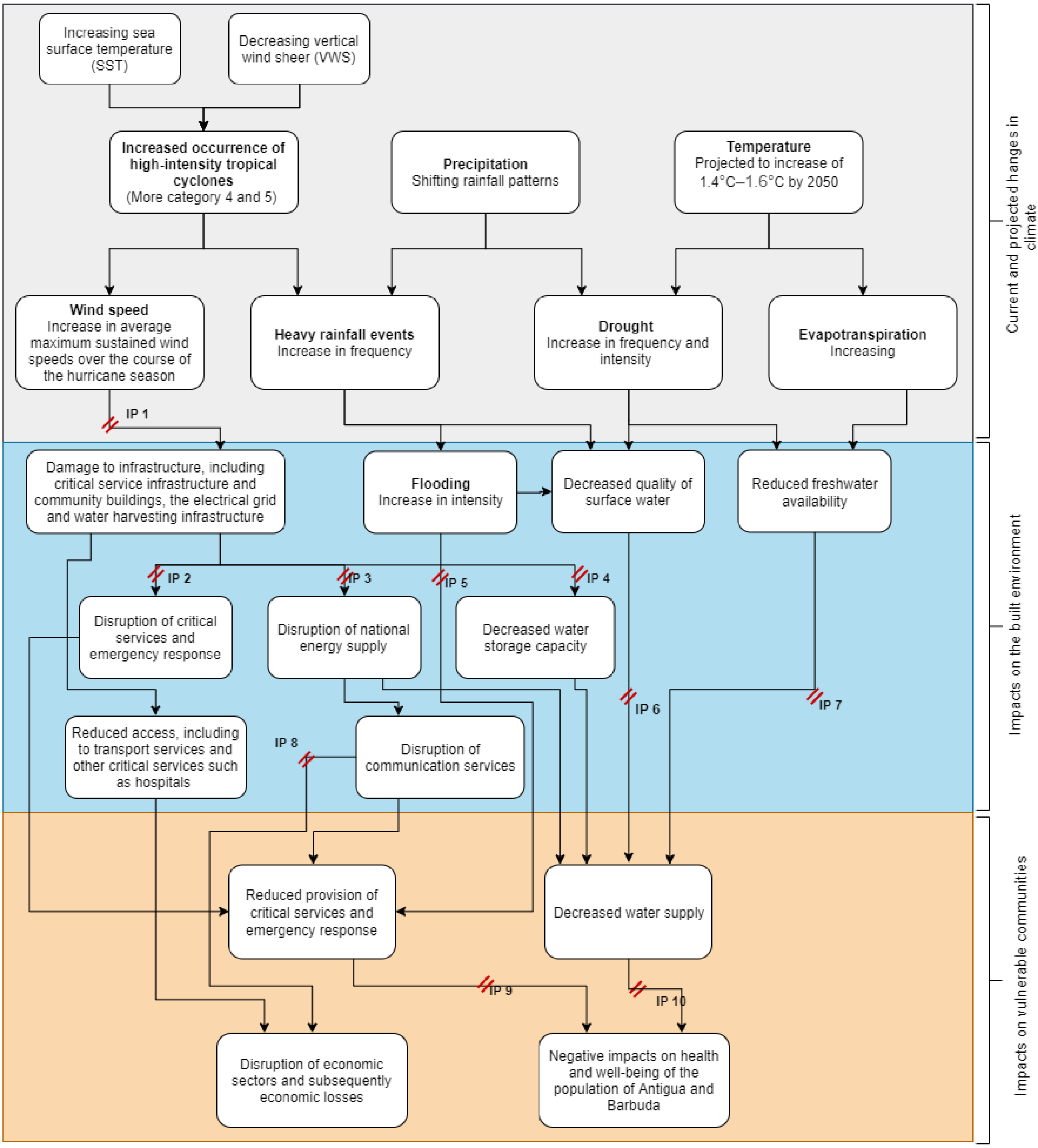


Figure 30. Schematic representation of potential climate change impact pathways (IPs) on vulnerable communities in Antigua and Barbuda. The direction of the arrows shows the direction of the causal pathway. The red "//" symbol represents points along relevant impact pathways where project interventions will disrupt the identified impacts of extreme climate events.

4.1. Disruptions to critical services and emergency response

4.1.1. Impact description

Category 4 and 5 hurricanes — as well as the associated strong winds and heavy rainfall events — cause severe damage to Antigua and Barbuda's critical public service and community buildings (IP 1). This damage leads to disruptions in the provision of critical services (IP 2), such as medical care and emergency response, during and immediately after an extreme event. Category 4 and 5 hurricanes also affect the country's power and water supply systems as a result of damages to the associated centralised infrastructure (IPs 3 and 4). It can take up to 60 days for normal power and water supply services to resume following a Category 1 to 4 hurricane. After a Category 5 hurricane, the disruptions to these services can increase several-fold to 24 months, exacerbated by reduced access to water points for up to 1 month[268]. The damages to the country's power supply systems also have severe consequences for vulnerable communities in the country. Firstly, these damages disrupt communication services, which in turn results in representatives from the country's major economic sectors, including industry, tourism and agriculture, and private businesses being unable to take the necessary precautions and actions in preparation of an extreme climate event. This directly links to significant economic losses and further exacerbates existing financial problems preventing investment in proactive climate change adaptation responses[269] (IP 8). Secondly, damage to power supply infrastructure from a Category 5 hurricane disrupts communication services for up to six months. This disruption considerably reduces the capacity of the National Office of Disaster Services (NODS) and critical services to respond efficiently and effectively to the onset of extreme climate events (IP 5), as well as causing disruptions to economic activities. As a result, many vulnerable community members are unable to access the required healthcare and medical treatment following an extreme climate event. This in turn leads to an increase in the number and severity of personal injuries and illness as well as increases in the number of fatalities caused by these events (IP 9).

4.1.2. Gap analysis

At present, Antigua and Barbuda's infrastructure, particularly critical public service and community buildings, is only designed to withstand the impacts of hurricanes up to Category 3 in strength. Given that climate projections indicate an increase in frequency of Category 4 and 5 hurricanes experienced by Antigua and Barbuda, the associated impacts on critical infrastructure are likely to be more severe. These impacts are exacerbated by Antigua and Barbuda's limited capacity to adopt climate-resilient approaches to infrastructural development that account for the impacts of Category 4 and 5 hurricanes. The country also has limited capacity for early action in response to extreme climate events. As a result, Antigua and Barbuda continues to rely on conventional infrastructural development that is not climate-resilient and procedures that do not enable rapid and efficient response to impending climate threats. These conventional approaches to disaster response and development are consequently insufficient under future conditions of climate change.

4.1.3. Options analysis and preferred solution

Several options have been identified during the scoping phase of project design that would disrupt the climate impact pathways affecting critical infrastructure in Antigua and Barbuda. The options include: i) physical strengthening of infrastructure to withstand the impact of strong winds associated with category 4 and 5 hurricanes; ii) decentralising energy and water supply to reduce dependency on vulnerable centralised systems; iii) improving storm water drainage systems to reduce flooding associated with heavy rainfall; iv) introducing nature-based solutions to reduce impacts of flooding from heavy rainfall and storm surges; v) improving generation and dissemination of climate information to facilitate early action; and vi) improving communication protocols to strengthen the use of impact-based forecasts. Based on this analysis of option, a suite of adaptation interventions was proposed to initiate a shift away from current reactive infrastructural development towards establishing a proactive approach to development in which

[268] Further details on the impacts of Category 4 and 5 hurricanes on Antigua and Barbuda's basic services are presented in Annex 22: Building assessment.
[269] A detailed analysis of socio-economic conditions in Antigua and Barbuda is resented in Section 2 of this Feasibility Study.

infrastructure is able to withstand the impacts of Category 4 and 5 hurricanes. Under the project, the structural integrity of priority buildings – including police and fire stations, hospitals, clinics and schools – will be improved to withstand the impacts of Category 4 and 5 hurricanes, which will contribute to the disruption of IP 1. The specific structural improvements required were identified through a comprehensive building assessment, presented in Annex 22. These buildings will also be fitted with decentralised renewable energy (RE) systems, including detachable solar PV panels, and climate-resilient rainwater harvesting solutions. Implementing such solutions will disrupt IPs 3 and 4 by providing continued power and water supply to priority buildings during and immediately after a hurricane. In terms of addressing the problem of stormwater drainage, improved drainage channels were not considered to be cost-effective at the small scale required for individual target buildings. Instead, the installation of rainwater harvesting systems will be used to alleviate the inundation of existing stormwater drainage systems during a hurricane. Nature-based solutions were also considered as a potential option for alleviating the impacts of heavy rainfall and storm surges on critical infrastructure, but were removed following Hurricane Irma in 2017 which highlighted the need to prioritise more immediately effective responses. While it is recognised that nature-based solutions have the potential to mitigate against the impacts of hurricanes, the long timescale required for nature-based solutions to become effective against category 4 and 5 hurricanes made them unfeasible at this time. The Government of Antigua and Barbuda remains committed to investing in nature-based solutions as a long-term adaptation strategy to compliment the urgent adaptation solutions proposed under this project.

The capacity of Antigua and Barbuda Meteorological Services (ABMS) will be strengthened under the project to support these adaptation interventions. Specifically, training workshops and programmes will be conducted to improve the capacity of ABMS to process climate data in real time and disseminate early warning information products to integral decision-makers responsible for coordinating disaster response, such as the NODS. To achieve this, a centralised online server will be established and housed within ABMS to facilitate rapid and effective climate data collection and processing. Training will then be provided to staff within ABMS on firstly, how to transform this data into easily interpreted, locally appropriate early warning information products (e.g. infographics). And secondly, how to disseminate these products to the public and private sectors, as well as relevant decision-makers, in accordance with a formalised communication protocol that will be established and operationalised in the country. The combined effect of the climate proofing interventions and improved response to climate threats will disrupt IPs 5 and 9 by increasing the efficiency and effectiveness of emergency response. This will contribute to safeguarding the well-being of the population, reducing the number of personal injuries and loss of lives caused by extreme climate events. Furthermore, ABMS will be fitted with RE to ensure continued power supply during an extreme climate event. This will allow for impact-based forecasts and weather information to continue to be communicated to representatives from major economic generating sectors as well as private sector business owners, thereby disrupting IP 8. As a result, these representatives will have increased capacity to undertake preparatory action and respond to the onset of an extreme climate event. This in turn will lead to reductions in the economic losses that result from these events, as representatives from major income generating sectors will be able to resume normal operations more quickly following these events.

4.2. Decreased water supply to vulnerable communities

4.2.1. <u>Impact description</u>

Given that more than half of Antigua and Barbuda's freshwater supply is reliant on desalination systems[270], the increasing impacts of extreme climate events on this supply need to be urgently addressed. Desalination systems are energy-dependent and, as a result, disruptions to the country's centralised energy supply caused by these extreme events will reduce availability of freshwater resources and cause disruptions to the provision of such resources to communities. Furthermore, extreme climate events, such as the heavy

[270] Antigua Public Utilities Authorities (APUA). 2016. Available at: http://www.apua.ag/water-provision-in-antigua/

rainfall events associated with hurricanes, as well as droughts, will contribute to reduced quality (IP 6) and availability (IP 7) of already limited surface water resources. Such reductions are compounded by reduced vegetation cover — and consequently higher levels of run-off — caused by drought conditions and increased evapotranspiration rates that result from higher temperatures. Because of these reductions in water quality and availability, negative impacts on the health and well-being of vulnerable communities will be experienced (IP 10), including possible outbreaks of hepatitis A, cholera and typhoid fever. These adverse health impacts will be exacerbated by reduced provision of critical services because of extreme climate events (IP 9).

4.2.2. Gap analysis

Antigua and Barbuda is currently employing reactional methods for overcoming the impacts on water quality and availability that result from extreme climate events. Some water harvesting measures have been implemented in the country, however, these measures are not designed and installed to withstand the impacts of extreme climate events, particularly Category 4 and 5 hurricanes. Because of this insufficient design and implementation, most of these water harvesting measures are destroyed during an extreme event, rendering these measures ineffective. Conventional methods are therefore insufficient to address the increasing impacts of extreme climate events on water quality and availability. Urgent adaptation measures are consequently required to address these impacts.

4.2.3. Options analysis and preferred solution

In response to the abovementioned adaptation needs, the proposed project will address the adverse impacts that extreme climate events have on the health and well-being of Antigua and Barbuda's population through disrupting IP 6 and 7. Several options were considered for disrupting these impact pathways. This includes long-term solutions involving building the resilience of centralised water desalinisation and distribution systems. However, these solutions are costly and will take significant time to implement. An alternative, more cost- and time-effective approach involves the installation of climate-resilient water harvesting solutions on to critical public service and community buildings. These solutions will ensure that there is sufficient water supply to critical services and vulnerable community members housed in shelters during and immediately following an extreme climate event. This will in turn reduce the health risks associated with poor water quality and ensure that all critical service personnel and vulnerable community members have sufficient access to emergency freshwater supplies where required. In addition, proposed project interventions will strengthen the capacity of ABMS to process and manage climate data in real time and disseminate early warning information products to entities that are integral to ensuring efficient and effective disaster response. This will result in vulnerable communities having increased knowledge and capacity to undertake preparatory actions, such as stockpiling water resources, and securing private water harvesting measures that they may have installed on their homes. The combined effect of project interventions will be the disruption of IP 10 through the overall reduction of health risks associated with the poor water quality that results from heavy rainfall events and flooding. While it was not considered feasible under the proposed project, the Government of Antigua and Barbuda remains committed to addressing the resilience of the centralised water distribution systems, with other projects already under development.

5. Legal, institutional and strategic framework

In recent decades, the Government of Antigua and Barbuda (GoAB) has made considerable progress in strengthening and reforming its national policies/strategies and institutional structures — providing the basis for the management and regulation of development. To this end, the GoAB has established several policies, programmes and strategies to address the threat of climate change and associated challenges to increasing the resilience of the country's population. The Department of Environment (DoE) is responsible for the design, development and implementation of all national climate change policies, strategies, as well as action and implementation plans. In addition, the DoE is the National Designated Authority (NDA) for the Green Climate Fund (GCF) in Antigua and Barbuda.

In its efforts to address the effects of climate change and build resilience to future impacts, GoAB has developed and implemented the institutional structures and legal frameworks necessary to access international climate finance[271]. To provide a framework for leveraging national as well as international financial resources — for general environmental management and the implementation of Multilateral Environmental Agreements (MEAs) — the SIRF Fund was established in 2015 as part of the Environmental Planning and Management Act (described in Section 5.1 below) under the country's Financial Administration Act (2006).

The SIRF fund serves several purposes, including: i) streamlining finance — by reducing duplication across agencies and consolidating their efforts; ii) providing a consistent sources of financing for planning and contingency efforts to reduce vulnerability; iii) building resilience — particularly within the energy and water sectors; iv) achieving long-term financial stability — as a strategy for reducing the country's high debt burden; v) leveraging and supporting non-profit organisations by providing co-financing for project development and implementation; and vi) providing support for vulnerable groups such as farmers, fishers and building owners through increased access to finance and insurance products.

The SIRF Fund provides the framework for the development of a financial mechanism to implement the EPMA[272]. The fund is expected to become the primary mechanism for managing and attracting environmental, climate change mitigation and adaptation funding from domestic and international climate finance[273]. Innovative financial instruments and programmes are also being contributed to the Fund to further build climate change resilience. In addition, the SIRF Fund is the primary means for implementing Antigua and Barbuda's climate action targets, providing financing for the achievement of environmental objectives such as: i) reducing fossil fuel consumption; ii) supporting management of protected areas; and iii) promoting recycling of oil and financing measures for climate change adaptation with limited financial support from the government. Through the SIRF Fund, internal and external[274] funding sources are catalysed to enable the country to meet its climate change and sustainability goals in a coordinated, systematic and cost-effective manner. The three main contributors to the fund are outlined below.

- **International and regional funding agencies.** Potential contributions are sought from international organisations and financial mechanisms such as the Green Climate Fund (GCF), Adaptation Fund (AF), Global Environment Facility (GEF) and Caribbean Biodiversity Fund.
- **National funding sources.** The SIRF Fund will capitalise on levies and fees from *inter alia*: i) fees for tourist visits to protected areas and ecotourism; ii) water levies to pay for protected areas, watershed and waterways; and iii) carbon tax to pay for adaptation with focus on droughts, hurricane impacts and adaptation insurance.
- **Private sector finance.** The fund aims to catalyse private sector financing for sustainable business initiatives and provision of ecosystem services through research and development of traditional knowledge as well as the use of genetic resources, with the objective of supporting conservation and management of biodiversity.

[271] The Commonwealth. 2019. Antigua and Barbuda: Destined for climate finance success. Available at: http://thecommonwealth.org/media/news/antigua-and-barbuda-destined-climate-finance-success
[272] Environmental Protection and Management Act (EPMA), 2015. Available at: http://laws.gov.ag/wp-content/uploads/2019/02/a2015-11.pdf.
[273] The Commonwealth. 2019. Antigua and Barbuda: Destined for climate finance success. Available at: http://thecommonwealth.org/media/news/antigua-and-barbuda-destined-climate-finance-success.
[274] Multilateral bodies and international organisations that have committed funds to the SIRF fund include *inter alia* SPPARE, Caribbean Biodiversity Fund, Inter-American Development Bank and the Special Climate Fund.

The SIRF Fund will also fund the installation of ~20 MW of capacity to generate electricity for sale to APUA and an additional 5 MW to offset water generation costs and government electricity usage. Each MW of solar PV capacity installed is estimated to save the country ~US$610,000 annually. The establishment of the SIRF fund demonstrates the growing awareness in Antigua and Barbuda of the impacts of climate change on the country. Long-term planning for adaptation and mitigation in the country has gained considerable support in recent years from decision-makers as well as civil society[275]. This support is evident in the development of several cross-sectoral strategies, policies and programmes relating to climate change, natural resource management, disaster management and sustainable development. These strategies, policies and programmes are described in further detail below.

5.1. Legal framework

5.1.1. Environmental Protection and Management Act (2019)

The Environmental Protection and Management Act (EPMA)[276] was passed in 2015 and updated in 2019. The Act provides for: i) sustainable environmental protection and management of natural resources; ii) the allocation of administrative responsibility for the management of environmental matters; iii) Antigua and Barbuda's treaty obligations with respect to the environment to be put into effect; and iv) a framework financial mechanism to satisfy the requirements of the Act and for other related matters. In addition, the EPMA facilitated the establishment of the Sustainable Island Resource Framework (SIRF) Fund as a mechanism to increase the availability of — and improve access to — funding for sustainable natural resource management. The Act encourages this by catalysing the flow of public[277] and private[278] finance into the SIRF Fund and disbursing funds for environmental management[279].

5.1.2. Physical Planning Act (2003)

The objective of the Physical Planning Act[280] is the orderly and progressive development of land as well as the improvement of amenities. It concerns the regulation of power of control over land-use, acquisition and development of land as well as the construction of buildings. It also requires certain projects, prior to authorisation, to undertake an EIA. In addition, policies and plans will be set under the Act that will consider items such as: i) pollution; ii) safeguarding of water supplies, water catchment areas and mineral resources; and iii) erosion, landslides and flooding[281].

5.1.3. Public Health Act (1965)

The Public Health Act[282] regulates all matters concerning public health in Antigua and Barbuda and is implemented through the Central Board of Health. Additionally, the Health Policy for Antigua and Barbuda[283] states government commitment to the universal provision of health services as a right to all residents and citizens.

5.1.4. National Solid Waste Management Act (1995)

[275] Yale School of Forestry and Environmental Studies. 2019. Building Climate Resilience After Irma: An Interview with F&ES Alum Lia Nicholson. Available at: https://environment.yale.edu/news/article/climate-resilience-after-irma-lia-nicholson/.
[276] Environmental Protection and Management Act (EPMA), 2015. Available at: http://laws.gov.ag/wp-content/uploads/2019/02/a2015-11.pdf.
[277] For example, donor funding, government budgets, debt-for-nature swaps.
[278] For example, water levies, fees for access to protected areas, investment funds.
[279] For example, protect areas management, biodiversity conservation.
[280] Physical Planning Act. No. 6 of 2003. Government of Antigua and Barbuda.
[281] Antigua and Barbuda's Second National Communication on Climate Change.
[282] Government of Antigua and Barbuda. Public Health Act. No. 34 of 1965, amended in 1992.
[283] World Health Organisation (WHO) and the Government of Antigua and Barbuda. Health Policy for Antigua and Barbuda. 1997.

The National Solid Waste Management Act[284] provides for the effective storage, collection, transport, treatment and handling of all solid waste generated within Antigua and Barbuda. The Act established the National Solid Waste Management Authority, which: i) provides storage and handling facilities for solid waste; ii) converts existing and develops new landfill sites; iii) promotes recycling; iv) prepares solid waste management plans; and v)manages the OECS Waste Management Project.

5.1.5. The Disaster Management Act (2002)

The Disaster Management Act[285] provides a framework for the effective coordination of efforts to manage, mitigate, respond to, and recover from, natural as well as man-made disasters in Antigua and Barbuda[286]. This Act makes provision for a National Disaster Preparedness and Response Advisory Committee, which includes *inter alia* the: i) Police Force; ii) Fire Service; iii) Meteorological department; iv) Ministry of Environment; and v) Ministry of Public Health. The inclusion of multiple entities in this committee highlights Antigua and Barbuda's cross-sectoral approach to disaster management.

5.1.6. The Environmental Protection Levy Act 2002

The Environmental Protection and Levy Act was enacted to impose and collect an environmental protection levy on a wide variety of goods[287] imported into, or manufactured in, Antigua and Barbuda[288]. Funds collected from the levy — which are paid into the Consolidated Fund or to the National Solid Waste Management Authority — are used to finance activities aimed at the protection, preservation and enhancement of the environment in the country.

5.1.7. OECS Building Code

Caribbean countries are particularly vulnerable to the impacts of extreme events, including hurricanes, earthquakes and volcanic eruptions[289]. In 1992, the Member States of the Organisation of East Caribbean States (OECS) recognised the need to develop building standards and guidelines specifically adapted for each individual country to mitigate the damage caused by these events[290]. The draft OECS Building Code was subsequently developed with the objective of safeguarding human health and property through a set of spatial requirements for construction as well as guidelines for effective planning. Each revision of the OECS Building Code involves tailoring the code to the technical specifications of specific Member States. The 7th edition of the OECS Building Code is currently under peer review to tailor it to the technical specifications and standards of Antigua and Barbuda — specifically to account for Category 4 and 5 hurricanes. This updated version of the building code is expected to be formalised by Cabinet in 2020, which will align with the scheduling of proposed project interventions.

The OECS Building Code is the technical document used in Antigua and Barbuda to guide infrastructural development. This code incorporates elements of the Bahamas Building Code, which in turn was based generally on the South Florida Building Code[291]. As such, best practices from the wider region — particularly the United States — are incorporated into the OECS Building Code. It provides administrative and enforcement requirements regarding building practices as well as the use of materials and building systems[292]. The OECS Building Code is based on the Caribbean Uniform Building Code (CUBiC) — which

[284] Government of Antigua and Barbuda. National Solid Waste Management Act. No. 10 of 1995, amended in 2005.
[285] Government of Antigua and Barbuda. Natural Disaster Management Act. No. 13 of 2002.
[286] Government of Antigua and Barbuda. Natural Disaster Management Act. No. 13 of 2002.
[287] for example, automobiles, bicycle tyres, air conditioners, as well as plastic and glass containers.
[288] Government of Antigua and Barbuda. Environmental Protection Levy Act. 2002.
[289] OECS. 2016.OECS Building Code. 7th Edition.
[290] OECS. 2016. OECS Building Code June, 1992. Available at: https://www.oecs.org/en/ccu-resources/oecs-building-code-june-1992.
[291] OAS. 2002. Status of Building Codes in the Caribbean. Available at: https://www.oas.org/cdmp/bulletin/codemtrx.htm..
[292] OECS. 2016.OECS Building Code. 7th Edition.

was formally adopted in 1986 — as well as several national codes, including the Bahamas Building Code (1987), the Jamaica National Building Code (1984) and the Turks and Caicos Islands Building Code (1990). The OECS Building Code provides for revisions to be made based on practices and systems that can be proven to improve resistance to natural hazards. The code has subsequently been revised several times since its development to clarify certain specifications and to incorporate additional requirements for specific countries[293]. In Antigua and Barbuda, the national building code is based on the OECS Building Code and its use is mandated as regulations to the Development Control Ordinance[294].

Historically, Antigua and Barbuda had not been directly affected by many hurricanes above Category 4, with the strength of most hurricanes limited to Categories 1–3. As a result, most of the infrastructure in the country is not designed to withstand the impacts of high intensity extreme climate events — particularly Category 4 and 5 hurricanes. The damage caused by Category 5 hurricanes in recent years — particularly Luis, Maria and Irma — has highlighted the limitations of regulations for construction of buildings to withstand the wind speeds and high levels of rainfall cause by these events. In response, supplementary specifications for building practices have been incorporated into certain sections of the revised edition of the Code[295].

5.2. Institutional framework

5.2.1. Antigua and Barbuda Nationally Determined Contribution (2015)

Antigua and Barbuda's Nationally Determined Contribution (NDC), submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in 2015, outlines the country's commitments to GHG mitigation (Article 2) and adaptation (Article 4), in response to climate change and the effects thereof[296]. Through the NDC, adaptation and mitigation targets are put forward with some being conditional on international support. The NDC's conditional adaptation target relevant to the proposed project is the increased resilience of buildings to extreme climate events. Unconditional targets that the country has committed to include enhancing the enabling legal, policy and institutional environment for a low carbon development pathway, as well as updating of the Building Code to address the projected impacts of climate change.

The cost of implementing adaptation targets has been estimated at ~US$20 million annually until 2025, while the cost of mitigation targets has been estimated at ~US$220 million annually[297]. Given the limited financial capacity of Antigua and Barbuda, meeting the targets specified in the NDC is contingent upon receiving external support through *inter alia* the GCF, GEF and the Adaptation Fund. The conditional and unconditional targets specified in the NDC are outlined in Table 6 below.

Table 6. Targets specified in the 2015 NDC of Antigua and Barbuda[298].

Target	Target Year
Conditional adaptation targets	
Increase desalination capacity by 50% above 2015 levels	2025
Improve and prepare all buildings for extreme climate events	2030
Use off-grid renewable sources to meet 100% of electricity demand in essential services sectors	2030
Protect all waterways to reduce flooding and health impacts	2030

[293] Gibbs. 2003. Report on the Comparison of Building "Codes" and Practices which are in use in the Caribbean. Available at: https://www.humanitarianlibrary.org/sites/default/files/2014/02/No.1_Codes-PracticesReportA4.pdf.
[294] Wason, A. 2001. Status of Building Codes in the Caribbean (as of August 2001). Available at: http://www.oas.org/pgdm/document/codemtrx.htm.
[295] OECS. 2016.OECS Building Code. 7th Edition.
[296] Government of Antigua and Barbuda. Nationally Determined Contribution. 2015
[297] Government of Antigua and Barbuda. Nationally Determined Contribution. 2015
[298] Government of Antigua and Barbuda. 2015. Nationally Determined Contribution.

Target	Target Year
Make an affordable insurance scheme available to farmers, fishers, business owners and private homeowners, to mitigate the losses resulting from climate impacts	2030
Conditional mitigation targets	
Establish efficiency standards for imported vehicles and appliances	2020
Finalise technical studies with the intention to construct, and put into operation, a waste-to-energy (WTE) plant by 2025	2020
Achieve an energy matrix of 50 MW of electricity from renewable sources both on and off-grid in public and private sectors	2030
Protect the remaining wetland and watershed areas to enhance their use as carbon sinks	2030
Unconditional targets	
Enhance the established enabling legal, policy and institutional environment for low carbon emission development pathway to achieve poverty reduction and sustainable development	No target date set in the NDC
Update the Building Code to meet the projected impacts of climate change	2020

Interventions under the proposed project are aligned, in particular, with the following conditional adaptation target of the Antigua and Barbuda NDC: to *“improve and prepare all buildings for resilience to extreme climate events”*. In addition, proposed project activities are aligned with two unconditional targets, namely: i) *“enhance the established enabling legal, policy and institutional environment for low carbon emission development pathway to achieve poverty reduction and sustainable development”*; and ii) *“update the Building Code to meet the predicted impacts of climate change”*.

5.2.2. Third National Communication to UNFCCC

Antigua and Barbuda submitted its Third National Communication (TNC) to the UNFCCC in 2015. It outlines the country’s commitments to addressing the impacts of climate change in the country and provides details on *inter alia*: i) the socio-economic and environmental situation in the country; ii) emissions statistics and mitigation targets; and iii) vulnerability, impacts of climate change and proposed adaptation measures. In addition, Antigua and Barbuda’s TNC[299] identifies two major benefits associated with the early implementation of climate change adaptation measures: firstly, early action in response to climate change contributes significantly to improving livelihood security and saving lives during and following extreme events; and secondly, a proactive approach in responding to climate change leads to considerable economic savings as both public and private sector services and businesses are able to prepare for, and recover from, an extreme event more rapidly than they would in the absence of effective adaptation measures[300]. Climate change adaptation priorities outlined in the TNC include: i) improving the efficiency of water resource management; ii) increasing resilience of natural environments through ecosystems-based adaptation (EbA); and iii) updating the Building Code to increase the resilience of buildings to climate change impacts[301].

5.2.3. Government of Antigua and Barbuda Medium-Term Development Strategy 2016–2020

The Medium-Term Development Strategy (MTDS) outlines the strategies and actions to be undertaken from 2016–2020 to meet the national goal of becoming a developed country in 15–20 years[302]. Within the MTDS, seven Flagship Priorities are emphasised, with two of these directly relating to improved buildings and infrastructure. The proposed project aligns with Flagship Priority One, which focuses on *inter alia* the

[299] Antigua and Barbuda. 1993.Third National Communication on Climate Change to the United Nations Framework Convention on Climate Change (UNFCCC).
[300] For example, preparation for flooding can decrease the damage to infrastructure and reduce the costs associate with recovery and reconstruction.
[301] Antigua and Barbuda. 1993.Third National Communication on Climate Change to the United Nations Framework Convention on Climate Change (UNFCCC).
[302] Government of Antigua and Barbuda. Medium-Term Development Strategy 2016 to 2020 (MTDS). 2015.

renewal and maintenance of critical infrastructure. These Flagship Priorities have been designed to contribute directly towards achieving a Necessary Condition[303] for attaining the Sustainable Development Goals (SDGs), namely through building resilience of the country to climate change[304].

5.2.4. Antigua and Barbuda Country Paper on National Climate Change Issues (2001)

The Country Paper on National Climate Change Issues[305] (hereafter the 'Country Paper') identifies a need for improved coordination in development planning to prevent increasing vulnerability to droughts and extended dry periods, flooding and sea-level rise. In particular, the Country Paper proposes improved and updated planning and development control, as well as strengthening existing legislation such as the Building Code. Furthermore, it proposes resiting critical infrastructure, improving public education and awareness, and strengthening community-level disaster management systems[306].

5.2.5. Antigua and Barbuda Country Document for Disaster Risk Reduction (2016)

The Country Document for Disaster Risk Reduction (DRR) is an analysis of the status of DRR in Antigua and Barbuda[307]. The document details strategies for the comprehensive national management of risk, with environmental protection and safeguarding human lives as the primary objectives. It was prepared in accordance with the Sendai Framework, which recognises the role of the State as the primary entity responsible for the reduction of risk, but with comprehensive involvement of other stakeholders — including local governments and the private sector. The four primary objectives outlined by the Framework are: i) understanding disaster risk; ii) improving disaster risk management by strengthening disaster risk governance; iii) investing in DDR for increased resilience; and iv) enhancing preparedness for effective disaster response and recovery[308].

5.2.6. Policy Framework for Integrated Adaptation Planning and Management in Antigua and Barbuda (2002)

The Policy Framework for Integrated Adaptation Planning and Management in Antigua and Barbuda[309] provides basic guidelines for the establishment and implementation of a national climate change adaptation policy. The primary aim of the Framework is to identify social conditions and processes with potential influence on climate change impacts in Antigua and Barbuda. Options for adaptation planning and management are also presented.

5.2.7. Environmental Management Strategy and Action Plan (2004–2009)

The Environmental Management Strategy and Action Plan for 2004–2009 (EMSAP) highlights the country's vulnerability to climate change and outlines existing and emerging global challenges and proposes an integrated approach to sustainability in the form of 18 principles. Currently, however, the EMSAP does not adequately consider future climate change impacts on the country or provide any strategies for improving resilience and capitalising on adaptation-related funding opportunities.

[303] A 'necessary condition' is a condition that must be satisfied in order for the SDGs to achieved.
[304] Government of Antigua and Barbuda. Medium-Term Development Strategy 2016 to 2020 (MTDS). 2015.
[305] James 2001 Antigua and Barbuda Country Paper.
[306] The Country Paper reported that from 1990–1999, the number of hurricanes per year and the number of named storms had increased. Between 1990 and 1994, Antigua and Barbuda experienced ~5 hurricanes annually and a total of ~8 named storms. This increased to ~8 hurricanes per year and 13 named storms between 1995 and 1999.
[307] NODS. 2016. Country document for disaster risk reduction: Antigua and Barbuda, 2016. Available at: http://dipecholac.net/docs/country-doc-antigua-and-barbuda.pdf
[308] NODS. 2016. Country document for disaster risk reduction: Antigua and Barbuda, 2016. Available at: http://dipecholac.net/docs/country-doc-antigua-and-barbuda.pdf
[309] CPACC. Policy framework for integrated (adaptation) planning and management in Antigua and Barbuda. 2002

5.2.8. National Economic and Social Transformation Plan 2010–2014

The National Economic and Social Transformation (NEST) Plan for 2010–2014[310] was the primary policy document developed and used for conceptualising and implementing interventions related to economic and social development in Antigua and Barbuda. Objectives of the NEST Plan were to inform GoAB policy decisions and guide the development of the Medium-term Strategic Development Plan (MTSDP). Subsequently, the MTSDP was developed and succeeded the NEST plan, outlining the development priorities for 2015–2019.

5.2.9. Sustainable Island Resource Management Zoning Plan 2012

The Sustainable Island Resource Management Zoning Plan 2012 (SIRMZP)[311] is a strategic national spatial development framework designed to address current challenges surrounding development in Antigua and Barbuda. Specifically, this framework provides guidance on how private- and public-sector developments should be undertaken in accordance with national policies during a 20-year period. In addition, the SIRMZP serves as a revised National Physical Development Plan (NPDP), which meets the criteria of the Physical Planning Act[312]. The SIRZMP has the following functions, namely to: i) provide protection and sustainable management of ecosystems and associated ecosystem services; ii) promote the development of a cohesive mixed-use settlement network to offer housing options to households with different income levels and living preferences; iii) establish economic growth and employment centres; iv) outline proposals to improve the configuration and efficiency of road infrastructure; v) specify regulations and frameworks to guide development in line with national policy; and vi) provide a framework for the preparation of detailed plans which are aligned with national land-use priorities. Moreover, the use of GIS for the application and modification of the plan allows zones to be identified on existing maps to reveal social, economic and biophysical patterns, which can be used to inform development plans.

6. Past and ongoing projects

The Government of Antigua and Barbuda (GoAB) has demonstrated its commitment to addressing the current and projected impacts of climate change on the country. Outlined below are initiatives, programmes and projects with a focus on climate change — particularly those with the objectives of strengthening the resilience of vulnerable communities, developing renewable energy and reducing greenhouse gas (GHG) emissions. Several projects with a focus on cross-cutting environmental matters, including biodiversity conservation, are also described below.

6.1. Projects and initiatives with a focus on climate change

6.1.1. Regional initiatives and mechanisms

Caribbean Regional Resilience Building Facility (GFDRR)

Launched in 2019, the Caribbean Regional Resilience Building Facility[313] is a partnership between the European Union (EU), the World Bank Group and the Global Facility of Disaster Reduction and Recovery (GFDRR). In the aftermath of Hurricanes Irma and Maria — which hit the region in 2017 — the GFDDR was established with three primary functions. Firstly, it provides regional technical assistance for mainstreaming of resilience, to strengthen administrative and technical capacity for advancing recovery and identifying

[310] Food and Agriculture Organisation of the United Nations (FAO). 2016. Country Programming Framework for Antigua and Barbuda 2016–2019.
[311] Government of Antigua and Barbuda. Island Resource Management Zoning Plan 2012 (SIRMZP)
[312] Government of Antigua and Barbuda. Physical Planning Act. No. 6 of 2003.
[313] CRRBF. 2019. The Caribbean Regional Resilience Building Facility. Available at: https://www.gfdrr.org/sites/default/files/publication/Brochure-The-Caribbean-Regional-Resilience-Building-Facility.pdf

public investment project. Secondly, the GFDDR leverages investments in resilience, to provide methodological support for the prioritisation of plans and programs for increasing resilience. Under this component, grants are made available for co-financing of resilience investments as well as for ancillary technical assistance and financial service. Its final objective is to expand financial protection against disasters in participating states by providing support for expanded coverage under the Caribbean Catastrophe Risk Insurance Facility-Segregated Portfolio Company (CCRIF-SPC) as well as related mechanisms for insurance and risk-reduction[314].

Caribbean Climate Smart Accelerator (CCSA)

The Caribbean Climate Smart Accelerator (CCSA) is an initiative developed by a coalition of 26 governments in the region — as well as 40 private and public sector partners — to create the world's first climate-smart zone[315][316] . CCSA's primary objectives are to: i) accelerate socio-economic development in the region; ii) strengthen the resilience of infrastructure and societies; iii) create employment opportunities to catalyse economic growth; and iv) ensure that the Caribbean remains a priority for international development[317]. These objectives will be achieved by helping member states to accelerate projects they consider necessary for the rapid achievement of their climate change goals. The CCSA seeks to secure a sustainable future for countries in the region by mainstreaming the use of low-carbon technology, creating sustainable cities and modernising digital, physical and social infrastructure to overcome the challenges relating to climate change[318].

The Commonwealth Climate Finance Access Hub

The Commonwealth Climate Finance Access Hub[319] provides specialised assistance to members of the Commonwealth for the development of projects with a focus on climate change adaptation and mitigation — particularly to those nations that are most vulnerable to the impacts of climate change. The Hub assists these countries in accessing international sources of climate finance by helping them to comply with the complex requirements of international funding bodies and by providing support for technical and institutional capacity building. To achieve this, the Hub offers three primary services, namely: i) human and institutional capacity development through the long-term appointment of technical advisors for the development of climate finance capacity; ii) knowledge management with the objective of knowledge gathering and dissemination; and iii) technical management[320].

The Regional Gateway for Technology Transfer and Climate Change Action in Latin America and the Caribbean (REGATTA)

Antigua and Barbuda participates in the Regional Gateway for Technology Transfer and Climate Change Action in Latin America and the Caribbean (REGATTA), pioneered by UNEP[321]. REGATTA's objectives are to strengthen technical and institutional capacity of countries, as well as facilitate the exchange of technical knowledge on mitigation and adaptation to climate change. The initiative assists countries to increase their

[314] CRRBF. 2019. The Caribbean Regional Resilience Building Facility. Available at: https://www.gfdrr.org/sites/default/files/publication/Brochure-The-Caribbean-Regional-Resilience-Building-Facility.pdf
[315] A climate-smart zone has the objective of modernising digital, physical and social infrastructure to address climate change, and to facilitate a low-carbon future for the region.
Caribbeanaccelerator. 2019. The world's first climate-smart zone? Available at: https://www.caribbeanaccelerator.org/
[316] The World Bank. 2018. Caribbean Aims to Become World's First Climate-Smart Zone. Available at: https://www.worldbank.org/en/news/press-release/2018/08/09/caribbean-aims-become-world-first-climate-smart-zone
[317] The Caribbean Climate Smart Accelerator. 2019. Available at: https://www.caribbeanaccelerator.org/
[318] The Caribbean Climate Smart Accelerator. 2019. Available at: https://www.caribbeanaccelerator.org/.
[319] The Commonwealth. 2019. Climate Finance Access Hub. Available at: http://thecommonwealth.org/climate-finance-access-hub
[320] The Commonwealth. 2019. Climate Finance Access Hub. Available at: http://thecommonwealth.org/climate-finance-access-hub
[321] UNEP. 2019. REGATTA. Available at: http://www.cambioclimatico-regatta.org

climate-resilience through the development of pilot projects and provision of advisory services[322]. In addition, REGATTA contributes to the implementation of the Climate Technology Centre and Network (CTCN)[323] by providing information on relevant databases, institutions, financing opportunities as well as documents and tools[324].

The Caribbean Catastrophic Risk Insurance Facility (CCRIF)

The Caribbean Catastrophic Risk Insurance Facility is a multi-country insurance risk pool designed to reduce the impact that natural disasters have on member states. Insurance pay-outs are provided by the facility to cover short-term requirements after hurricanes or earthquakes. It facilitates the provision of insurance at a lower rate than would be possible for individual countries. The CCRIF covers the areas of risk management, risk modelling, asset management, information technology as well as technical assistance and corporate communication[325].

Weather-Ready Nations (WRN) Programme

Weather-Ready Nations (WRN) Programme is an initiative of the National Oceanic and Atmospheric Association (NOAA) and the United States Agency for International Development (USAID)[326]. The designated coordinating agency is the Caribbean Institute for Meteorology and Hydrology (CIMH). WRN's objective is to strengthen the capacity of national meteorological and hydrological services (NMHS) — as well as national disaster management agencies (NDMAs) — for readiness, responsiveness and resilience to extreme climate events. WRN is focussed on reducing the impacts from hydrometeorological hazards on, and enhancing the resilience of, local communities in participating nations. The programme involves the use of impact-based forecast and warning services for disaster risk reduction (DRR), which informs sector- and location-specific responses to meteorological and hydrological hazards. A major component of the project is the implementation of a uniform colour alert protocol for early warning of impending hurricanes. At present, the programme is being implemented in only one Caribbean SIDS, namely Barbados. However, funds have been allocated for the expansion of the programme into several other countries in the region, including Antigua and Barbuda.

Caribbean Disaster Emergency Management Agency (CDEMA) Early Warning Systems (EWS) Regional Readiness Project

This GCF project, entitled 'Caribbean Disaster Emergency Management Agency (CDEMA) Early Warning Systems (EWS) Regional Readiness Project', is currently under development, with the readiness and preparatory support proposal having been submitted in August 2019. The objectives of the proposal are to provide support for improving capacity and mechanisms at national and regional level for achieving climate-resilience in the Caribbean. This will be achieved by advancing the development and implementation of multi-hazard early-warning systems (MHEWS) in the region. These systems will enable national authorities and local communities to effectively prepare and respond to the impacts of climatic hazards. This will be achieved by: i) further integrating climate change and disaster risk information into resilience efforts; ii) improving risk management at the national and regional level; and iii) strengthening the national- and regional-level technological capacity and social resilience of major sectors.

6.1.2. Regional projects with a focus on adaptation and resilience

[322] Antigua and Barbuda's Third National Communication to the UNFCCC. 2015. Available at: https://unfccc.int/resource/docs/natc/antnc3.pdf
[323] UNEP. 2019. REGATTA. Available at: http://www.cambioclimatico-regatta.org
[324] CTCN. 2011. Regional Gateway for Technology Transfer and Climate Change Action in Latin American and the Caribbean. Available at: https://www.ctc-n.org/resources/regional-gateway-technology-transfer-and-climate-change-action-latin-american-and
[325] CCRIF. 2015. Available at: https://www.ccrif.org/content/about-us.
[326] National Weather Service. n.d. Weather-ready nations. Available at: https://www.weather.gov/wrn/wrns

Climate change impacts pose a considerable threat to the economy, infrastructure and citizens of SIDS. In response to this threat, many initiatives have been undertaken to promote climate-resilience in the Caribbean. Several of these initiatives have prioritised: i) capacity building for planning and the sustainable management of buildings and ecosystems; and ii) the improvement of access to finance to support adaptation interventions. Details of previous and ongoing initiatives with a climate change and environmental focus are outlined below.

Integrated physical adaptation and community resilience through an enhanced direct access pilot in the public, private, and civil society sectors of three Eastern Caribbean small island developing states (2018–2023; GCF; US$20,000,000)

This project was developed in response to the GCF request for proposals (RfP) to pilot initiatives for Enhanced Direct Access (EDA) for the effective operationalisation of adaptation at sub-national, national and regional levels. The project was designed to meet several objectives of the GCF RfP, which include: i) enhancing country ownership of projects and programmes by devolving decision-making at country level to improve involvement and input from stakeholders; ii) assisting governments in the implementation of concrete adaptation measures by using ecosystem-based approaches where appropriate; iii) enhancing climate-resilience through tangible adaptation benefits; and iv) increasing the resilience of privately-owned physical assets through concessional microfinancing.

The Global Climate Change Alliance (GCCA) climate change adaptation and sustainable land management in the Eastern Caribbean Project (2013–2018; SCCF; US$14,575,000)

The Global Climate Change Alliance (GCCA) initiative was established by the EU in 2007 to strengthen the dialogue and level of cooperation on climate change between developing countries — particularly Least Developed Countries (LDCs) and SIDS. Through the GCCA, the project was implemented with the OECS Commission serving as the implementing entity. Improving the resilience of the region's natural resource base to the impacts of climate change was the primary objective of the OECS Commission. The GCCA/OECS project resulted in effective and sustainable land-management frameworks designed and developed based on adaptation pilot projects with a focus on resilience of physical infrastructure as well as ecosystems. In addition, base maps — including geotechnical hazard maps — were produced through the project to determine the capacity of land to support land-use planning and to revise the National Building Codes and Ordinances. In Antigua and Barbuda, the GCCA/OECS project was aligned with the Special Climate Change Fund (SCCF) project (see Section 6.1.3 below) in updating the Building Code and in developing Local Area Development Plans[327].

Caribbean Community Climate Change Centre (CCCCC) Global Climate Change Alliance (GCCA) Project (2011–2015; EU; US$12,452,032)

The EU GCCA project was a Caribbean Forum (CARIFORUM) regional project assisting 16 participating Caribbean countries in increasing their capacity to design and implement climate change adaptation policies and interventions. Overall, the objective of the project was to support sustainable development in the Caribbean and further the progress of participating countries towards the Millennium Development Goals (MDGs). Two particularly relevant components of the GCCA project — which was executed by the CCCCC in collaboration with the GoAB — were to: i) conduct a 'Vulnerability and Capacity Assessment (VCA) in the south-west coast and watershed area of Antigua; and ii) determine the impacts of projected climate change on the water sector in the community. The project was implemented by the Environment Division of the Ministry of Agriculture, Lands, Housing and the Environment. A notable output of the project was the

[327] GCCA. 2018. Climate change adaptation and sustainable land management in the Eastern Caribbean. Available at: http://www.gcca.eu/programmes/climate-change-adaptation-and-sustainable-land-management-eastern-caribbean.

National Strategy and Action Plan to Address Climate Change in the Water Sector for Antigua and Barbuda[328].

Caribbean Planning for Adaptation to Climate Change (CPACC) (1997–2001; GEF; US$5,600,000)

CPACC was developed and implemented by the Organisation of American States (OAS) [329]. The goal of the project was to build capacity in the Caribbean region for adaptation to climate change impacts, particularly sea-level rise. This was accomplished through the completion of vulnerability assessments, adaptation planning and capacity building activities. CPACC was comprised of five pilot and four regional projects which included: i) the design and establishment of a sea level/climate monitoring network; ii) establishment of databases and information systems; iii) an inventory of coastal resources; and iv) formulation of initial adaptation policies. The pilot project most relevant to Antigua and Barbuda involved the formation of proposals for the development of economic and regulatory instruments for meeting environmental objectives.

Mainstreaming Adaptation to Climate Change (MACC) (2004–2007; GEF; US$9,300,000)

The Mainstreaming Adaptation to Climate Change (MACC) project[330] was a five-year GEF-funded project with the objective of mainstreaming climate change adaptation strategies into sustainable development agendas of the SIDS and low-lying countries of CARICOM. A learning-by-doing approach to capacity building was used, consolidating the achievements of CPACC and the Association of Caribbean Corporate Counsel (ACCC). The MACC initiative was developed to increase technical capacity for the monitoring of sea level rise and climatic indicators — both nationally and regionally — as well as for adaptation planning. The project was developed through the World Bank and implemented by the CARICOM Secretariat[331].

6.1.3. National initiatives and projects with a focus on adaptation and resilience

The Environmental Information Management and Advisory System (EIMAS)

The limited availability of financing and technical capacity to adapt to future climate change impacts compromises the resilience of Antigua and Barbuda's communities. Without adaptation-oriented planning and associated building guidelines, coastal and inland communities and infrastructure — particularly low-lying buildings — will be increasingly exposed to extreme climate events. However, baseline data for analysing the effect of past developments with an environmental focus for informing planning processes are limited. In response, the Environmental Information Management and Advisory System (EIMAS) was developed under the Environmental Protection and Management Act (2015) to address data gaps by using geographic information systems (GIS) technology[332]. EIMAS — which is managed by the DoE — is used for mapping and monitoring protected areas, as well as for informing decision-making. The implementation of EIMAS is establishing physical development and improved human settlements as an integral factor for consideration in climate resilience activities.

Building climate resilience through innovative financing mechanisms for climate change adaptation (2016–2020; SCCF; US$11,390,000)

[328] Caribbean Community Climate Change Centre. 2014. National Adaptation Strategy and Action Plan to Address Climate Change in the Water Sector in Antigua and Barbuda.
[329] CARICOM. 2015. Caribbean Planning for Adaptation to Climate Change (CPACC) Project. Available at: https://caricom.org/projects/detail/caribbean-planning-for-adaptation-to-climate-change-cpacc-project.
[330] OAS. 2002. Mainstreaming Adaptation to Climate Change (MACC). Available at: http://www.oas.org/macc/Docs/MACC-BRO.pdf.
[331] OAS. 2002. Mainstreaming Adaptation to Climate Change (MACC). Available at: http://www.oas.org/macc/Docs/MACC-BRO.pdf.
[332] DoE. 2019. Programmes. Available at: https://www.environment.gov.ag/programs.

With a grant of US$5 million from the GEF, the Special Climate Change Fund (SCCF) project[333] was developed in 2016 and is expected to be completed in 2020. Its objective is to address the vulnerability of local communities to increasing frequency and intensity of extreme climate events through the: i) development of innovative financing mechanisms to fund adaptation interventions that increase climate resilience; ii) demonstration of cost-effective adaptation interventions that protect community assets; iii) improvement of knowledge-sharing on innovative financing mechanisms and cost-effective adaptation approaches; and iv) mainstreaming of climate change adaptation into national and local policies and development planning. The project is being implemented by the Environment Division of the Ministry of Agriculture, Lands, Housing and the Environment, and UNEP is the Accredited Entity. It focused on the development of a Local Area Development Plan for McKinnon's Pond, building on previous work conducted — which included participatory processes. The McKinnon's Pond Local Area Development Plan will contribute to a greater McKinnon's watershed Local Area Plan (LAP) that will be developed through the Adaptation Fund project discussed below. Another aspect of the SCCF project is the updating of the Building Code to include best practices for climate-proofing buildings against predicted impacts of climate change. In addition, the SCCF project will establish the SIRF Revolving Fund for Adaptation and capitalise the SIRF Fund with an initial investment of US$1.6 million.

An integrated approach to physical adaptation and community resilience in Antigua and Barbuda's northwest McKinnon's watershed (2017–2020; AF; US$9,970,000)

This Adaptation Fund project[334] — implemented by the DoE — has the objective of reducing the vulnerability of local communities in Antigua and Barbuda by increasing the ability of the north-west McKinnon's watershed to withstand extreme rainfall events, as well as to increase the resilience of the built environment at the national level to climate change. The project's three primary objectives are to: i) implement interventions that support natural and physical drainage systems; ii) disburse concessional loans to vulnerable households and businesses; and iii) support social adaptive capacity and encourage local ownership of adaptation interventions. Through an integrated approach, the project will ensure that vulnerable communities in the north-west watershed will be able to withstand projected climate change impacts such as increased rainfall intensity.

6.1.4. Projects with a focus on renewable energy

Sustainable Pathways — Protected Areas and Renewable Energy (SPPARE) (2015–2018; GEF; US$10,619,726)

The SPPARE project[335] — implemented by the Environment Division of the Ministry of Agriculture, Lands, Housing and the Environment — addresses the requirement for increased revenue to fund annual operational costs for protected areas and forests systems in Antigua and Barbuda. As the National Executing Agency for GEF projects, the DoE — assisted by other agencies via structures such as Technical Advisory Committees (TACs) and Project Management Committees (PMCs) — is responsible for the coordination of SPPARE.

The project uses, and builds on, existing innovative funding sources by, for example, selling renewable electricity to the national utility. This generates the finances required to safeguard protected areas and the valuable ecosystem services they provide. One of the main outcomes of the SPPARE project was

[333] GEF. 2019. Building climate resilience through innovative financing mechanisms for climate change adaptation. Available at: https://www.thegef.org/project/building-climate-resilience-through-innovative-financing-mechanisms-climate-change.
[334] Adaptation Fund. 2019. An integrated approach to physical adaptation and community resilience in Antigua and Barbuda's northwest McKinnon's watershed. Available at: https://www.adaptation-fund.org/project/integrated-approach-physical-adaptation-community-resilience-antigua-barbudas-northwest-mckinnons-watershed/.
[335] GEF. 2019. Sustainable Pathways Protected Areas and Renewable Energy (SPPARE Project). Available at: https://www.thegef.org/project/sustainable-pathways-protected-areas-and-renewable-energy

consequently the development of a financial strategy for regulating and maintaining protected areas. This was achieved by: i) reaching a formalised agreement for the SIRF Fund to receive profits from renewable energy systems and increase revenue for protected areas systems by US$2 million annually; ii) undertaking a pilot installation of wind and/or solar energy with potential for scaling-up; iii) improving management effectiveness of a financially sustainable pilot protected area; iv) restoring surrounding watershed forests that are fundamental to improved water management and pumped hydro-energy storage; and v) reducing the threat of fire to forested areas. SIRF Fund resources funded the second component of the SPPARE project, which involved piloting a local area plan (LAP) designed for the Mount Obama National Park.

Energy for Sustainable Development in Caribbean Buildings (ESD) (2014–2018; GEF Trust Fund; US$5,900,000)

The overall objective of the Energy for Sustainable Development in Caribbean Buildings (ESD) project[336] was to build technical and institutional capacity to reduce the growth of energy demand in five Caribbean countries — including Antigua and Barbuda. Particular actions under the project to achieve the objective included: i) improving the efficiency of energy use in buildings; ii) increasing the use of energy conservation interventions; and iii) promoting the use of renewable energy resources. UNEP was the Accredited Entity for the project, and the Caribbean Community Climate Change Centre (CCCCC) was the Executing Agency.

Grid-Interactive Solar PV Systems for Schools and Clinics in Antigua (2018–2019)

This project is currently under development by the Department of Environment, with funding from the SIRF fund and support from the Government of Italy's Ministry for the Environment, Land and Sea[337]. The objective of the project is to install renewable energy technology on priority schools and clinics in Antigua and Barbuda to ensure that these entities can operate in the period following extreme climate events. Another objective of the project was to ensure that greenhouse gas emissions and other waste and pollutants from schools are reduced and that knowledge about the environment is disseminated. The initial call for proposals was designed to provide up to 16 schools and clinics with a maximum grant of US$50,000 for the achievement of these objectives through the development of a Site Environmental Management Plan.

Small Island Developing States Sustainable Energy Initiative (SIDS DOCK) (2002–2016; EDF; US$14,500,000)

To provide SIDS with an institutional mechanism that will assist in the transformation of national energy sectors, the DOCK project was developed. The title of the initiative alludes to the fact that it was designed to serve as hub for connecting the energy sector in SIDS with global financial markets, as well as for sustainable energy technologies and carbon markets[338]. Interventions were developed to catalyse sustainable economic development, generate financial resources to address adaptation to climate change and ultimately to develop a sustainable energy economy within SIDS. The project was funded by the EU's 10th European Development Fund (EDF), and implemented by World Bank, Alliance of Small Island States (AOSIS) and the Government of Denmark — with UNDP acting as the Accredited Entity[339].

Sustainable Energy for the Eastern Caribbean (SEEC) Programme (2013–2015; GEF; US$3,013,698)

[336] GEF. 2018. Energy for sustainable development in Caribbean buildings. Available at: https://www.thegef.org/project/energy-sustainable-development-caribbean-buildings.
[337] DOE. 2017. Call for proposals. Available at: https://environment.gov.ag/assets/uploads/attachments/4bdd0-approved-call-for-proposals-grants-program-grid-interactive-solar-pv-systems-final-version-.pdf.
[338] SIDS DOCK. Nd. What is SIDS DOCK? Available at: https://sidsdock.org/what-is-sids-dock.
[339] Government of Grenada. 2010. SIDS DOCK Briefing note. Available at: https://www.gov.gd/egov/pdf/SIDS_DOCK_doc.pdf.

The SEEC programme[340] — implemented in the six countries of the Organisation of the Eastern Caribbean States (OECS) — was developed to reduce fossil fuel dependency in the region. SEEC's objective was to promote the implementation of energy efficiency (EE) interventions and renewable energy (RE) projects and solutions by increasing climate-friendly, financially viable investments. The project was comprised of four components, which included: i) building and strengthening institutional capacity; ii) providing technical assistance for RE and EE projects; iii) development of investment and financial mechanisms for pilot projects with a focus on EE; and iv) development of investment and financial mechanisms for pilot projects with a focus on RE.

6.2. Projects and initiatives without a focus on climate change adaptation

Biodiversity and Protected Area Management (BIOPAMA) Programme

The BIOPAMA programme — funded by the EU 10th European Development Fund (EDF) —included activities to: i) address threats to biodiversity in African, Caribbean and Pacific (ACP) countries; and ii) reduce poverty in local communities living in and around protected areas. These activities included building the capacity of institutions and networks by improving access to knowledge to inform policies and decision-making on biodiversity conservation, protected areas management as well as to facilitate benefit-sharing between stakeholders. The programme was developed and implemented by the International Union for Conservation of Nature (IUCN), European Commission Joint Research Centre (EC-JRC) and Access and Benefit Sharing (ABS) Capacity Development Initiative.

The Sustainable Island Resource Management Mechanism (SIRMM)

The Sustainable Island Resource Management Mechanism (SIRMM) was led by the DoE and was the result of a GEF-funded infrastructure project (2005–2011) implemented in Antigua and Barbuda. The main objective of SIRMM was to establish a comprehensive policy and develop an institutional framework for the management of island biodiversity. SIRMM and its associated projects integrated four outcomes, including: i) provision of easy and reliable access to information for environmental management by all stakeholders; ii) development of a Sustainable Island Resource Management Plan; iii) strengthening of policy and institutional reforms to provide a framework for implementation of SIRMM; and iv) establishment of requirements for the implementation of SIRMM as well as mechanisms for collecting and documenting lessons learned and best practices.

National Capacity Self-Assessment Project (2014)

The National Capacity Self-Assessment Project (NCSAP), undertaken in 2014, assessed the capacity requirements and constraints facing national efforts to improve environmental conservation and sustainable development programmes. It involved an assessment of the institutional capacity framework initiated under global environmental management obligations such as the UNFCCC. As part of the NCSAP, an analysis of systemic, institutional and sectoral requirements related to climate change adaptation was undertaken. The project also highlighted the scientific and technical linkages and synergies that exist between the numerous conventions and their associated national instruments.

Demonstrating the Development and Implementation of a Sustainable Island Resource Management Mechanism in a Small Island Developing State (SIDS) (2007–2013; GEF; US$7,896,330)

[340] European Commission. 2019. Sustainable Energy for the Eastern Caribbean Program. Available at: https://ec.europa.eu/europeaid/blending/sustainable-energy-eastern-caribbean-seec-program-0_en.

The ‘Demonstrating the Development and Implementation of a Sustainable Island Resource Management Mechanism in a Small Island Developing State (SIDS)’ project[341] was developed by the Division of Environment of the Ministry of Works, Transport and Environment, with UNDP as the Accredited Entity. Objectives of the project were to: i) promote integrated ecosystem management with a particular focus on biodiversity conservation; ii) ensure the sustainability and maintenance of ecosystem functioning through resource-use planning and management by implementing a SIRMM approach; and iii) promote continued sustainable economic development across the country.

The Path to 2020 — Antigua and Barbuda (2018–2021; GEF; US$8,320,477)

The objective of this project[342] — with GEF grant funding of US$2,729,153 — is to ensure the protection and sustainable use of biodiversity and protected areas, under the umbrella of the newly-enacted Environmental Protection and Management Act (EPMA). This objective will be achieved by: i) strengthening the regulatory, institutional and financial mechanisms for the effective implementation of the Act; ii) expanding the protected area network; and iii) promoting the sustainable use and conservation of biodiversity. The Accredited Entity for the project is UNEP and the Executing Entity is the DoE.

Integrating Water, Land, Resources and Ecosystems Management in Caribbean Small Island Developing States (IWEco) (2016–2020; GEF; US$89,039,262)

Antigua and Barbuda is one of ten participating Caribbean countries in the IWEco project — developed by UNEP and UNDP, with a grant of US$20,722,571 from GEF. The objectives of the overall IWEco project included: i) implementing an integrated approach to water, land and ecosystems services management; ii) ensuring that the integrated approach is supported by policy, institutional and legislative reforms; iii) adopting technologies to accelerate contribution to global targets on access to safe and reliable water supplies and improved sanitation; and iv) contributing to improved ecosystem functioning in the Caribbean. The project was implemented by UNEP and the Caribbean Public Health Agency (CARPHA).

Integrating Watershed and Coastal Area Management in Small Island Developing States of the Caribbean (IWCAM) (2007–2010; GEF; US$1,143,100)

The IWCAM initiative included a demonstration project, titled ‘Mitigation of groundwater and coastal impacts from sewage discharges from St John’s’. This demonstration project’s objective was to address coastal sewage and wastewater pollution from St John’s using a series of phased and coordinated initiatives. The project preceded an overall plan to identify a cost-effective solution to the challenge of sewage, both within St John’s and nationwide. UNEP was the Accredited Entity for the GEF-funded project, with the Secretariat of the Cartagena Convention and the Caribbean Environmental Health Institute implementing the project.

Developing a Strategic Approach to Sustainable Land Management (SLM) (2011–2014; GEF Trust Fund; US$1,488,000)

This project’s objective was to build local and regional capacity for supporting sustainable land management and to develop pilot demonstration activities for addressing land degradation at the community level in nine Caribbean countries — including Antigua and Barbuda[343]. By increasing the capacity of countries such as Antigua and Barbuda to apply adaptive management tools in SLM, the project contributed to the goal of a decline and reversal of land degradation globally — particularly desertification and deforestation. It was

[341] GEF. 2014. Demonstrating the Development and Implementation of a Sustainable Island Resource Management Mechanism in Antigua and Barbuda: Terminal Evaluation. Available at: https://erc.undp.org/evaluation/documents/download/8492.
[342] GEF. 2019. The Path to 2020 - Antigua and Barbuda. Available at: https://www.thegef.org/project/path-2020-antigua-and-barbuda.
[343] GEF. 2019. Developing a Strategic Approach to Sustainable Land Management. Available at: https://www.thegef.org/project/developing-strategic-approach-sustainable-land-management.

executed by the Environment Division of the Ministry of Agriculture, Lands, Housing and the Environment. The Implementing Agency for the project was the GEF Secretariat.

Sustainable Financing and Management of Eastern Caribbean Marine Ecosystem Project (2011–2016; GEF; US$19,122,000)

This project's primary objective was to contribute to increasing the long-term sustainability of protected area networks in the Organisation of Eastern Caribbean States (OECS) region. Activities under this project included *inter alia* the: i) establishment of sustainable financing mechanisms — including the Caribbean Biodiversity Fund (CBF); ii) strengthening of marine protected area networks; and iii) deployment of a regional monitoring and information system for protected area networks. The Implementing Agency for the project was the World Bank and the Executing Entities were The Nature Conservancy and UNEP[344], with a grant of US$8,750,000 received from the GEF.

Public and Social Sector Transformation (PSST) project (2013–2018; World Bank; US$10,000,000)

The PSST project was funded by a World Bank Specific Investment Loan and implemented by the Ministry of Finance, the Economy and Public Administration. Objectives of the PSST project included: i) strengthening capacity in managing public policies and the public service; ii) improving efficiency of social protection spending by using an integrated monitoring and targeting system; and iii) improving the income and employability of vulnerable population sectors through temporary employment and training programmes.

Monitoring and Assessment of Multilateral Environmental Agreements (MEA) Implementation and Environmental Trends in Antigua and Barbuda (2016; GEF; US$1,830,000)

The objective of the project[345] was to strengthen institutional capacity for effective management of information systems for national multilateral environmental agreements (MEA) and obligations, as well as monitoring their impacts and progress. It was executed by the DoE, with UNDP as Implementing Agency and a grant of US$880,000. The project's objectives were to: i) enhance institutional arrangements and operational platforms for environmental monitoring; and ii) improve the generation, access and use of environmental information and knowledge in the country.

7. Best practices and lessons learned

Extreme climate events, particularly hurricanes and tropical storms, cause severe damage to Antigua and Barbuda's critical infrastructure[346] and housing, as well as disruptions to basic services[347]. The impacts of these events are expected to worsen significantly under future climate change conditions because of the expected increase in the frequency of Category 4 and 5 hurricanes. International and regional best practices for increasing the resilience of the building sector to withstand Category 4 and 5 hurricanes, as well as lessons learned from national and regional initiatives, are discussed below.

7.1. Increasing building code compliance

[344] The World Bank. 2019. Sustainable Financing & Management of Eastern Caribbean Marine Ecosystem Project. Available at: http://projects.worldbank.org/P103470/sustainable-financing-management-eastern-caribbean-marine-ecosystem?lang=en&tab=details.
[345] GEF. 2019. Monitoring and Assessment of MEA Implementation and Environmental Trends in Antigua and Barbuda. Available at: https://www.thegef.org/project/monitoring-and-assessment-mea-implementation-and-environmental-trends-antigua-and-barbuda.
[346] including hospitals/clinics, police and fire stations as well as buildings that serve as storm shelters
[347] including health, education, telecommunication, electricity, water, sewage and waste systems

The wind speeds experienced during Hurricane Irma in 2017 were unprecedented and exceeded the regulations of the OECS Building Code, resulting in severe damage to the country's infrastructure. The impacts of Hurricane Irma on Antigua and Barbuda highlighted the need to regularly revise the building code and to approach the document as an evolving tool to be adjusted regularly according to changing climatic conditions[348]. Revising building codes to account for extreme events has been proven to be an effective measure for reducing the damages associated with these events. For example, after Hurricane Andrew struck Florida in 1992, the state introduced new building regulations which have since significantly reduced damage from extreme climate events[349]. These updates to the Florida Building Code have shown to reduce the damage caused by hurricanes by up to 72%[350]. Similar reductions in damages are likely to be experienced as a result of revisions to the OECS Building Code, which were conducted in 2015. This code was revised to provide standards and guidelines for implementing climate-resilient measures to improve the resilience of buildings to withstand the maximum sustained wind speeds of Category 4 and 5 hurricanes[351]. Such measures include increasing the structural integrity of buildings through installing hurricane shutters and securing roofs with hurricane straps. The OECS Building Code is currently under peer review to tailor it to the technical specifications and standards of Antigua and Barbuda.

Applying the building code requires effective technology, accurate data, accountability and local governments with strong technical capacity[352]. The code stipulates that planning authorities should ensure all developments are aligned with the physical, social and economic environment in each Member State[353]. Furthermore, the building code regulations should be closely followed by government entities responsible for construction and maintenance of buildings as well as architects and construction staff. To ensure that there is uptake of the building code, training will be provided under Output 2 of the project to relevant government decision-makers such as the Development Control Authority (DCA) and Public Works Department, as well as the local workforce. This training will focus on the effective application of the building code. In addition, awareness raising campaigns will be conducted on the availability of this training and to promote the benefits of complying with the regulations of the building code, which accounts for Category 4 and 5 hurricanes. The relevant construction guidelines and designs for climate-proofing infrastructure in accordance with the building code are described in the sections below.

[348] Donovan.2017. How the Caribbean can prepare for more violent hurricanes. Available at: https://www.americasquarterly.org/content/how-caribbean-can-prepare-more-violent-hurricanes
[349] Donovan.2017. How the Caribbean can prepare for more violent hurricanes. Available at: https://www.americasquarterly.org/content/how-caribbean-can-prepare-more-violent-hurricanes
[350] Simmons, Kevin M., Jeffrey Czajkowski, and James M. Done. "Economic effectiveness of implementing a statewide building code: the case of Florida." *Land Economics* 94, no. 2 (2018)
[351] Regulations in this Building Code include measurements using the Imperial System. This system has therefore been used for referring to measurements. For ease of reference, the conversions are as follows: 1 foot is equal to 0.3048 m, and 1-inch equals 0.0254 m.
[352] Hare, M. et al., 2014. A Best Practices Notebook for Disaster Risk Reduction and Climate Change Adaptation: Guidance and Insights for Policy and Practice from the CATALYST Project. TWAS The World Academy of Sciences-for the advancement of science in developing countries
[353] OECS. 2016.OECS Building Code. 7th Edition.

7.2. Climate-proofing infrastructure

Under Activity 1.1 of the proposed project, priority buildings will receive climate-proofing interventions to strengthen their ability to withstand the impacts of Category 4 and 5 hurricanes. Interventions under this activity, focused on increasing the structural integrity of priority critical public service and community buildings, are expected to deliver adaptation benefits for 50 years, while the installation of solar PV panels and climate-resilient water harvesting solutions on targeted buildings are expected to deliver adaptation benefits for 20 years [354,355]. The expected lifetime of project interventions was determined based on consultations with local engineers as well as experts and representatives from the DoE, MoW and DCA. In addition, these buildings will be fitted with renewable energy (RE) and climate-resilient water harvesting solutions. Examples of proposed adaptation interventions to increase the structural integrity of infrastructure to withstand the wind speeds of high-intensity hurricanes (Category 4 and 5) are presented below. Site-specific designs and physical upgrades to priority buildings will be undertaken with consideration of the best practices described in this section.

7.2.1. Best practices for reducing wind damage

The design of all climate-proofing interventions will adhere to the OECS Building Code. This code states that engineering designs are conducted in accordance with internationally recognised standards; the standards of the American Society of Civil Engineers (ASCE) are often the most commonly used standards, making provision for wind speeds of ~270 km/h (which are associated with Category 5 hurricanes). Moreover, the OECS Building Code includes a clause to account for the future impacts of climate change, which recommends that wind speeds listed in the relevant section of the code should be increased by a factor of 1.13 for most buildings and 1.10 for critical facilities[356]. The OECS Building Code therefore adequately accounts for the projected increase in frequency of Category 4 and 5 hurricanes in Antigua and Barbuda.

Factors that influence the impact that wind has on infrastructure in the country include: i) the source of loading — external pressure exerted by moving air; ii) the type and duration of loading — storms last for several hours, with loads fluctuating but force exerted predominantly in one direction; iii) predictability of loads — which can be accurately ascertained from records or analysis of site and win patterns; iv) external shape and size of the infrastructure; and v) the design of non-structural elements — wind loading is confined to external cladding[357]. Taking these factors into account, wind can cause significant damage to buildings during extreme events. Wind entering a building through an opening on the windward side may result in severe pressure on the internal surfaces which — in combination with external suction — may cause the roof to blow off or the walls to explode[358] (demonstrated in Figure 35 a). To mitigate this effect, pressure may be relieved by creating an opening on the leeward side of the building, corresponding with the opening on the windward side (Figure 35 b).

[354] UNDP. 2011. Pacing the Way for Climate-Resilient Infrastructure. Available at: https://www.uncclearn.org/sites/default/files/inventory/undp_paving_the_way.pdf
[355] GIZ. 2011. Climate proofing for development. Available at: https://www.adaptationcommunity.net/?wpfb_dl=34
[356] OECS. 2016.OECS Building Code. 7th Edition.
[357] OECS. 2016.OECS Building Code. 7th Edition.
[358] DOE. 2019. Guide on Best Construction Practices

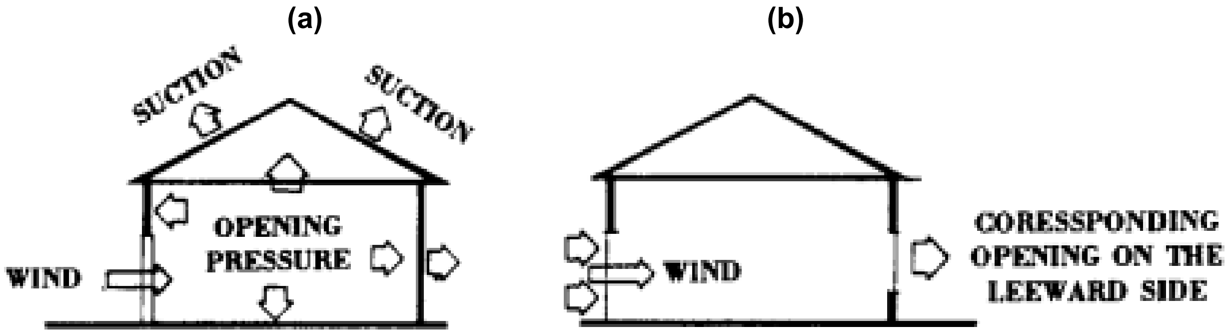


Figure 35. (a) Pressure on internal surfaces from wind entering through openings on the windward side; (b) Relieving pressure exerted on the internal surfaces of a building[359].

Roof design should also include consideration of the maximum sustained wind speeds of Category 4 and 5 hurricanes. It is necessary to ensure that the design of buildings for improved resilience under future climate change conditions do not include long overhangs, which increase the risk of wind damage. Roof pitch should not be less than 25˚, as to reduce the effects of uplifting forces. In addition, hip roofs (Figure 36) have been found to be more resistant to hurricanes than gable roofs (Figures 37). Research and lessons learned have shown that hip roofs with a pitch of 25˚–40˚ are the most wind-resistant

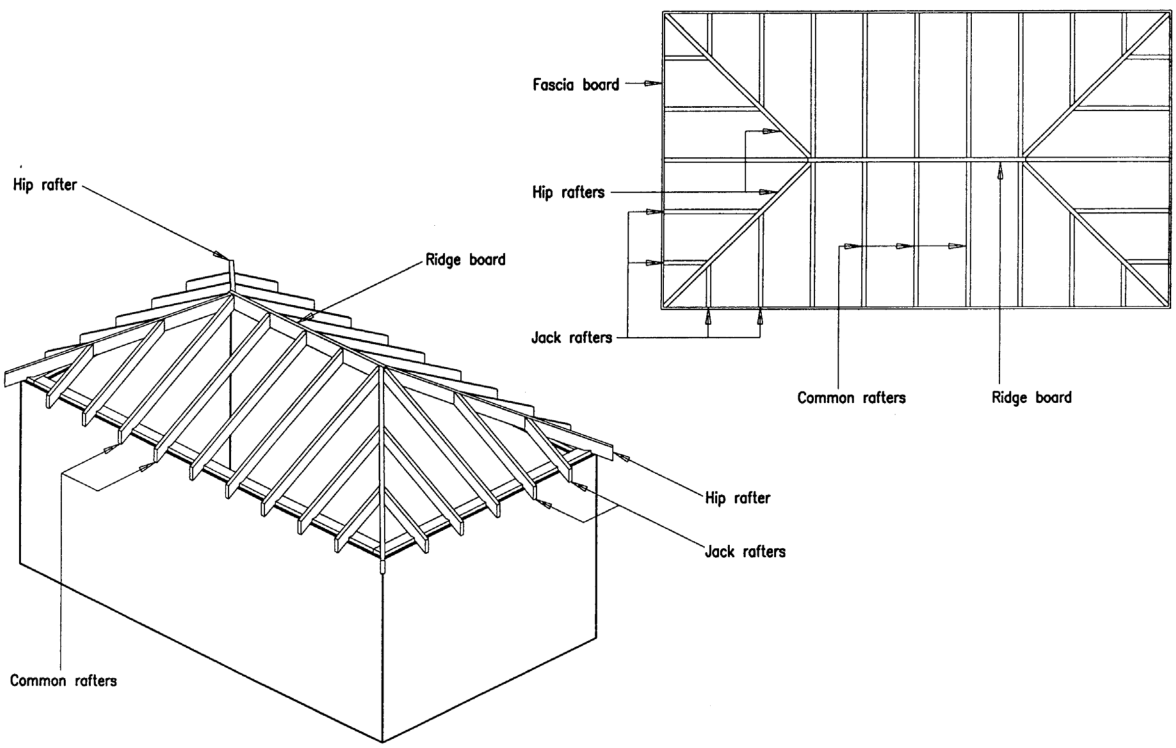


Figure 36. Hip roof configuration with a pitch of 25–40˚[360].

[359] DOE. 2019. Guide on Best Construction Practices.
[360] DOE. 2019. Guide on Best Construction Practices.

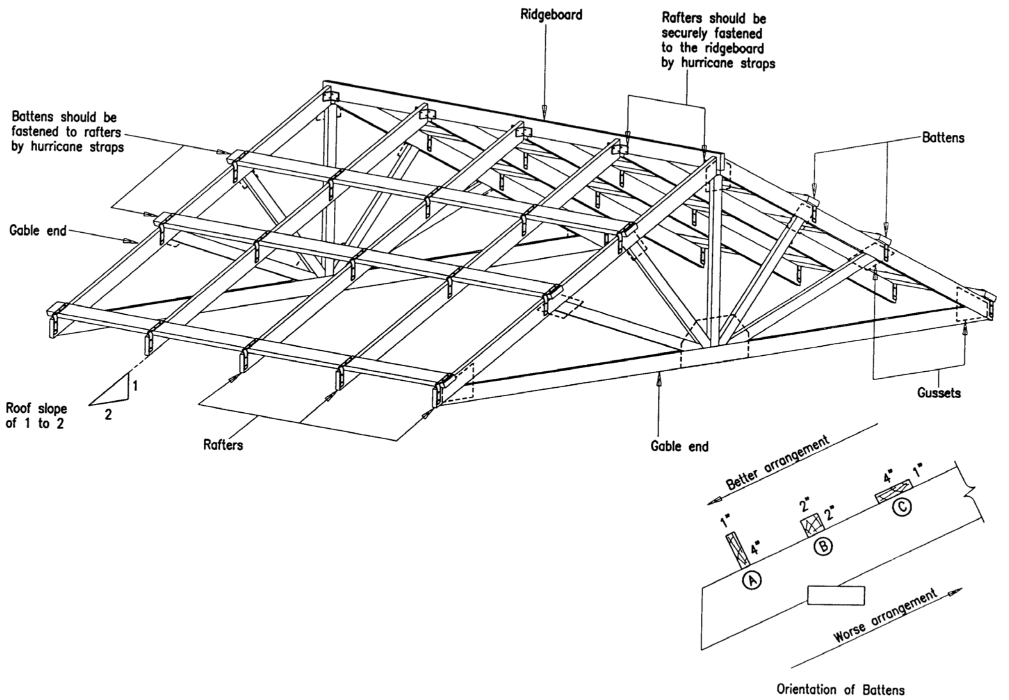


Figure 37. Gable roof[361].

It is recommended that verandas and patio roofs should be built as external structures, rather than as part of the main building structure. Experience has shown that when this principle is not followed, damage to the entire building is more common. In addition, roof sheeting should be carefully considered. Sheets that are too thin may tear loose from screws. To avoid this, broad fittings with a washer or dome head are recommended. Nails should not be used to secure roof material, as these possess a greater likelihood of becoming detached. Proper drive screws should be used and inserted into purlins by at least two inches[362]. Damage from wind on roof material can also be decreased by reducing rafter span and extending the wall vertically for extra support. In addition, the roof can be further strengthened by using a collar tie to create an A-frame which secures the two sides in the central ridge (Figure 38).

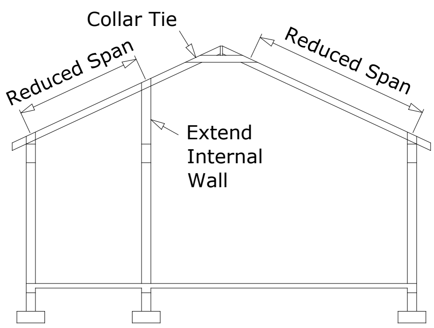


Figure 38. Reduced rafter span for improved roof strength[363].

7.2.2. Timber building construction

The maximum sustained wind speeds associated with Category 4 and 5 hurricanes result in considerable damage to wooden building infrastructure. Several best practices exist to reduce the impacts of these

[361] DOE. 2019. Guide on Best Construction Practices.
[362] DOE. 2019. Guide on Best Construction Practices
[363] DOE. 2019. Guide on Best Construction Practices.

hurricanes on this type of infrastructure, including: i) bracing all corners and intersections adequately (see Figure 31 below); ii) securing sills to building foundations to avoid the separation of buildings from their foundations; iii) fastening roof sheeting securely to rafters — which should in turn be securely fastened to wall plates and ring beams; iv) anchoring of foundations in a secure manner (Figure 32); and v) reinforcing wall openings[364]. In addition, climate-resilient timber — for example, pitch pine or mahogany — should be used for hurricane shutters and window frames to increase the structural integrity of buildings. These best practices will be applied to the design and implementation of climate-proofing interventions to be implemented under Output 1 of the proposed project, where wooden infrastructures are targeted to receive adaptation upgrades.

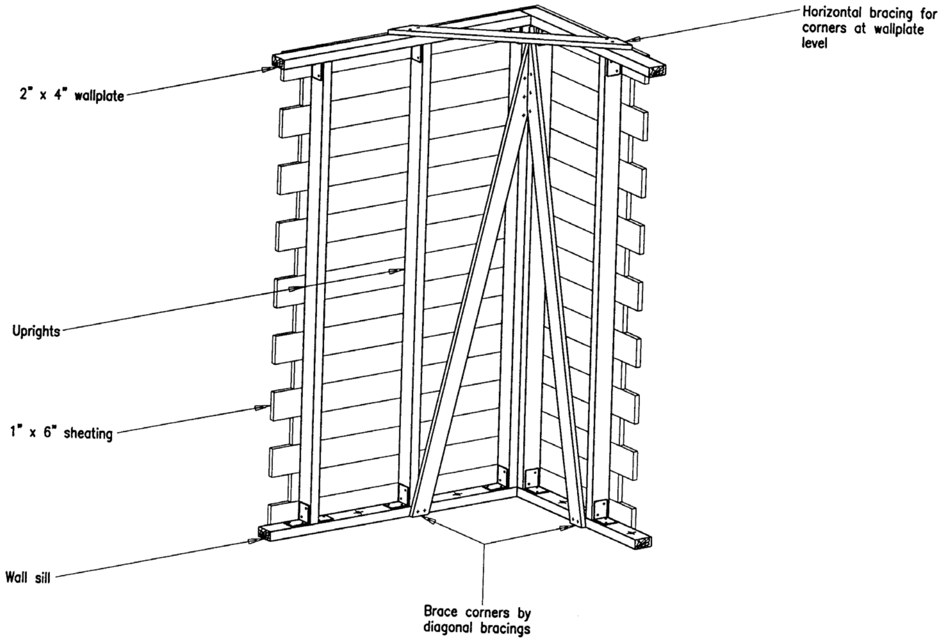


Figure 31. Details of timber frame corner brace[365].

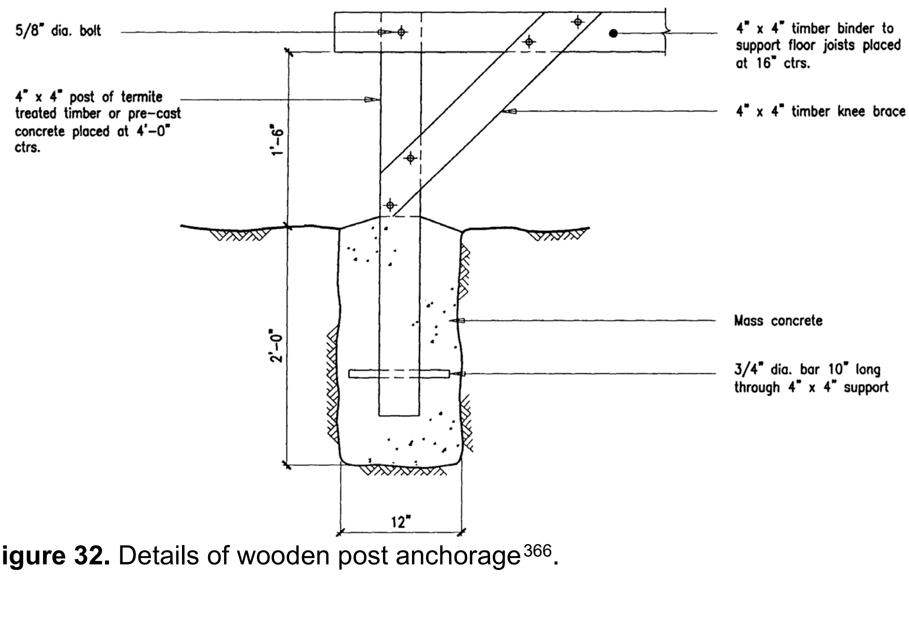


Figure 32. Details of wooden post anchorage[366].

[364] DOE. 2019. Guide on Best Construction Practices.
[365] DOE. 2019. Guide on Best Construction Practices.
[366] DOE. 2019. Guide on Best Construction Practices.

7.2.3. Concrete building constructions

The resilience of buildings constructed with concrete can be increased by following the general principle of ensuring that all elements are securely fixed together. Best practices for doing this include: i) anchoring walls vertically to floors (Figure 33); ii) reinforcing openings for doors and windows with concrete columns or lintels; iii) capping all walls with a continuous concrete beam of the same width as the wall and a minimum of 8 inches deep; iv) installing horizontal and vertical wall reinforcement (Figure 34); and v) anchoring the roof to the wall plate, which is anchored to the ring beam[367]. These best practices will be applied to the design and implementation of climate-proofing interventions that will be implemented under Output 1 of the proposed project.

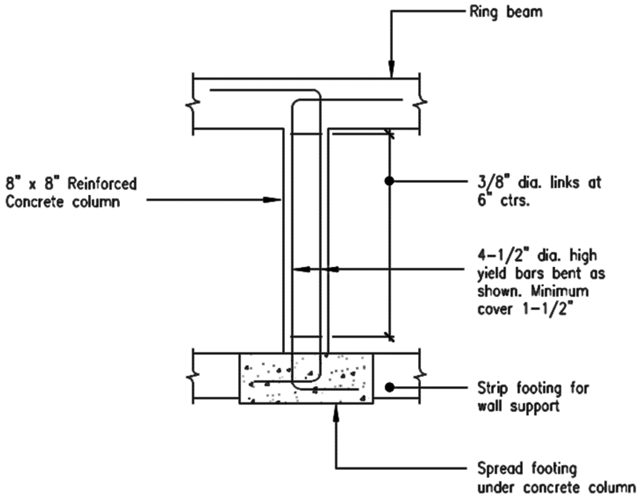


Figure 33. Column Anchorage Detail[368].

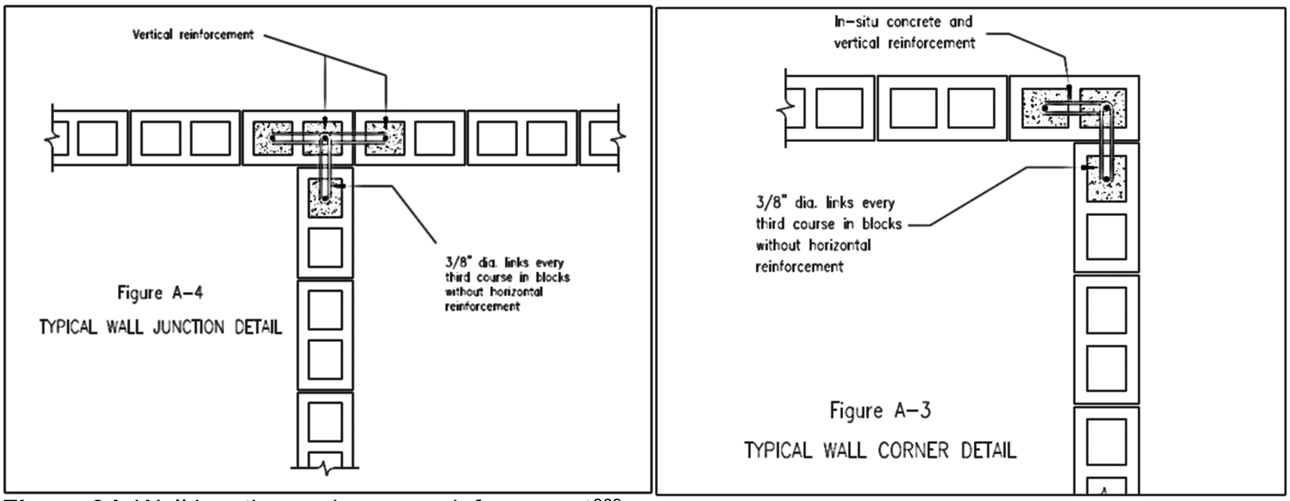


Figure 34. Wall junction and corner reinforcement[369].

7.2.4. Installing renewable energy infrastructure

[367] DOE. 2019. Guide on Best Construction Practices
[368] DOE. 2019. Guide on Best Construction Practices.
[369] DOE. 2019. Guide on Best Construction Practices.

The installation of renewable energy infrastructure should be guided by international best practices. These include guidelines for increasing the resilience of interventions and to ensure their efficiency. In addition, logistical considerations and regulations on improved energy efficiency are provided.

Solar panels

The installation of solar panels is part of a broader strategy of the Government of Antigua and Barbuda (GoAB) to implement policies for adaptation to and mitigation of climate change. The 'Solar PV facility screening study for public and educational facilities on Antigua and Barbuda' — a technical report compiled by the United Nations Electricity Partnership (2018)[370] — provides recommendations for the appropriate installation of solar panels. The report informed the suitability of ground and roof installation on several public buildings. The criteria for the assessment of site suitability for the installation of solar panels include: i) roof structure and covering; ii) building structure; iii) access for installation and maintenance; iv) wind exposure; v) shading — which influences the precise, preferred location of the installation and particularly impacts the potential for ground mounting; vi) tilt — a south-facing orientation and a comprehensive tilt analysis are recommended; and vii) security and potential for flooding[371].

In more than half of the 18 buildings surveyed for the UN report, investments in the strengthening of roofs and replacement of sheet steel roof coverings were recommended. The report noted that the installation of solar panels, prior to the upgrading of degraded roof sheeting, is not economically viable. In these cases, it is preferred that the roof sheeting should be renewed before the installation of the panels. This should be considered on a case by case basis. The study highlights the need for detailed design, costing and final site and scope selection.

The installation of solar panels should be undertaken in accordance with several recommendations. These include: i) ensuring the complementarity of components; ii) considering potential failure points; iii) designing systems in a maintenance-friendly manner — a well-maintained PV array has a lifespan of up to 25 years[372]; iv) mapping out the roof prior to installation to ensure that the configuration maximises the amount of sunlight received; v) considering the effects of wind in combination with the shape of the roof or other architectural elements; vi) accounting for the potential effects of seismic activity on the stability of panels; and vii) ensuring placement takes account of potential peak energy demand[373].

For the management of hurricane risk, vulnerability of solar PV panels — as well as typical roof structures in Antigua and Barbuda — can be decreased through good design, precautionary actions and investment in climate-proofing interventions[374]. Flat-lying roof installations are recommended for resilience to hurricane-force winds, as well as for the reduction of cost. Roof-mounted PV panels should be flush to the roof and low profile, with a maximum air gap of 50 mm[375]. A 50% increase in the density of fixtures — above the standard prescribed density — is recommended for the installation of solar panels, because these are the most common failure points[376]. Weak roof pitches should be reinforced prior to the installation of solar panels by: i) replacing nails and corroded screws with new screws; and ii) reinforcing timber frame joints with straps, ties and clips. Weatherproofing of control and battery rooms should be prioritised, as these can be severely damaged by water infiltration.

[370] UN electric. 2018. Solar PV facility screening study for public and educational facilities on Antigua and Barbuda.
[371] UN electric. 2018. Solar PV facility screening study for public and educational facilities on Antigua and Barbuda.
[372] UN electric. 2018. Solar PV facility screening study for public and educational facilities on Antigua and Barbuda.
[373] Graphicsproducts. n.d. 5 Solar Installation Best Practices You Need to Know. Available at: https://www.graphicproducts.com/articles/5-solar-installation-best-practices-you-need-to-know/
[374] UN electric. 2018. Solar PV facility screening study for public and educational facilities on Antigua and Barbuda.
[375] UN electric. 2018. Solar PV facility screening study for public and educational facilities on Antigua and Barbuda.
[376] UN electric. 2018. Solar PV facility screening study for public and educational facilities on Antigua and Barbuda.

Logistics and procurement

Transportation and logistics relating to the procurement and delivery of solar panels can pose significant challenges to projects. The Fiji LaKaRo Solar Fuel Saving Project demonstrated that this aspect should be carefully considered in project design, particularly on remote islands. This was also observed in Tuvalu, where the simultaneous implementation of several projects resulted in increased pressure on port infrastructure. By including buffers in schedules to account for this potential challenge, the timely implementation of interventions can be ensured. Proactive planning can also ensure that limitations in port capacity can be overcome[377]. These lessons will be taken into account during the implementation of Activity 1.4, where renewable energy equipment will be installed on priority buildings. Furthermore, the lessons learned from logistical challenges that were encountered during the implementation of the Fijian solar project were drawn on to design an effective mechanism for reducing the risk of these challenges arising under the proposed project. Specifically, a climate-resilient bunker will be constructed under Activity 1.3 of the project to stock critical supplies, including backup solar PV panels and other renewable energy equipment. This will ensure that logistical challenges are avoided and solar PV panels for priority buildings are easily accessible during and immediately after an extreme climate event.

7.3. Best practices for construction using climate-resilient methods

Under Output 1 of the proposed project, a climate-resilient bunker will be constructed, and shelters will be built on to five selected clinics. The design and construction of this infrastructure will follow the regulations of the OECS Building Code, which account for the impacts of Category 4 and 5 hurricanes. In addition, best practices that will be followed for the design and installation of drainage solutions as well as the selection of building materials and building sites for these structures are presented below.

7.3.1. Drainage and septic tanks

Section 814 of the OECS Building Code notes that more frequent Category 4 and 5 hurricanes will increase the pressure on drainage systems in Antigua and Barbuda. Several best practices exist for fitting septic tanks to account for increased storm water run-off and ensure that this run-off does not enter into these tanks[378]. Firstly, the largest possible area available for effluent disposal — through soakaways or land drains — should be chosen for the location of septic tanks[379]. And secondly, these tanks should be installed: i) downstream of cisterns; ii) at least 5 feet from any building; iii) at least 8 feet from any property boundary; iv) at least 10 feet away from any tree; v) 25 feet from any stream; and vi) at least 150 feet from any drinking well[380]. Soakaways may not be within 10 feet of a site boundary, 15 feet from a building, 100 feet from a stream used for freshwater supply or 150 feet from a well.

Additionally, drainage disposal should be located downstream from water cisterns and the location and size of soakaways should be approved by the Ministry of Health[381]. Soakaway pits should also be lined with stones or concrete blocks, with open joints backed by at least 3 inches of course gravel. Land drains constructed of pipes should be laid in areas not surfaced with impervious materials. In addition, pipe trenches should be at a minimum width of 1 foot 6 inches, minimum depth of 3 feet and a maximum length of 100 feet. Pipe runs may not be located within 5 feet of one another or any building or site boundary, and they may not be located within 50 feet of any well. Lastly, pipes should be a maximum length of 2 feet or alternative and should have holes covering at least 20% of their surface[382].

[377] International Renewable Energy Agency (IRENA). 2016. A Path to Prosperity: Renewable energy for islands. Third Edition. Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_Path_to_Prosperity_Islands_2016.pdf
[378] OECS. 2016.OECS Building Code. 7th Edition.
[379] DOE. 2019. Guide on Best Construction Practices
[380] DOE. 2019. Guide on Best Construction Practices
[381] DOE. 2019. Guide on Best Construction Practices
[382] DOE. 2019. Guide on Best Construction Practices

7.3.2. Bearing capacity of soil and slope stability

Section 1302.3 of the OECS Building Code notes that deep foundations are less vulnerable to destabilisation caused by changes in rainfall patterns and groundwater levels. Foundations may also be affected by increasing subsidence in some soils, which results in lower bearing capacity. In addition, Section 1309.2 notes that although land slippages can be triggered by several factors — including earthquakes, volcanic activity and human intervention — these effects are expected to worsen under future climate conditions, as precipitation patterns become more erratic. This is the result of: i) reduction of vegetative cover on slopes as a result of drought; ii) weakening of the structure of slopes as a result of wetting and drying shrinkage of clay soils; iii) introduction of planes of weakness as a result of heavy rainfall; and iv) increased risk of slippage as a result of sudden changes in groundwater levels adjacent to slopes. To avoid these risks, the following best practices will be considered during the design and construction of the climate-resilient bunker and shelters: i) re-using existing foundations or building on sites where there has previously been human activity will be prioritised for these project activities; ii) construction will ideally take place at least 10 m away from the base of a slope; and iii) construction undertaken on a terrace will ideally take place 6 m from the back and 6 m from the crest of the terrace. In addition, in accordance with Section 602 of the OECS Building Code, Construction activities under Activities 1.2 and 1.3 of the project will prioritise the reuse of construction materials from the demolition of buildings. Moreover, no materials of sufficient quality and quantity will discarded, but instead will be reused where feasible.

7.4. Increasing access to financial resources for climate change action

Antigua and Barbuda has limited financial capacity to address the challenge of adapting to extreme climate events. Funding constraints — particularly at national level — constitute a considerable risk to project sustainability[383] and can result in limited technical and human resource capacity for implementation of interventions[384]. Lessons learned from the implementation of the Barbados Programme of Action (BPOA)[385] and the Mauritius Strategy of Implementation (MSI)[386] have demonstrated that management plans for adaptation to climate change are more effective when access to financing is improved[387]. Best practices and lessons learned for accessing financial resources for climate change adaptation are described in further detail below.

Collaboration with the international community for the development of funding mechanisms and accessing international sources of finance have been proven to increase the sustainability of project interventions — particularly in the Caribbean region where capacity limitations are often a significant challenge[388]. To address this challenge, countries should develop funding mechanisms for adaptation finance by mobilising resources both nationally and internationally. For example, in Antigua and Barbuda the SIRF fund has been established to mobilise financial resources for projects relating to environmental sustainability (see Section 5). The fund generates revenue from the sale of ecosystem services and the provision of other services — including wastewater management and the treatment and resale of used oil — at lower rates than the

[383] GEF. 2019. Integrating Watershed and Coastal Area Management in Small Island Developing States of the Caribbean. Available at: https://www.thegef.org/project/integrating-watershed-and-coastal-area-management-iwcam-small-island-developing-states
[384] European Commission. 2019. European Commission. 2019. Sustainable Energy for the Eastern Caribbean (SEEC) Programme. Available at: https://ec.europa.eu/europeaid/blending/sustainable-energy-eastern-caribbean-seec-program-0_en. Available at: https://ec.europa.eu/europeaid/blending/sustainable-energy-eastern-caribbean-seec-program-0_en.
[385] Officially known as the United Nations Programme of Action on the Sustainable Development of Small Island Developing States — a document detailing the economic, social and environmental vulnerabilities of island nations.
[386] The strategy developed for the implementation of the plan of action for the sustainable develop of SIDS
[387] Gore-Francis, J. 2013. Antigua and Barbuda SIDS 2014 Preparatory Progress Report. Available at: http://wedocs.unep.org/bitstream/handle/20.500.11822/8437/Antigua_and_Barbuda.pdf?sequence=3&isAllowed=y.
[388] Gore-Francis, J. 2013. Antigua and Barbuda SIDS 2014 Preparatory Progress Report. Available at: http://wedocs.unep.org/bitstream/handle/20.500.11822/8437/Antigua_and_Barbuda.pdf?sequence=3&isAllowed=y.

private sector[389]. SIRF has several different channels, including for funding mitigation, adaptation, forestry, NGOs and protected areas[390]. Because of the complex nature of the Fund, its role should be clearly defined within the project context. The 'Sustainable Pathways — Protected Areas and Renewable Energy (SPPARE)' project has demonstrated that this is a necessary prerequisite for ensuring the efficient allocation of resources and the ability of international partners to provide oversight of the implementation of funds. For the proposed project, the SIRF Fund will serve as a source of co-financing. The 'Integrating Watershed and Coastal Area Management in Small Island Developing States of the Caribbean' project demonstrated that tracking of co-financing should be systematic and continuous to improve project outcomes[391]. Lessons learned and best practices from how the SIRF Fund operates were taken into consideration when designing Activity 2.2 of the proposed project. In particular, best practices were considered for creating entry points to increase public and private sector access to financial resources specifically for climate change adaptation in the building sector. Lessons learned that are generated through the implementation of this proposed project activity will continue to be shared to improve the effectiveness of the SIRF Fund as a viable option for accessing financing for adaptation within the building sector.

7.5. Policy- and decision-making for sustainable development and disaster planning

In Antigua and Barbuda, many development policies implemented in the past decades have insufficiently addressed the impacts of climate change and consequently do not result in patterns of sustainable development[392]. Indeed, the promotion of sustainable development has not been adequately facilitated by the process for creating a suitable legislative environment[393]. However, opportunities exist to integrate climate change considerations into policies for the achievement of development goals[394]. Under the proposed project, amendments to the Physical Planning Act 2003 will be drafted (Activity 2.1) to make provision for the building code, which accounts for the impacts of Category 4 and 5 hurricanes. The best practices and lessons learned presented below were used to inform the design of this project activity and will also be considered during implementation.

A strong correlation exists between good governance and effectiveness in risk reduction and disaster preparedness. Best practices in this regard can be summarised in 12 primary considerations, including: i) social cohesion and solidarity; ii) trust between civil society and government; iii) political commitment; iv) efficient coordination; v) institutional knowledge-sharing and cooperation; vi) consideration of the most vulnerable groups within society; vii) attention to critical infrastructure; viii) investment in human development; ix) investment in economic development; x) implementation of effective systems for risk communication; xi) social capital; and xii) institutional capital[395]. For the development and implementation of interventions related to disaster risk reduction (DRR) and disaster risk management (DRM), political will is necessary to overcome limitations in availability of finance from international funding bodies[396].

The shifting political landscape in Antigua and Barbuda is a significant factor in the potential for success of projects with the objective of building resilience to the impacts of climate change[397]. Therefore, effective

[389] Gore-Francis, J. 2013. Antigua and Barbuda SIDS 2014 Preparatory Progress Report. Available at: http://wedocs.unep.org/bitstream/handle/20.500.11822/8437/Antigua_and_Barbuda.pdf?sequence=3&isAllowed=y.
[390] Andrew. D., n.d. Antigua and Barbuda GEF Funded Protected Areas Project: Financial Assessment & SPPARE Project. Available at: https://www.cbd.int/doc/meetings/ecr/cbwecr-2014-03/other/cbwecr-2014-03-day2-05-en.pdf.
[391] GEF. 2019. Integrating Watershed and Coastal Area Management in Small Island Developing States of the Caribbean. Available at: https://www.thegef.org/project/integrating-watershed-and-coastal-area-management-iwcam-small-island-developing-states.
[392] Sustainable development and climate change: lessons from country studies
[393] Gore-Francis, J. 2013. Antigua and Barbuda SIDS 2014 Preparatory Progress Report. Available at: http://wedocs.unep.org/bitstream/handle/20.500.11822/8437/Antigua_and_Barbuda.pdf?sequence=3&isAllowed=y.
[394] Sustainable development and climate change: lessons from country studies
[395] Hare, M. et al., 2014. A Best Practices Notebook for Disaster Risk Reduction and Climate Change Adaptation: Guidance and Insights for Policy and Practice from the CATALYST Project. TWAS The World Academy of Sciences-for the advancement of science in developing countries
[396] Sustainable development and climate change: lessons from country studies
[397] Gray, B., 2018. Building resilience in Small Island Developing States: social media during the 2017 Atlantic hurricane season.

project design and implementation require careful consideration of the policy and institutional landscape. Lessons learned from the 'Demonstrating the Development and Implementation of a Sustainable Island Resource Management Mechanism in a Small Island Developing State' project have shown that the success of project outcomes, as well as their sustainability, can greatly benefit from the buy-in of technical government staff and direct involvement of higher-level government officials[398,399]. Frequent and regular updates to senior public servants and parliament officials can assist in garnering high-level political support for project activities[400]. In addition, the involvement of highly visible regional institutions, relevant national ministries and multi-stakeholder committees and the inclusion of awareness-raising campaigns in project interventions, can increase the potential for high-level political support[401]. Personnel from implementing ministries can take ownership of interventions by being intricately involved in the design phase of projects [402]. The legitimacy of interventions can also be increased by involving grassroots organisations and NGOs[403].

Timeframes required for project development and implementation are another important consideration. Achievement of policy and institutional reforms are challenging when the time frame is short, and a certain degree of flexibility is required to accommodate project components relating to policy changes[404]. Therefore, deliverables including policies and institutional changes requiring parliamentary approval must allow for realistic project duration[405]. In addition, experiences from the Public and Social Sector Transformation (PSST) project highlighted that the timing of project implementation can impact the success of the interventions and should ideally coincide with the start of the administrative cycle[406]. For example, shortly after the implementation of the PSST project, national elections were held, which negatively impacted the planned schedule. With a new administration in office — with different priorities to those outlined in the project outcomes — a year-long restructuring of the project had to be undertaken[407].

7.6. Strengthening cross-sectoral collaboration

Effectiveness of project outcomes can be increased through considering best practices and lessons learned from past and ongoing initiatives for improving cross-sectoral cooperation and collaboration. The scientific and technical advisory panel (STAP) that reviewed the 'Building climate resilience through innovative financing mechanisms for climate change adaptation' project noted that an adaptive strategy in a single sector may have adverse effects on response measures in other sectors[408]. Initial policy responses to climate change in many Caribbean countries were focussed on single sectors rather than on multisector challenges[409]. The Development Control Authority (DCA) — a statutory corporation governed by the

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398 Demonstrating the Development and Implementation of a Sustainable Island Resource Management Mechanism in a Small Island Developing State

399 GEF. 2019. Integrating Watershed and Coastal Area Management in Small Island Developing States of the Caribbean. Available at: https://www.thegef.org/project/integrating-watershed-and-coastal-area-management-iwcam-small-island-developing-states

400 Demonstrating the Development and Implementation of a Sustainable Island Resource Management Mechanism in a Small Island Developing State (SIRMM SIDS)

401 Deeb A. 2002. Lessons learned – Caribbean: Planning for Adaptation to Global Climate Change (CPACC). Climate Change Discussion Paper, Environment Department and the World Bank.

402 World Bank. 2019. Public and Social Sector Transformation (PSST) project. Available at: http://projects.worldbank.org/P126791/public-social-sector-transformation-project-psst?lang=en.

403 World Bank. 2013. Project appraisal document on a proposed loan in the amount of US$10 million to Antigua and Barbuda for a public and social sector transformation project (PSST).

404 World Bank. 2019. Public and Social Sector Transformation (PSST) project. Available at: http://projects.worldbank.org/P126791/public-social-sector-transformation-project-psst?lang=en.

405 GEF. 2014. Demonstrating the Development and Implementation of a Sustainable Island Resource Management Mechanism in a Small Island Developing State (SIRMM SIDS): Terminal Evaluation

406 World Bank. 2019. Public and Social Sector Transformation (PSST) project. Available at: http://projects.worldbank.org/P126791/public-social-sector-transformation-project-psst?lang=en.

407 http://documents.worldbank.org/curated/en/829301506636121252/pdf/IL-FRESDATA-EXT-P126791-09-28-2017-1506636107234.pdf.

408 GEF. 2019. Building climate resilience through innovative financing mechanisms for climate change adaptation. Available at: https://www.thegef.org/project/building-climate-resilience-through-innovative-financing-mechanisms-climate-change.

409 IEG. 2011. Adapting to Climate change: assessing the World Bank Group Experience. Available at: http://ieg.worldbank.org/sites/default/files/Data/reports/cc3_full_eval.pdf.

Physical Planning Act (2003) — has highlighted the need to link physical, socio-economic and environmental factors for sustainable development[410]. Increased cross-sectoral coordination can ensure that best practices and lessons learned from different national and regional projects can be incorporated into project design. This is reflected in the review — undertaken in 2014 — of refurbishment and construction projects across the United Nations system organisations[411].

To improve the effectiveness of coordination, the involvement of stakeholders — including local communities, non-governmental organisations and decision-makers — is a necessary consideration for the success of adaptation projects in Antigua and Barbuda. Stakeholder engagement can facilitate more effective community engagement, as well as improved ownership and the incorporation of local and traditional knowledge into project design[412]. This is reflected in the Environmental Management Act which includes a clause that provides for the promotion of stakeholder involvement in the management of the environment in the country — including in responding to the impacts of climate change.

Stakeholder engagement at all levels is particularly important for disaster risk reduction and management in Antigua and Barbuda, particularly under changing climate conditions. The Country Document for Disaster Risk Reduction (DRR) in Antigua and Barbuda[413] was prepared in accordance with the Sendai Framework, which recognises that although the State is the primary entity responsible for DRR, responsibility should be shared by other stakeholders[414]. Several best practices can be adopted for increasing stakeholder involvement, for example, implementing Climate Smart Community Disaster Management (CSCDM). The Caribbean Natural Resources Institute (CANARI) has documented and published a series of guidelines detailing best practices for the implementation of CSCDM, which highlights the necessity of engaging stakeholders at all stages of project development[415]. Appropriate and informative public engagement helps to build political support for project activities[416] and supports the uptake as well as sustainability of these activities.

The abovementioned best practices and lessons learned have been incorporated into the design of all project activities, particularly those surrounding the adoption of climate-resilient measures for the building sector. For these activities, training programmes will be conducted under Output 2 of the proposed project for all government staff, as well as the local workforce, on the implementation, operation, monitoring and maintenance of these measures. Awareness raising campaigns will also be conducted under this proposed project output to promote the availability of these courses and increase the uptake of climate change adaptation measures across the country's building sector. Engaging the relevant stakeholders using local best practices has been proven to considerably increase the sustainability of project interventions. Such engagements also allow for traditional knowledge to be incorporated into the project design, which further increases buy-in to these interventions. This was particularly significant for Output 1 of the proposed project, where stakeholders expressed the importance of including traditional building practices into the design and implementation of climate-proofing interventions under this project output. Traditional knowledge will also be considered in the development and provision of training programmes that will specifically target technical

[410] Regional Observatory on Planning and Development in Latin America and the Caribbean. Development Control Authority (DCA) of Antigua and Barbuda. Available at: https://observatorioplanificacion.cepal.org/en/institutions/development-control-authority-dca-antigua-and-barbuda.
[411] Cazeau, J.W. & Callejas, J. F., 2014. Capital/Refurbishment/Construction Projects
Across The United Nations System Organizations. Available at: https://www.unjiu.org/sites/www.unjiu.org/files/jiu_document_files/products/en/reports-notes/JIU%20Products/JIU_REP_2014_3_English.pdf.
[412] Deeb A. 2002. Lessons learned – Caribbean: Planning for Adaptation to Global Climate Change (CPACC). Climate Change Discussion Paper, Environment Department and the World Bank.
[413] an analysis of the status of DRR in Antigua and Barbuda
[414] NODS. 2016. Country document for disaster risk reduction: Antigua and Barbuda, 2016. Available at: http://dipecholac.net/docs/country-doc-antigua-and-barbuda.pdf.
[415] UNFCCC. 2019. Climate smart community disaster management programme, Available at: https://unfccc.int/sites/default/files/climate_smart_community_disaster_management_programme.pdf.
[416] Demonstrating the Development and Implementation of a Sustainable Island Resource Management Mechanism in a Small Island Developing State (SIRMM SIDS)

personnel — including engineers, architects and draughtsmen — on how to design and implement climate-resilient solutions in the building sector.

Finally, careful consideration of gender dynamics — including access to resources, legal protection, decision-making power and vulnerability to violence — is an international best practice. Although Antigua and Barbuda is not characterised by high levels of acute gender-specific disadvantages, gender considerations should be mainstreamed into project design to ensure social equality is maintained[417]. Consultations with Antigua and Barbuda's Monitoring and Evaluation Specialist were held to determine what best practices and lessons learned should be considered in the design of project activities. From this consultation, it emerged that women are often not included in decision-making at a national and local level, resulting in the decisions taken benefitting men more than women. To address these biases, targets for women's participation in all project activities have been set and are detailed in Annex 8: Gender Action Plan.

7.7. Institutional and technical capacity for climate-responsive planning

Antigua and Barbuda — like other SIDS in the region — has limited technical and human resource capacity for effective climate change adaptation. The development of a national pool of specialised staff has historically been hindered by the emigration of individuals with technical knowledge and skills[418]. Although some progress has been made in this regard, the inherent complexity of the global climate change challenge is compounding the barriers relating to capacity limitations. Successful adaptation to climate change requires long-term planning and a focus on sustainability. These objectives can be achieved by enhancing the commitment from regional and national entities and by strengthening institutional and technical capacity[419]. Several projects have succeeded in building technical and institutional capacity for climate change adaptation in the Caribbean, from which lessons and best practices can be drawn to inform the proposed GCF project[420]. For example, the 'Caribbean: Planning for Adaptation to Global Climate Change (CPACC)' project has demonstrated that a flexible approach to institutional capacity building is required and that the best response to limitations at national level is the development of core capacity at the regional level[421]. However, limited local-level capacity to respond to requests for information, which leads to delays, is a continuing challenge for the Sustainable Energy for the Eastern Caribbean (SEEC) Programme[422].

As a member of the Commonwealth of Nations, Antigua and Barbuda draws on best practices from neighbouring countries and other member states. The country's legislation and financial processes as well as its environmental management systems share similarities with several other members of the Commonwealth. The efficiency of projects in Antigua and Barbuda, therefore, can be improved through cooperation with neighbouring countries and regional organisations — particularly through knowledge-sharing and technical support[423]. Regional cooperation requires the involvement of project managers and coordinators who are familiar with the local context and the cultural environment within which interventions

[417] UNFCCC. 2019. Climate smart community disaster management programme, Available at: https://unfccc.int/sites/default/files/climate_smart_community_disaster_management_programme.pdf.
[418] Deeb A. 2002. Lessons learned – Caribbean: Planning for Adaptation to Global Climate Change (CPACC). Climate Change Discussion Paper, Environment Department and the World Bank.
[419] Deeb A. 2002. Lessons learned – Caribbean: Planning for Adaptation to Global Climate Change (CPACC). Climate Change Discussion Paper, Environment Department and the World Bank.
[420] IEG. 2011. Adapting to Climate change: assessing the World Bank Group Experience. Available at: http://ieg.worldbank.org/sites/default/files/Data/reports/cc3_full_eval.pdf.
[421] Deeb A. 2002. Lessons learned – Caribbean: Planning for Adaptation to Global Climate Change (CPACC). Climate Change Discussion Paper, Environment Department and the World Bank.
[422] European Commission. 2019. Sustainable Energy for the Eastern Caribbean (SEEC) Programme. Available at: https://ec.europa.eu/europeaid/blending/sustainable-energy-eastern-caribbean-seec-program-0_en.
[423] GEF. 2019. Integrating Watershed and Coastal Area Management in Small Island Developing States of the Caribbean. Available at: https://www.thegef.org/project/integrating-watershed-and-coastal-area-management-iwcam-small-island-developing-states.

are implemented[424]. The SIRMM SIDS project demonstrated that pairing of international or regional consultants with local and national consultants not only ensures that the national and cultural priorities are accounted for in the design of projects, but that the capacity of local consultants to manage projects is also strengthened[425]. By applying this practice, regional cooperation can improve the effectiveness and potential for upscaling capacity-building interventions. However, tensions over ownership and responsibility may arise. Therefore, there should be a balance between the use of external consultants and local capacity building[426]. In countries with limited capacity — including Antigua and Barbuda — there is also a risk of placing excessive pressure on local institutions to maximise national participation. For example, despite being willing to participate in a project, Ministries of Energy may still struggle to meet the requirements of implementation of renewable energy infrastructure. Therefore, the careful assessment of capacity, government commitment and responsive support through a regional institution can help to mitigate this risk[427]. Where national capacity is weak for action on global challenges — particularly climate change — a regional coordinating mechanism can be an effective means of engaging the collective capacity of existing institutions. The long-term potential for strengthening of capacity in Antigua and Barbuda can also be significantly enhanced through a proactive guiding role of organisations such as the UNFCCC.

In Antigua and Barbuda, technical capacity for the implementation of interventions with a focus on promoting energy efficiency (EE) and renewable energy (RE) can also be a challenge. The Energy for Sustainable Development in Caribbean Buildings (ESD) project demonstrated that in Antigua and Barbuda, the barriers to the implementation of EE and RE are not the same for different technologies and between the country's two islands[428]. The technical assessment of the project suggested that a systematic analysis should be conducted to identify, rank and prioritise barriers for different technologies and islands. The country's renewable energy assessment[429] notes that the public in Antigua and Barbuda is not sufficiently engaged with renewable energy technology and that public awareness campaigns can greatly improve the potential for engagement in future sustainability initiatives.

The abovementioned lessons and best practices were used to inform the design of all capacity-building activities to be implemented under the proposed project. These lessons and best practices will also be taken into account during the implementation of the capacity-building activities to ensure that these activities are conducted in a locally appropriate way. Furthermore, lessons learned and best practices for promoting country ownership have been used to inform the design of all project interventions. Awareness raising was one such best practice that has been incorporated into the project design. These campaigns will be conducted under Output 2 of the project, targeting both the public and private sectors, to: i) demonstrate the benefits of the proposed project interventions; and ii) promote the uptake of climate change adaptation for the building sector and contribute to the adoption of a climate-resilient sustainable development practices across the country.

7.8. Knowledge management of climate information

Effective collection and dissemination of climate information is an international best practice. This is highlighted by the CPACC project, which demonstrated the need for strengthening data collection networks

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[424] GEF. 2014. Demonstrating the Development and Implementation of a Sustainable Island Resource Management Mechanism in a Small Island Developing State (SIRMM SIDS): Terminal Evaluation

[425] GEF. 2014. Demonstrating the Development and Implementation of a Sustainable Island Resource Management Mechanism in a Small Island Developing State (SIRMM SIDS): Terminal Evaluation

[426] Gore-Francis, J. 2013. Antigua and Barbuda SIDS 2014 Preparatory Progress Report. Available at: http://wedocs.unep.org/bitstream/handle/20.500.11822/8437/Antigua_and_Barbuda.pdf?sequence=3&isAllowed=y.

[427] Deeb A. 2002. Lessons learned – Caribbean: Planning for Adaptation to Global Climate Change (CPACC). Climate Change Discussion Paper, Environment Department and the World Bank.

[428] GEF. 2019. Energy for Sustainable Development in Caribbean Buildings (ESD). Available at: https://www.thegef.org/project/energy-sustainable-development-caribbean-buildings.

[429] IRENA. 2016. Antigua and Barbuda Renewables Readiness Assessment. Available at: http://admin.theiguides.org/Media/Documents/Renewable%20RA_Antigua_and_Barbuda_2016.pdf.

through increased support at national level and a greater focus on sustainability[430]. In the past — particularly in the 1970s — disaster management was often response-driven. In recent years, however, best practices for strengthening climate information services have shifted to focus on risk reduction[431]. For example, the extreme events of 2017 demonstrated the need for a repository of best practices and a knowledge network of professionals, providing technical support for reducing the vulnerability of local communities to climate change impacts[432]. Antigua and Barbuda SIDS 2014 Preparatory Progress Report notes that a considerable amount of climate data for the establishment of baselines for monitoring and review were lacking, outdated and poorly recorded. There was also limited exchange between agencies holding different types of data. In addition, there was no standardised means to verify and certify data[433]. The Preparatory Progress Report notes the necessity of designating a single government agency as the central data certification and storage hub[434]. Moreover, the process of information collection and dissemination should also be relatively flexible and iterative. The use of technology can greatly improve the management of climate information and facilitate early action amongst public decision-makers and the private sector. These best practices have been used to inform the design of project activities under Output 3 and they will also be used to inform the implementation of this output.

8. Barriers to the preferred solution

8.1. Barrier 1. Limited financial capacity of the Government of Antigua and Barbuda to invest in climate proofing critical public service buildings to withstand Category 4 and 5 hurricanes

Because of long-standing problems in the fiscal and banking sectors, the Government of Antigua and Barbuda (GoAB) has limited financial capacity to invest in climate-proofing critical public service and community buildings to withstand Category 4 and 5 hurricanes. These problems include an unsustainable public debt, high non-performing loans and delays in bank resolution[435,436]. Because of these factors, the GoAB is currently prioritising addressing these existing financial problems to restore fiscal and debt sustainability. As a result, limited resources are available to be channelled towards financing climate change adaptation measures for the building sector, including renewable energy and climate-resilient water harvesting solutions.

8.2. Barrier 2. Limited stock and secure storage capacity for renewable energy equipment

There is currently limited stock of renewable energy equipment available in the country and no secure location to store additional back-up equipment, which exacerbates the impacts of extreme events on the country’s power supply. Extreme climate events cause severe damage to the centralised power supply systems used by the country, highlighting the need for the installation of renewable energy equipment. Because of the remote location of Antigua and Barbuda, it is difficult to access this equipment, such as replacement solar PV panels, to restore power after these events to critical service buildings that are equipped with decentralised renewable energy systems. This compounds the problem, resulting in delays in power supply of up to 24 months being experienced following a Category 5 hurricane.

[430] Deeb A. 2002. Lessons learned – Caribbean: Planning for Adaptation to Global Climate Change (CPACC). Climate Change Discussion Paper, Environment Department and the World Bank.
[431] Halsnæs, K., Shukla, P.R. and Garg, A., 2008. Sustainable development and climate change: lessons from country studies. Climate Policy, 8(2)
[432] Halsnæs, K., Shukla, P.R. and Garg, A., 2008. Sustainable development and climate change: lessons from country studies. Climate Policy, 8(2)
[433] Gore-Francis, J. 2013. Antigua and Barbuda SIDS 2014 Preparatory Progress Report. Available at: http://wedocs.unep.org/bitstream/handle/20.500.11822/8437/Antigua_and_Barbuda.pdf?sequence=3&isAllowed=y..
[434] Gore-Francis, J. 2013. Antigua and Barbuda SIDS 2014 Preparatory Progress Report. Available at: http://wedocs.unep.org/bitstream/handle/20.500.11822/8437/Antigua_and_Barbuda.pdf?sequence=3&isAllowed=y.
[435] Bank resolution refers to the restructuring of a bank by a resolution authority through the use of resolution tools in order to safeguard public interests, including the continuity of the bank's critical functions, financial stability and minimal costs to taxpayers.
[436] International Monetary Fund. 2015. Antigua and Barbuda. IMF Country Report number 15/189.

8.3. Barrier 3. Limited technical capacity within critical public service institutions to preserve vital information

There is currently limited technical capacity within critical public institutions to preserve vital information that is housed within public institutions – including hospitals, clinics and police stations – either through the protection of physical infrastructure or the provision of reliable backup systems. During a major storm, servers/computers hosting critical information at these institutions are likely to be damaged, resulting in the loss of vital information for public health and security. Without effective and efficient protocols to secure this information, it will continue to be lost, considerably impacting the ability of critical services to continue providing adequate public health and safety services during and after an extreme event to the country's population.

8.4. Barrier 4. Climate change adaptation is not adequately mainstreamed into building sector policies and regulations

Climate change adaptation for the building sector has not been sufficiently mainstreamed into Antigua and Barbuda's regulatory frameworks. In particular, the Physical Planning Act (2003) has not been amended to make provision for the newly revised national building code — which includes appropriate actions for reducing the risk of buildings to the impacts of Category 4 and 5 hurricanes. As a result, the guidelines established in the building code are not formalised into legislation, reducing their enforceability. There is also limited technical and institutional capacity within the Public Works Department (PWD) and Development Control Authority (DCA) to adequately apply the regulations stipulated in the building code, thereby amplifying the conditions in which buildings may remain susceptible to the impacts of Category 4 and 5 hurricanes.

8.5. Barrier 5. Limited knowledge of viable climate change adaptation options for the building sector

While there is a firm understanding of the need to climate-proof buildings in Antigua and Barbuda, there is limited knowledge within public institutions such as PWD and DCA, as well as design engineers/architects and local communities of the climate proofing measures available for the building sector. Because of this, decision-makers within PWD and DCA as well as citizens of the country continue to use conventional building methods that are not suitable to withstand the impacts of Category 4 and 5 hurricanes. Without sufficient capacity building across the public and private sector, infrastructural development will continue to be at risk to the adverse impacts of these events.

8.6. Barrier 6. Limited financial mechanisms within the country to support investment into climate-resilient development of the building sector

Given the existing financial problems in Antigua and Barbuda, there are currently limited financial mechanisms available to support ongoing investment into climate-resilient development in both the public and private sectors. This includes limitations in the: i) provision of adaptation finance through existing government development funds; ii) replenishment of such funds; and iii) consideration of climate change adaptation by the banking and insurance sectors. As a result, public and private sector actors are unable to access financial support for increasing their adaptive capacity to extreme climate events such as hurricanes and tropical storms.

8.7. Barrier 7. Limited technical capacity within NODS, DCA and PWD for long-term monitoring, maintenance and planning for adaptation measures in the building sector

There is limited technical capacity within public institutions, such as NODS, DCA and PWD for the long-term monitoring, maintenance and planning for these measures. These capacity limitations extend to the local workforce who are ultimately responsible for the installation and maintenance of equipment. The limitations are largely as a result of limited provision of training courses and awareness to the public and private on how to effectively implement, monitor and maintain climate-proofing measures for the building sector.

8.8. Barrier 8. Limited technical capacity in the ABMS and NODS to adequately disseminate early warnings to support early action

There is currently limited technical capacity in the ABMS and NODS to adequately disseminate early warnings to support early action, particularly to prepare shelters and secure renewable energy equipment ahead of a storm. This limited capacity is largely as a result of existing climate information servers being unable to process climate data in real time, resulting in delays in the development and dissemination of early warning information products to decision-makers responsible for coordinating disaster response. These delays are exacerbated by the absence of a formalised communication protocol within ABMS and between relevant entities to facilitate early action in response to impending extreme climate events. Because of these delays, the public and private sector is unable to take the necessary preparatory actions required to ensure personal safety and protect critical supplies such as food and medicine. Moreover, there are delays in deploying emergency response services, which increases risk of injury and loss of life.

9. Project interventions to overcome barriers

A suite of climate change adaptation interventions will be implemented under the proposed project to overcome the existing barriers described in Section 8 above. These interventions include: i) implementing climate-proofing interventions in critical public service and community buildings to increase their climate resilience; ii) mainstreaming climate change adaptation into the building sector and relevant financial mechanisms; and iii) strengthening Antigua and Barbuda's climate information services to facilitate early action in response to extreme climate events. The ways in which proposed project interventions will contribute to overcoming the existing barriers and initiating a paradigm shift towards climate-resilient sustainable development in Antigua and Barbuda's building sector are described in detail below.

The proposed project will contribute to GCF's paradigm shift objective of increased climate-resilient sustainable development through enhancing the resilience of Antigua and Barbuda's building sector to extreme climate events such as hurricanes and tropical storms. The proposed transformative approach will shift the country's building sector away from reactive development — involving costly recovery actions after an extreme climate event — towards a proactive approach in which buildings are adapted to withstand the increased frequency of high-intensity hurricanes. This proactive approach will include direct investments into critical public service and community buildings to climate-proof them against Category 4 and 5 hurricanes, as well as mainstreaming climate resilience into the building sector and relevant financial mechanisms to facilitate the upscaling of such interventions across all buildings in the country. The effectiveness of climate-proofing interventions will be enhanced by formalising communication protocols between the ABMS and relevant government agencies to facilitate early action within the building sector to respond to extreme climate events. This will include strengthening the capacity of ABMS to collect, process and manage climate data, thereby improving the accuracy and reliability of early warnings. The combined effect of project interventions will result in a standard of climate resilience for Antigua and Barbuda's building sector being established that can be readily scaled up and replicated nationally and regionally. Proposed project outputs are described below with detailed descriptions of all project activities described in Section E.6 of the Funding Proposal.

9.1. Climate proofing buildings

9.1.1. Output 1. Climate-proofing interventions implemented in critical public service and community buildings to improve resilience to, and recovery from, extreme climate events

Output 1 will contribute to GCF Outcome A7.0 — Strengthened adaptive capacity and reduced exposure to climate risks — by climate-proofing critical public service and community buildings (hereafter referred to as 'priority buildings') to withstand the adverse impacts of Category 4 and 5 hurricanes and safeguarding critical basic supplies. To achieve this, the structural integrity of priority buildings will be strengthened through several adaptation interventions, including the installation of hurricane shutters and using hurricane straps to secure roofs. These interventions will physically protect buildings, thereby reducing damages and maintaining operability of critical services during and directly after an extreme event. The climate-resilience of critical services will be further enhanced through the decentralisation of power and water supplies to priority buildings. Decentralising power and water supplies will reduce the dependence of critical services on vulnerable central systems which are often disrupted for prolonged period both during and after an extreme climate event. This will ensure that priority buildings and the critical services they support maintain an uninterrupted power and water supply when centralised systems are disrupted. To decentralise power supply, renewable energy (RE) systems will be installed on priority buildings, comprising solar PV panels and battery packs. The installation of solar panels account for site-specific requirements, including exposure to climate hazards and the energy requirements of the building. Specifically, solar panels will be installed using hurricane-proof clamps, that will secure panels during periods of extreme winds, while allowing for easy removal prior to extreme winds to prevent damage from flying debris. Maintenance staff at priority buildings, along with teams from the PWD will be trained to safely remove and store panels prior to a Category 4 or 5 hurricane making landfall (See Activity 2.4). To ensure continued power supply during the period that the panels are removed, the storage capacity of battery packs will be sufficient to meet basic electricity demands of priority buildings for 24–48 hours. The effectiveness of battery packs will be enhanced through the installation and use of energy-efficient equipment in priority buildings to reduce demand. To ensure uninterrupted supply of water to priority buildings, climate-resilient rainwater harvesting solutions will be installed. These solutions will be site-specific and secured to withstand the maximum sustained windspeeds associated with Category 4 and 5 hurricanes. Coupled with these water harvesting systems will be the installation of stormwater drainage solutions on 14 buildings situated less than 30 m from inundation zones in Antigua and Barbuda. While flooding is not recognised as a primary hazard at these 14 project sites, these solutions will mitigate the risk of potential flooding that may result from heavy rainfall associated with Category 4 and 5 hurricanes. This flood risk mitigation will be achieved through installing drainage gutters at the 14 target sites to ensure that water from these heavy rainfall events is distributed into the existing drainage systems to avoid localised flooding. Further details on the technical design of climate-proofing interventions and a list of the specific priority buildings that will be targeted by the project are provided in Annex 2: Feasibility Study.

In addition to adaptation investments in existing priority buildings, the project will construct two types of climate-proof structure to protect human life, preserve vital information within public institutions and secure basic supplies — including RE equipment, building materials, food and medicine. First, five climate-resilient storm shelters will be built on to public clinics to provide places of safety for vulnerable community members whose own homes are not equipped to withstand Category 4 and 5 hurricanes. These shelters will be sufficiently equipped to protect community members and provide the necessary services during an extreme climate event. Attaching shelters to selected clinics will improve health and safety, not only because nurses will be present on site to treat the sick and injured, but also because the greater distribution of small shelters will reduce health risks associated with crowding in public schools which are currently used as shelters. Furthermore, by limiting the need for schools to function as shelter, the project will reduce the downtime for schools resulting from prolonged occupation after an event. All five shelters will be equipped with RE and climate-resilient water harvesting equipment to reduce their reliance on centralised supply systems. Second, a climate-resilient bunker will be constructed at a central location to store supplies required by critical services during and immediately after an extreme event. The bunker will be operated by a sub-committee for disaster preparedness, comprising representatives from the health, environment, public works and welfare sectors, who will be responsible for maintaining supplies of medicine, RE equipment, building materials and food, respectively. This bunker will also serve as a battery recharge site, allowing for battery packs to recharged and swapped out at priority buildings if RE systems cannot be made operational again before battery systems run out. In addition to these physical interventions, back-up protocols will be developed and operationalised to secure vital information within critical public institutions, including hospitals, clinics, schools, police and fire stations. In so doing, critical service providers will have increased access to emergency supplies, and vital information will be preserved. Project activities that will be implemented under this output are described below.

Operation and maintenance of climate-proofing interventions

All operations and maintenance activities required under the project will be financed by the Government of Antigua and Barbuda. Furthermore, the sustainable operation and management of construction-related project interventions has been secured by identifying key government institutions to oversee specific project activities. MoW will oversee the implementation of climate-proofing measures on critical infrastructure (Activity 1.1), while the Ministry of Health, Wellness and the Environment (MoHWE) will be responsible for managing the shelters that will be built on to five clinics in the country (Activity 1.2). In addition to the operations and maintenance plan for climate-proofing interventions described above, multiple project partners have been engaged to ensure the management and restocking of critical supplies that will be housed within the climate-resilient bunker (Activity 1.3). Responsibilities for the stocking of these supplies will be as follows: i) RE stock and medical supplies will be maintained by the MoHWE; ii) food supplies will be maintained by the Ministry of Social Transformation; and iii) building supplies will be maintained by MoW. To ensure that climate change adaptation measures to be constructed under the project provide maximum benefits, relevant project partners have committed to maintaining all climate proofing measures implemented under the project (including physical upgrades as well as decentralised RE and climate-resilient water harvesting solutions) for at least 20 years after implementation of the project. A framework for effective operations and maintenance of these measures, including the associated costing, is presented in Annex 21.

Activity 1.1. Implement climate-proofing measures on critical infrastructure.

To ensure that critical public services remain functional during and directly after a hurricane, the proposed project will invest in improving the structural integrity of critical infrastructure to enable buildings to withstand Category 5 hurricanes. Preliminary assessments have identified appropriate climate-proofing interventions, as presented in Annex 22: Building assessment. Co-finance will also be provided to invest in baseline repair work required to upgrade priority buildings in accordance with the building code. Targeted infrastructure will include hospitals/clinics, police and fire stations, storm shelters, relevant government buildings and schools.

To ensure continuous supply of power and water during and after an extreme event, when centralised systems are down, this activity will install decentralised systems at critical public service buildings. For energy supply, RE systems will be installed, comprising solar PV panels and battery packs. The solar panels will be removable, allowing maintenance teams to take down the panels ahead of a large storm to prevent damages. During these periods, the buildings will run on battery reserves, with power being directed to critical equipment. Energy efficient equipment will also be installed where feasible to maximise battery life. This will include energy efficient cooling and ventilation systems, particularly in shelters where the density of people will be relatively high. In the case of batteries not lasting throughout the downtime, the replacement protocol developed in Sub-activity 1.3.4. will be initiated. All RE measures will be based on regional/international best practices, Environmental Management Systems (EMS) plans and the national building code. In addition to targeting critical service buildings, the project will provide RE solutions to schools to ensure that they remain operational immediately after these events. As a result, students will not miss a formative part of their education. Funding will be provided to the schools via the Sustainable Island Resource Framework Fund (SIRF Fund).

Given that the water supply in Antigua and Barbuda is heavily dependent on a reliable energy supply, when the national grid goes down water supply is disrupted. To ensure that those buildings that are used as shelters or provide critical services have a safe and reliable water supply during and directly after an extreme climate event, the project will provide climate-resilient water harvesting equipment (including solar pumps). This decentralised water supply is essential to maintain health and sanitation standards in these buildings. The water harvesting systems have been designed to ensure that they do not result in increases to mosquito populations. Coupled with these water harvesting systems will be the installation of stormwater drainage solutions on 14 buildings situated less than 30 m from inundation zones in Antigua and Barbuda. While flooding is not recognised as a primary hazard at these 14 project sites, these solutions will mitigate the risk of potential flooding that may result from heavy rainfall associated with Category 4 and 5 hurricanes. This flood risk mitigation will be achieved through installing drainage gutters at the 14 target sites to ensure that water from these heavy rainfall events is distributed into the existing drainage systems to avoid localised flooding. A comprehensive list of target buildings is provided in Section 10 of this Feasibility Study.

Activity 1.2. Construct climate-resilient storm shelters built on to five public clinics.

To facilitate the transition away from using schools as storm shelters, the project will commission five purpose-built storm shelters attached to public clinics. Attaching the shelters to clinics will not only reduce downtime for schools after being used as shelters but will also improve the health conditions as nurses will be present on site to treat the sick and injured. The shelters will also be equipped with renewable energy systems and water harvesting equipment to reduce reliance on centralised supply systems (see Activity 1.4 below). To ensure the effective operation of and adherence to national health and safety requirements for storm shelters, an emergency protocol will be developed for each shelter. These protocols will include details on the: i) responsible parties; ii) carrying capacity of the shelter; iii) preparation actions ahead of a storm; iv) sanitation, food and water requirements; v) approved duration of stays; and vi) communication channels with the National Office of Disaster Services (NODS). In between extreme events, the buildings will function as community centres as well as training facilities for the clinics. These centres will also display awareness material on the impacts of climate change and adaptation options available in the local context.

Activity 1.3. Construct a climate-resilient bunker to store emergency supplies for the health, energy, building and welfare sectors.

After an extreme event, emergency supplies are required quickly to return the country to normalcy. This includes the need for renewable energy equipment, building materials, food and medicine. To address the need for a secure location to store such supplies, the project will construct a climate-resilient bunker that will service the health, energy, building and welfare sectors. The bunker will be managed by a ministerial sub-committee for disaster preparedness who will be responsible for coordinating efforts between relevant stakeholders. Four specific units will be established within the bunker, each focussing on a specific sector. The first unit will serve the health sector, providing safe storage for medicine and medical supplies which can be quickly distributed after an event. The second unit will be managed by Antigua and Barbuda's Department of Environment (DoE) and will be used to store backup solar panels to replace those damaged during a storm. Furthermore, backup batteries will be stored and charged at the bunker, allowing for replacements to be provided to critical services should renewable energy (RE) systems not be made operational again before battery systems run out. The third unit will service the Public Works Department (PWD), storing timber and other building materials that can be used as shutters during preparation or for repairs after an extreme event. To ensure that timber is not wasted or left unused/untreated for too long, a protocol will be developed for managing the stock that is not used at the end of each hurricane season, including making provision for the resale of timber to local suppliers at bulk discount rates. The government will front the costs for importing bulk timber ahead of the storm season, which will reduce costs of individual suppliers importing in small batches. This will ensure that emergency stocks to not have a negative impact on the livelihoods of private sector timber suppliers. Finally, the fourth unit will be used to store critical food supplies to support emergency responders who have limited opportunity to access personal supplies during and after an extreme event. The distribution of this food will be controlled by the Ministry of Social Transformation.

Activity 1.4. Implement measures to preserve vital information/data within public institutions.

Extreme climate events cause long-lasting disruptions to power supplies in Antigua and Barbuda, as well as physical damage to computer servers that store vital medical and security information from hospitals, police stations and other critical areas of the government. As a result, it is critical for vital information and data housed within public institutions to be protected and backed up to ensure that no losses are experienced during a storm. Under this activity, protocols will be developed for how to effectively and efficiently back up all vital information and data preceding a storm and IT teams within each public institution will be trained on the application of these protocols. RE solutions will be installed on relevant priority buildings, ensuring continued energy supply is provided for the completion of data backups (Activity 1.4). Furthermore, physical protection measures will be designed and implemented on the relevant public buildings to reduce the risk of critical IT infrastructure being damaged by an extreme event.

9.2. Planning and climate finance

9.2.1. Output 2. Climate change adaptation mainstreamed into the building sector and relevant financial mechanisms

Output 2 of the project will contribute to GCF Outcome A5.0 — Strengthened institutional and regulatory systems for climate-responsive planning and development — and support the implementation of adaptation interventions under Output 1. The strengthened regulatory frameworks, combined with capacity buildings and skills development in the building sector, will create an enabling environment for the upscaling and replication of project interventions across the country. This upscaling potential will be achieved by: i) mainstreaming climate change adaptation into the building sector, as well as the public and private financial sectors; ii) strengthening the capacity of the public and private sectors to design, implement, operate and maintain climate-adaptive measures for the building sector; and iii) raising awareness within the public and private sectors on the benefits of adopting these adaptation measures.

Mainstreaming climate change adaptation into the building sector

To compliment the ongoing SCCF project[437] described in B1 — which updated the national building code to develop standards that account for the impacts of Category 4 and 5 hurricanes — the proposed project will draft regulations for the Physical Planning Act (PPA) of 2003 to make provision for the inclusion of the updated building code in national regulatory frameworks. This will, in turn contribute to establishing a standard for climate-resilient development across the country. Antigua and Barbuda's building code incorporates elements of the Bahamas Building Code, which in turn was based generally on the South Florida Building Code[438]. Applying the Florida Building Code, which makes provision for Category 4 and 5 hurricanes, has been shown to reduce the damage caused by hurricanes by up to 72%[439]. Similar reductions can therefore be expected, and the adaptation impact of this intervention enhanced, by: firstly, updating the building code to include design criteria that accounts for Category 4 and 5 hurricanes (which is currently being done under the SCCF-funded project); and secondly, strengthening the technical and institutional capacity of technical staff involved in infrastructural design and development (e.g. staff from the MoW, DCA and NODS, as well as building inspectors, engineers, architects and draughtsmen; and the private sector) to apply the updated code. To further contribute to the mainstreaming of climate change adaptation into the building sector, recommendations will be made for the Environmental Management Systems plans (EMS plans) to be updated to include climate-resilient measures. The mechanism for the development of these recommendations will include engaging with relevant project partners to review the EMS plans and identify entry points for the inclusion of climate change adaptation for the building sector. Following this review, recommendations will be drafted proposing the relevant revisions to the EMS plans and milestones for these revisions will be set. The target for these revisions to be complete is the end of Year 2 of project implementation. Annual meetings will be held thereafter with relevant stakeholders to collate and share lessons learned from implementing the EMS plans and ensure that these plans are updated regularly where necessary.

Mainstreaming climate change into public and private financial sectors

Under the SCCF-funded project, entry points for climate change adaptation financing within the SIRF Fund have been established to increase public and private sector access to financial resources for adaptation, including for the building sector. In its current form, the SIRF Fund is optimised for small grants to vulnerable households, with individual applications capped at 5% of the total funds available at a given time. This acts

[437] entitled: "Building climate resilience through innovative financing mechanisms for climate change adaptation".
[438] OAS. 2002. Status of Building Codes in the Caribbean. Available at: https://www.oas.org/cdmp/bulletin/codemtrx.htm..
[439] Simmons, Kevin M., Jeffrey Czajkowski, and James M. Done. "Economic effectiveness of implementing a statewide building code: the case of Florida." *Land Economics* 94, no. 2 (2018)

as a barrier to small- to medium-sized businesses, which often require larger investments to implement adaptation interventions. The proposed GCF project will overcome this barrier by creating additional entry points to increase the access of both the public and private sectors to financial resources for implementing climate-proofing measures. In particular, the project will introduce incremental cost reasoning to SIRF Fund selection criteria, which will allow for the development costs to be split between baseline and adaptation measures. This will reduce the investment requires from the SIRF Fund, with baseline costs being covered through alternative funding sources. Additional mechanisms will then be identified to further bridge the financing gap, including incentive programmes, levies and insurance/risk management products. Options for ramping-up the replenishment of the SIRF fund will also be explored to increase the relative value of the 5% cap. This will include engaging with public and private sector stakeholders in Year 1 of project implementation to identify entry points for unlocking finance for climate-resilient sustainable development in Antigua and Barbuda. Through the consultation process, the most appropriate options discussed above will be selected and validated by all project partners. These consultations will happen in Year 1 of implementation. The SIRF Fund guidelines will be updated and validated by all project partners following these discussions by the end of Year 2. To promote the use of the SIRF Fund as a mechanism for financing climate-adaptive measures for the building sector, decision-makers from NODS, DCA and PWD, as well as private sector representatives, will be trained on how to access financial resources under the SIRF Fund — within the specified thresholds. This training will be provided regularly commencing in Year 3. Finally, from the beginning of Year 3 to the end of the project implementation period (Year 6), annual engagement workshops will be held to collate and share lessons learned from public and private sector interactions with the SIRF Fund and processes for replenishment will be discussed and revised where necessary.

In addition to enhancing access of the private sector to the SIRF Fund for larger scale adaptation investments, the project will refine the SIRF Fund selection criteria for adaptation interventions. Using an evidence-based approach that draws lessons learned from the SCCF and Enhanced Direct Access (EDA) projects[440], as well as the implementation of on-the-ground adaptation interventions under Activity 1.1 of this project, the list of adaptation options supported by the SIRF Fund will be refined. This process will ensure that all options are optimised for the local conditions and markets, and that clear guidelines are set for assessing the eligibility of each application.

Capacity building and awareness raising for the public and private sectors

To ensure the sustainability and upscaling potential of climate-proofing measures implemented under Output 1, training programmes will be developed with partner organisations such as Antigua and Barbuda Institute for Continuing Education (ABICE). The training programmes will focus on how to appropriately apply the regulations of the building code during the design, installation and monitoring of climate change adaptation measures specific to the building sector. Appropriate local training institutes such as ABICE will deliver these programmes to public and private sector representatives, including staff from MoW and DCA as well as building inspectors, engineers, architects and draughtsmen. A certified training course will also be developed for and delivered to the local workforce through these training institutions. This training course will focus on how to support the installation, operation and maintenance of climate-resilient physical upgrades to buildings as well as RE and climate-resilient water harvesting solutions. To contribute to the uptake of these capacity-building interventions, gender-sensitive awareness-raising campaigns will be designed and conducted for the public and private sectors. These campaigns will promote the availability of training on climate change adaptation for the building sector as well as on the benefits of implementing these measures. The combination of interventions implemented under Output 2 will enable the public and private sector actors to build sufficient capacity for the independent adoption and maintenance of climate-resilient solutions for the building sector. This will maximise the adaptation benefits delivered by these

[440] Under the GCF project, entitled *Integrated physical adaptation and community resilience through an enhanced direct access pilot in the public, private, and civil society sectors of three Eastern Caribbean small island developing states* (referred to as the EDA project in this Funding Proposal), the SIRF Fund is being used as a mechanism for financing adaptation at a household level. Lessons learned from this intervention will be used to inform interactions with the SIRF Fund under the proposed GCF project.

solutions and ensure their sustainability beyond the project lifetime. Activities that will be implemented under this project output are listed below.

Activity 2.1. Mainstream climate change adaptation into the building sector by making provision for the building code in the Physical Planning Act (2003) and updating the EMS plans.

To promote the uptake of climate-resilient development across Antigua and Barbuda, climate change adaptation will be mainstreamed into the country's building sector. This will be achieved in three primary ways. Firstly, regulations for the Physical Planning Act (2003) will be drafted to make provision for including the updated building code in the national regulatory framework. Doing so will facilitate the formalisation of the code, which addresses Category 4 and 5 hurricanes, into policy. This will in turn contribute to establishing a standard for climate-resilient development across the country. Secondly, a Strategic Impact Assessment (SIA) of the building code regulations will be conducted to assess the environmental and social safeguards and gender risks, consequences and mitigation measures related to the enactment of these regulations in the Physical Planning Act (2003). This SIA will ensure that the building code is able to be applied by the most vulnerable groups in the country, particularly the elderly and those people who have disabilities. Thirdly, recommendations will be made for the EMS Plans to be updated to include climate-resilient measures for the building sector. Engagements will be held with project partners to review the EMS Plans and identify entry points for the inclusion of climate change adaptation for the building sector. Following this review, recommendations will be drafted proposing the relevant revisions to the EMS Plans. The target for these revisions to be completed is the end of Year 2 of project implementation. Annual meetings will be held thereafter with relevant stakeholders to collate and share lessons learned from implementing the EMS plans and ensure that these plans are updated regularly where necessary.

Activity 2.2. Mainstream climate change adaptation for the building sector into public and private financial, insurance and banking sectors.

Activity 2.2 will complement the SCCF project to maximise the effectiveness and accessibility of the SIRF Fund's adaptation window. First, public and private sector stakeholders will be engaged to identify additional entry points for accessing climate finance through the SIRF fund for investments. For the private sector, this will focus on developments that require investments that exceed the current 5% cap. Key to this process will be the introduction of incremental cost reasoning to selection criteria, which will allow for the development costs to be split between baseline and adaptation measures. This will reduce the investment requires from the SIRF fund, with baseline costs being covered through alternative financial windows. Additional mechanisms will then be identified to further bridge the financing gap, including incentive programmes, levies and insurance/risk management products. Options for ramping-up the replenishment of the SIRF fund will also be explored to increase the relative value of the 5% cap. Private sector access to climate finance through the SIRF Fund will be further enhanced by enabling the public sector to use the SIRF Fund to sustainably procure bulk building materials required for climate-proofing infrastructure. This requires that relevant government entities – such as the Ministry of Health, Wellness and the Environment (MoHWE) – be made eligible to borrow capital from the SIRF Fund to purchase materials at a reduced price from international suppliers. Private entities — for example, businesses, hotels and homeowners — could then buy the materials they need from the MoHWE at this reduced price, thereby bridging the financial gap in adaptation financing. This approach will demonstrate the effectiveness of the bulk-import model as a viable option for financing climate change adaptation in Antigua and Barbuda's building sector.

In addition to enhancing access of the private sector to the SIRF fund for larger scale adaptation investments, this activity will refine the selection criteria for adaptation interventions. Using an evidence-based approach that draws lessons learned from the SCCF and EDA projects, as well as the implementation of on-the-ground adaptation interventions under Activity 1.1 of this project, the list of adaptation options supported by the SIRF Fund will be refined. This process will ensure that all options are optimised for the local conditions and markets, and that clear guidelines are set for assessing the eligibility of each application.

Through the consultation process, the most appropriate options discussed above will be selected and validated by all project partners. These consultations will happen in Year 1 of implementation. The SIRF fund guidelines will be updated and validated by all project partners following these discussions by the end of Year 2. To promote the use of the SIRF Fund as a mechanism for financing climate-adaptive measures for the buildings sector, decision-makers from NODS, DCA and PWD, as well as private sector representatives, will be trained on how to access financial resources under the SIRF Fund — within the specified thresholds. This training will be provided regularly commencing in Year 3. Finally, from the beginning of Year 3 to the end of the project implementation period (Year 6), annual engagement workshops will be held to collate and share lessons learned from public and private sector interactions with the SIRF Fund and processes for replenishment will be discussed and revised where necessary.

Activity 2.3. Train relevant staff from the National Office of Disaster Services (NODS), Development Control Authority (DCA) and the Public Works Department (PWD) as well as the private sector on operational procedures for long-term monitoring, maintenance and upscaling of climate-resilient renewable energy (RE) and water harvesting technologies in accordance with the national building code.

Training will be provided to relevant staff from NODS as well as building inspectors from DCA and building maintenance teams from PWD on operational procedures for long-term monitoring, maintenance and upscaling of climate change adaptation interventions that will be implemented under Output 1. Building-specific operations and maintenance (O&M) plans will be used to inform this training to ensure that the knowledge shared during these trainings is technically sound. Furthermore, the training provided will include procedures for conducting monitoring and maintenance activities as well as scaling up project interventions in accordance with the national building code. This will be done to ensure that these interventions continue to deliver adaptation benefits to the population of Antigua and Barbuda over the long term. Using the knowledge from these trainings, a long-term monitoring framework will be developed for each building fitted with climate-proofing measures under the project. This framework will include a cost-benefit analysis to quantify the avoided losses as a result of these climate-proofing measures and demonstrate the benefits of adopting climate change adaptation technologies in Antigua and Barbuda's building sector.

In addition, training programmes will be developed with partner organisations such as Antigua and Barbuda Institute for Continuing Education (ABICE) for the public and private sector representatives, including staff from the Ministry of Works (MoW) and Development Control Authority (DCA) as well as building inspectors, engineers, architects and draughtsmen. This training will focus on how to apply the regulations of the national building code during the installation of climate change adaptation measures that are specific to the building sector, such as renewable energy and climate-resilient water harvesting solutions. In addition, awareness raising campaigns will be designed and conducted to increase the uptake of climate change adaptation measures for the building sector across the public and private sectors. The focus of these campaigns will be on key aspects of the national building code as well as the availability of certified climate change courses and the benefits of implementing climate change adaptation measures within the building sector. Incentives, such as paid leave, are already being provided to government staff members to attend training courses to increase their technical expertise in relevant fields. This process will be complemented through designing and conducting a gender-sensitive awareness raising campaign within the government system to encourage staff members from relevant government entities to participate in training sessions focused on monitoring climate change adaptation technologies.

Activity 2.4. Train local workforce on the installation, operation and maintenance of climate-proofing measures for the targeted buildings.

The local workforce will be trained on how to support the installation, operation and maintenance of climate change adaptation solutions that will be installed in targeted buildings under Activity 1.1. To facilitate this training, suitable training institutions in the country, such as ABICE, will be engaged to develop and deliver a certified training programme that focuses on: i) installing, operating and maintaining climate-proofing measures for the building sector; and ii) implementing early action protocols (developed under Output 1) preceding an extreme climate event. The training course that will be developed under this activity will apply regional and international best practices for climate change adaptation measures in the building sector. Furthermore, the course will align with the national building code to ensure that there is uptake of building standards and procedures that account for Category 4 and 5 hurricanes. Lastly, to ensure that there is uptake of climate change adaptation technologies across Antigua and Barbuda's local workforce, an awareness raising campaign will be designed and conducted to encourage participation in the training course and promote the value of having increased knowledge on how to effectively install, operate and maintain these technologies.

9.3. Climate information services

9.3.1. <u>Output 3. Climate information services strengthened to facilitate early action within the building sector to respond to extreme climate events</u>

Project interventions under Output 3 will contribute to GCF Outcome A6.0 – Increased generation and use of climate information in decision-making – by strengthening Antigua and Barbuda's early warning system (EWS) as well as the capacity of Antigua and Barbuda Meteorological Services (ABMS) to facilitate rapid information sharing and early action preceding an extreme climate event. Interventions under this project output will complement the *Caribbean Disaster Emergency Management Agency (CDEMA) Early Warning Systems (EWS) Regional Readiness Project.* This project is currently under development and is focused on improving regional coordination of EWS across the Caribbean. Although the interventions under the CDEMA project are thematically aligned with the proposed project, the scope of the CDEMA project is not at a sufficient level to improve the production and dissemination of early warnings at a national and local level in Antigua and Barbuda to facilitate early action. Output 3 of the proposed project will fill this gap in two ways. Firstly, a centralised online server will be established and housed within ABMS to process climate data in real time, overcoming existing shortfalls in the data processing capabilities. This will enable ABMS to reliably and timeously forecast extreme climate events using data from the country's existing weather stations. The centralised server will be equipped to process data in several formats which will reduce processing time given that data is inputted from the country's weather stations using several different operational platforms. To further strengthen the capacity of ABMS to produce early warnings, training workshops will be conducted for ABMS staff on how to: i) collect, process and manage climate data generated by the server; and ii) use the generated data to develop early warning information products, including easily interpretable infographics. A knowledge exchange trip will also be conducted to the nearest Regional Climate Centre (RCC), under the auspices of the World Meteorological Organisation (WMO), which is currently implementing an impact-based forecasting approach to early warnings focused on early action.

To complement the abovementioned capacity-building interventions and ensure the effectiveness of early warnings, communication and early action protocols will be formalised between AMBS and relevant government agencies to facilitate rapid information sharing preceding an extreme climate event. The communication protocol will define which agencies need to be notified at each stage of hurricane development, from initial identification of a tropical disturbance through to a full hurricane. The communication protocol will be underpinned by specific early action protocols linked to specific stages of hurricane development. Each stage will require action from different stakeholders, including NODS, DoE, the Ministry of Health, Wellness and Environment (MoHWE), the Ministry of Education Science and

Technology (MoEST) and the general public. As the threat level increases, so will the required level of response. The early action protocols will define what needs to be done at each stage, as well as how it should be done and who is responsible. These protocols will include variable responses to allow flexibility depending on the anticipated intensity of incoming storms. This will include specific responses for each priority building to ensure that critical services are adequately prepared for a hurricane.

The combined effect of the early warnings and early action protocols will complemented Output 2 of the project which will ensure that relevant public institutions responsible for coordinating emergency response —such as NODS — as well as critical service providers — such as hospitals, clinics, police and fire stations — have the technical capacity to implement early action protocols preceding an extreme climate event. This will minimise the adverse impacts of these events on critical infrastructure and vulnerable local communities. Project activities that will be implemented under Output 3 are listed below.

Activity 3.1. Strengthen the capacity of ABMS to collect, process and manage climate data.

Under this project activity, a centralised online server will be established and housed within Antigua and Barbuda Meteorological Services (ABMS) to overcome the current barrier of an insufficient climate data processing system. This online server will enhance the real-time processing of climate data to ensure that climate threats are detected in advance and facilitate impact-based forecasting. To support the establishment of the server, staff within ABMS will receive training on: i) efficient and effective methods for collecting, processing and managing climate data in real time; and ii) how to develop early warning information products, including infographics that are locally appropriate and easily interpreted by vulnerable communities. A knowledge-exchange trip will also be conducted to the nearest Regional Climate Centre (RCC), under the auspices of the World Meteorological Organisation (WMO), which is currently implementing an impact-based forecasting approach to early warnings focused on early action. This trip will therefore facilitate knowledge transfer between experts at RCC and ABMS staff on the impact-based forecasting process, how to appropriately apply this forecasting approach within the context of Antigua and Barbuda and the benefits of implementing such an approach.

Activity 3.2. Establish a formalised communication protocol to facilitate rapid information sharing and early action preceding an extreme climate event.

A formal communication protocol will be developed and operationalised under Activity 3.2 to support the development of early warning information products and impact-based forecasts (Activity 3.1). This will be done to facilitate effective communication of impact-based forecasts from ABMS to decision-makers within relevant government entities responsible for preparation ahead of an extreme climate event. To support this communication protocol, the capacity of ABMS will be strengthened to ensure that the dissemination of climate information is locally appropriate and effective. Early action protocols will also be developed for critical public service and community buildings, with variable responses built into these protocols to account for variable intensities of incoming storms. Training will then be provided to the relevant public and private sector actors on the application of these protocols to ensure decision-makers, that are integral to disaster response (such as NODS), have sufficient capacity to respond efficiently and effectively to the threat of an extreme climate event.

10. Selection process for target infrastructure

Antigua and Barbuda's critical public service buildings[441] and community buildings[442] provide vital services to local communities during and immediately after extreme climate events, particularly hurricanes and tropical storms. These critical public buildings are not designed to withstand the forces generated by

[441] including fire stations, hospitals, clinics, police stations
[442] including community centres, churches and schools

Category 4 and 5 hurricanes and, as a result, the communities that use them are left extremely vulnerable to these events. There is consequently an urgent need to increase the resilience of critical public service and community buildings to withstand the impacts of such extreme events. To achieve this, the Climate Technology Centre and Network (CTCN) — the operational arm of the UNFCCC — was commissioned to undertake a building assessment with the objective of identifying priority buildings to receive climate-proofing measures under the proposed project (Annex 22: Building Assessment). The criteria for this selection process are described in further detail below.

10.1. Selection of representative sample of priority buildings

In January 2018, a preliminary scoping mission was undertaken by a Senior Engineer from UNEP to identify buildings to receive climate-proofing interventions under the proposed project. The mission involved the selection and assessment of a representative sample of critical public service and community buildings across the island of Antigua, with the objectives of identifying appropriate climate-proofing measures for these buildings. In addition, the sample was used to determine the costs associated with business as usual upgrades as well as climate-proofing interventions. Indicative costing for business as usual as well as adaptation upgrades is presented in Section 10.2.1 below. Engineering Construction and Management Consulting Limited (ECMC) — a private consultancy based in Saint Lucia and operating throughout the OECS countries[443] — was contracted by CTCN shortly after this mission to provide technical assistance for the identification and selection of appropriate interventions. During the initial scoping exercise, 34 buildings were selected as the representative sample from the public building portfolio of more than 200 buildings[444]. This sample represented 50% of the critical public service buildings and 20% of the community buildings targeted for receiving adaptation measures. Buildings that make up the representative sample are listed below.

1. All Saints Clinic
2. All Saints Fire Station
3. All Saints Police Station
4. Analytical services 1
5. Analytical services 2
6. Antigua State College 1
7. Antigua State College 2
8. Bendals health clinic
9. Bolans health clinic
10. Clareview Psychiatric Hospital 1
11. Clareview Psychiatric Hospital 2
12. Clareview Psychiatric Hospital 3
13. Clareview Psychiatric Hospital 4
14. High Court of Justice
15. Defence Force Building 1
16. Defence Force Building 2
17. Department of Environment 1
18. Department of Environment 2
19. Fiennes Building 1
20. Fiennes Building 2
21. Good Shepherd Children’s Home
22. MET office (airport terminal)

[443] CTCN. Engineering Construction and Management Consulting Limited. Available at: https://www.ctc-n.org/network/network-members/engineering-construction-and-management-consulting-limited.
[444] Detailed inspection reports and photo records from this process are stored by the AB Department of Environment, within the Health and Environment Ministry.

23. Ministry of Finance
24. Ministry of Tourism
25. National Archives
26. National Office of Disaster Services
27. Parham health clinic
28. Police Headquarters
29. Potters health clinic
30. Prison Block
31. St John's Fire Station
32. Swetes health clinic
33. Victory Centre
34. Nyabinghi School

10.1.1. Identified interventions for upgrading target buildings

The results of the building assessments undertaken by CTCN were compared against the set of design criteria listed below[445].

- compliance with national building legislation and standards;
- affordable repairs and maintenance;
- heritage protection;
- reduced operating costs;
- reduced environmental and climate impacts;
- wind loading and debris risk management;
- flood security;
- earthquake resistance;
- low electricity consumption;
- increased electricity supply autonomy;
- low water consumption and increased water autonomy; and
- reduced wastewater pollution.

Based on the process described above, a suite of potential adaptation and non-adaptation interventions was developed. These measures — which reflect the full scope of work required for upgrading priority buildings in Antigua and Barbuda — are presented in Table 7 below.

Table 7. Potential adaptation and non-adaptation interventions for target buildings.

Categorisation	Potential interventions
Adaptation upgrades	
Extreme weather resistance (roofs, doors and windows)	Roof structural upgrades
	Roof cover and fastening upgrades
	Replace windows and frames
	Replace doors and frames
Water supply	Potable water reserve tanks
	Solar hot water units
	Electric water heater
	Install or upgrade rainwater tanks
	Install water-saving taps, toilets and fixtures
	Install dual source internal plumbing and fix pipe leaks
	Install or upgrade water and rainwater tank pumps
Stormwater drainage	Stormwater drainage upgrade
	Roof guttering repair or replacement

[445] Further details on the upgrade scope and design criteria for the priority buildings are presented in Section 4 of Annex 22: Building assessment.

Off-site emergency RE strategic stocks (50% eligible)	PV panel, racking and balance of system (BOS) strategic stock
General electrical (50% eligible)	General wiring repair and upgrade
	Perform major repairs and maintenance
Non-adaptation upgrades	
General structural repairs	Concrete slabs, columns and beams for major structural repairs
	External walls – minor crack repair
	External walls – minor crack repair
	Foundation work
	Other structural work
General building repairs	Internal walls – repair
	Parapets and railings repair
	Stairways and ramps repair
	False ceiling repair or replacement including insulation
	Flooring repair or replacement
General electrical (50% eligible)	General wiring repair and upgrade
	Install sensors and timers
	Replace FLs with LEDs
	Install ceiling fans
	Install or replace split unit ACs
	Install or replace central HVAC system
	Perform major repairs and maintenance
Wastewater treatment	Septic tank cleaning and upgrade
	Other wastewater treatment infrastructure
On-site power supply and storage	Rooftop or local ground mount PV
	Li battery bank
Off-site emergency RE strategic stocks	Allocation of warehouse space
Off-site emergency DG back up supply	Trailer-mounted generators with tanks

10.1.2. Cost estimates for upgrading target buildings

CTCN's building assessment was used to determine the cost of upgrading the targeted buildings. These costs are based on the representative sample of priority buildings (34 buildings; representative of 50% of priority buildings targeted under the project) within the project scope[446]. The estimated cost of upgrading the representative sample of 34 priority buildings is ~US$18 million. Extrapolating this cost using an average cost per square meter of floor space against the total floorspace of all priority buildings in Antigua and Barbuda indicates that the cost of upgrading all of the priority buildings in the country is estimated to be ~US$36 million. Further extrapolation of these cost estimates indicates that upgrading all 200 buildings within the public building portfolio will cost ~US$90 million. Under a post-disaster scenario, where rapid recovery is required, these prices could increase by up to 30%.

Table 8 below provides an estimate for the cost of both adaptation and non-adaptation building upgrades. Cost categories for interventions deemed eligible for adaptation financing include: i) extreme weather resistance; ii) water supply; and iii) stormwater drainage. Interventions under the cost categories that do not qualify for adaptation financing include general structural repairs, general building repairs, general electrical repairs and wastewater treatment.

Table 8. Estimated cost of adaptation and non-adaptation building upgrades.

Cost categorisation	Estimated cost
Adaptation upgrades	

[446] according to 2018 pricing

Extreme weather resistance	US$3,030,000
Water supply	US$1,960,000
Stormwater drainage	US$530,000
Off-site emergency RE strategic stocks (50% eligible)	US$220,000
General electrical (50% eligible)	US$1,605,000
Subtotal adaptation cost	**US$7,345,000**
Non-adaptation upgrades	
General structural repairs	US$1,230,000
General building repairs (50% eligible)	US$1,630,000
General electrical (50% eligible)	US$1,605,000
Wastewater treatment	US$100,000
On-site power supply and storage	US$5,470,000
Off-site emergency RE strategic stocks (50% eligible)	US$220,000
Off-site emergency DG back up supply (50% eligible)	US$470,000
Subtotal non-adaptation cost	**US$10,725,000**
Cost of all building upgrades (adaptation and non-adaptation) for representative sample of 34 buildings, which have a total building footprint of 18,860 m^2	**US$18,070,000**
Average total upgrade cost per square metre of floor space	**US$960**
Estimated total cost of all priority building upgrades, which have a total building footprint of 33,267 m^2	**US$31,936,320**

10.2. Selection of priority buildings to receive adaptation measures under the project

Lists of critical public service and community buildings were obtained from key government departments in Antigua and Barbuda, including the: i) Ministry of Public Works (MoW) — which provided a list of government buildings; ii) Ministry of Health, Wellness and the Environment (MoHWE) — which provided a list of all the clinics; iii) Ministry of Education Science and Technology (MoEST) — which provided a list of all school buildings; and iv) National Office of Disaster Services (NODS) — which provided a list of all designated hurricane shelters. From this, a comprehensive list of all critical public service and community buildings in the country was compiled. This list was then cross-referenced with those buildings targeted by other projects currently being developed and implemented by the DoE to: i) ensure that there was no repetition between the buildings selected to receive climate-proofing measures and those buildings that are being upgraded through other initiatives; and ii) build on existing projects and programmes in the country, therefore, contributing to the scaling-up of climate-resilient measures for the building sector. Following this cross-referencing, the selected buildings were categorised into five groups, namely protective services, emergency services, medical services, schools/shelters and critical offices, including those used by the government.

Priority buildings to be targeted under the project were selected from the remaining list of critical public service and community buildings using the criteria described below. Each building identified during the selection process had to meet two of these criteria to qualify as a priority building to receive climate-proofing interventions under the proposed project.

- The building provides essential services to the population of Antigua and Barbuda before and after an extreme climate event. These services include: i) protective or emergency services; ii) medical services; iii) post-disaster assessment and response; and iv) critical management and administration (including critical government offices).
- The location of the building maximises the number of beneficiaries.
- The location of the building provides essential services to vulnerable local communities.

Based on the above criteria, 54 critical buildings were selected to receive climate-proofing measures under the proposed project. These buildings accompanied with the business as usual and adaptation upgrades that each building will receive are presented in Table 9 below. The surface area of each building is known and has been used to estimate total intervention costs based on the

Table 9. Building matrix showing the list of priority buildings that will receive climate-proofing interventions under the proposed project accompanied by the type of interventions that each of these buildings will receive.

Matrix of priority buildings to be receive upgrades under the project										
Columns marked with an '1' represent that the corresponding intervention is required for the specific building while a '0' shows that the corresponding intervention is not required.										
No.	Building	Floor size (m2)	Extreme Weather Resistance	Solar PV + Batteries	Water Supply Interventions	General Electric and EE	General Structural Repairs	General Building Repairs	Storm Water Drainage	Wastewater Treatment
1	All Saints Clinic	446	1	0	1	1	1	1	1	1
2	All Saints Fire Station	200	1	1	1	1	1	1	1	1
3	All Saint's Police Station	760	1	1	1	1	1	1	1	1
4	Analytical services 1	320	1	1	1	1	1	1	1	1
5	Analytical services 2	680	1	1	1	1	1	1	1	1
6	Antigua State College 1	1,320	1	1	1	1	1	1	1	1
7	Antigua State College 2	189	1	1	1	1	1	0	0	1
8	Bendals health clinic	284	1	0	1	1	1	1	1	1
9	Bolans health clinic	114	1	0	1	1	1	1	1	1
10	Clareview Psychiatric Hospital 1	580	1	0	1	1	1	1	1	1
11	Clareview Psychiatric Hospital 2	203	1	0	1	1	1	1	1	1
12	Clareview Psychiatric Hospital 3	159	1	0	1	1	1	1	1	1
13	Clareview Psychiatric Hospital 4	270	1	0	1	1	1	1	1	1
14	High Court of Justice	6,471	1	1	1	1	0	1	1	1
15	Defence Force Building 1	468	1	1	1	1	1	1	1	0
16	Defence Force Building 2	609	1	1	1	1	1	1	1	1
17	Department of Environment 1	330	1	0	1	1	0	1	1	0

18	Department of Environment 2	240	1	0	1	1	0	1	1	0
19	Fiennes Building 1	126	1	0	1	1	1	1	1	0
20	Fiennes Building 2	294	1	0	1	1	0	1	1	0
21	Good Shepherd Children's Home	283	1	1	1	1	0	1	1	1
22	Met office	234	1	1	1	1	1	1	1	1
23	Ministry of Finance	2,558	1	1	1	1	1	1	1	1
24	Ministry of Tourism	2,060	1	1	1	1	1	1	1	1
25	National Archives	906	0	1	1	1	0	1	1	0
26	National Office of Disaster Services	647	0	0	1	1	1	1	1	1
27	Parham health clinic	108	1	0	1	1	1	1	1	1
28	Police Headquarters	668	1	1	1	1	1	1	1	1
29	Potters health clinic	220	1	0	1	1	1	1	1	1
30	Her Majesty's Prison	800	1	1	1	1	1	1	1	1
31	St John's Fire Station	600	1	1	1	1	1	1	1	1
32	Swetes health clinic	177	1	0	1	1	1	1	1	1
33	Liberta Police Station	125	1	1	1	1	0	1	1	1
34	Liberta Primary School	329	1	1	1	1	1	1	1	1
35	Urlings Primary School	468	1	1	1	1	1	1	1	1
36	Jennings Primary School	812	1	1	1	1	1	1	1	1
37	Bolans Primary School	530	1	1	1	1	1	1	1	1
38	Bendals Primary School	675	1	1	1	1	1	1	1	1
39	Pigotts Clinic	228	1	1	0	1	0	0	1	1
40	Princess Margaret Secondary School	610	1	1	1	1	1	1	1	1
41	Cedar Grove Clinic	602	1	0	1	1	0	0	1	0
42	Old Road Clinic	164	1	0	1	1	1	1	1	1
43	Freetown Primary School	368	1	0	1	1	1	1	1	1
44	Emergency Medical Service	478	1	1	1	1	1	1	1	1

45	Gray's Farm Clinic	495	1	0	0	1	0	1	0	1
46	Grays Farm Police Station	217	1	1	1	1	0	1	1	1
47	Willikies Primary School	404	1	1	1	1	1	1	1	1
48	Red Cross	470	1	1	1	0	0	1	1	1
49	Cedar Grove Primary	1,357	1	1	1	1	1	1	1	1
50	Clare Hall Secondary School	642	1	1	1	1	1	1	1	1
51	Bethesda Clinic	109	1	0	0	1	0	0	1	0
52	Cobbs Cross Primary School	362	1	1	1	1	1	1	1	1
53	Barbuda Fire Station	140	1	1	1	1	0	1	1	1
54	Barbuda Council & Treasury	358	1	1	1	1	0	0	1	1
Total		**33,267**	**52**	**34**	**51**	**53**	**39**	**49**	**52**	**46**

10.3. Justification for the selection of direct project beneficiaries

A climate vulnerability analysis was undertaken to support the selection of the 54 critical public service and community buildings to receive climate change adaptation measures under the project. The methodology for this analysis is presented below, followed by the associated findings.

10.3.1. Methodology

Hydraulic flood analysis was undertaken using the estimated Hurricane Irma precipitation total and calibrated through the observed ERA5[447] hourly precipitation reanalysis data at the 1:100-year occurrence to inform storm event rainfall characteristics. This design storm was used as the precipitation input for flood modelling over Antigua and Barbuda. The modelling was done with the HEC RAS hydrologic model[448] which was simulated over the SRTM 30 m topography data. This data will force the potential water direction coalescing into informal gravity-driven drainage channels.

The population density was assessed using WorldPop 100 m gridded population data[449]. The locations of the lower-income populations were assessed with the Global exposure datasets – Population and Environment dataset[450]. The areas with populations considered low and lower-middle were used to determine the location of the more vulnerable dwellings and therefore the more vulnerable populations. These areas were then classified by the Jenks natural breaks measures, highlighting areas with increased number of low to low-medium income dwellings.

10.3.2. Findings from the vulnerability analysis

The selection of these buildings was done in a manner which ensures that critical services provide maximum coverage to high-population areas, the poorest communities and those individuals living in areas outside of the main drainage channels. The distribution of project interventions therefore covers the majority of built-up areas in Antigua and Barbuda, with increased coverage in the more densely populated and exposed communities (Figure 35; and Table 10).

[447] ERA5 reanalysis hourly data 2000 – 2018 ECMWF https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5
[448] U.S. Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS), https://www.hec.usace.army.mil/software/hec-ras/
[449] WorldPop gridded population
[450] GAR15 UNEP-GRID, Global exposed economic stock

Figure 35. Distribution of project intervention sites across Antigua and Barbuda.

Table 10. Population coverage of critical public service and community buildings that will receive climate-proofing interventions under the proposed project.

Parish	Populations	Intervention buildings
Saint John	51,737	28
Saint Mary	7,341	5
Saint George	8,055	3
Saint Peter	5,325	1

Saint Paul	8,128	5
Saint Philip	3,347	2
Barbuda	1,634	2

Project intervention sites were also selected by accounting for the location of lower-income communities in Antigua and Barbuda, where infrastructure is less resilient to the extreme winds and heavy downpours associated with Category 4 and 5 hurricanes (Figures 36 and 37). To ensure maximum coverage of these vulnerable groups by project interventions, a walk-time analysis was undertaken at 5-, 15- and 30-minute intervals from these vulnerable communities to critical public service and community buildings targeted under the project (Table 11). This was done to support the selection of target intervention sites and ensure that maximum coverage of critical services is provided to the most vulnerable people as a result of project interventions.

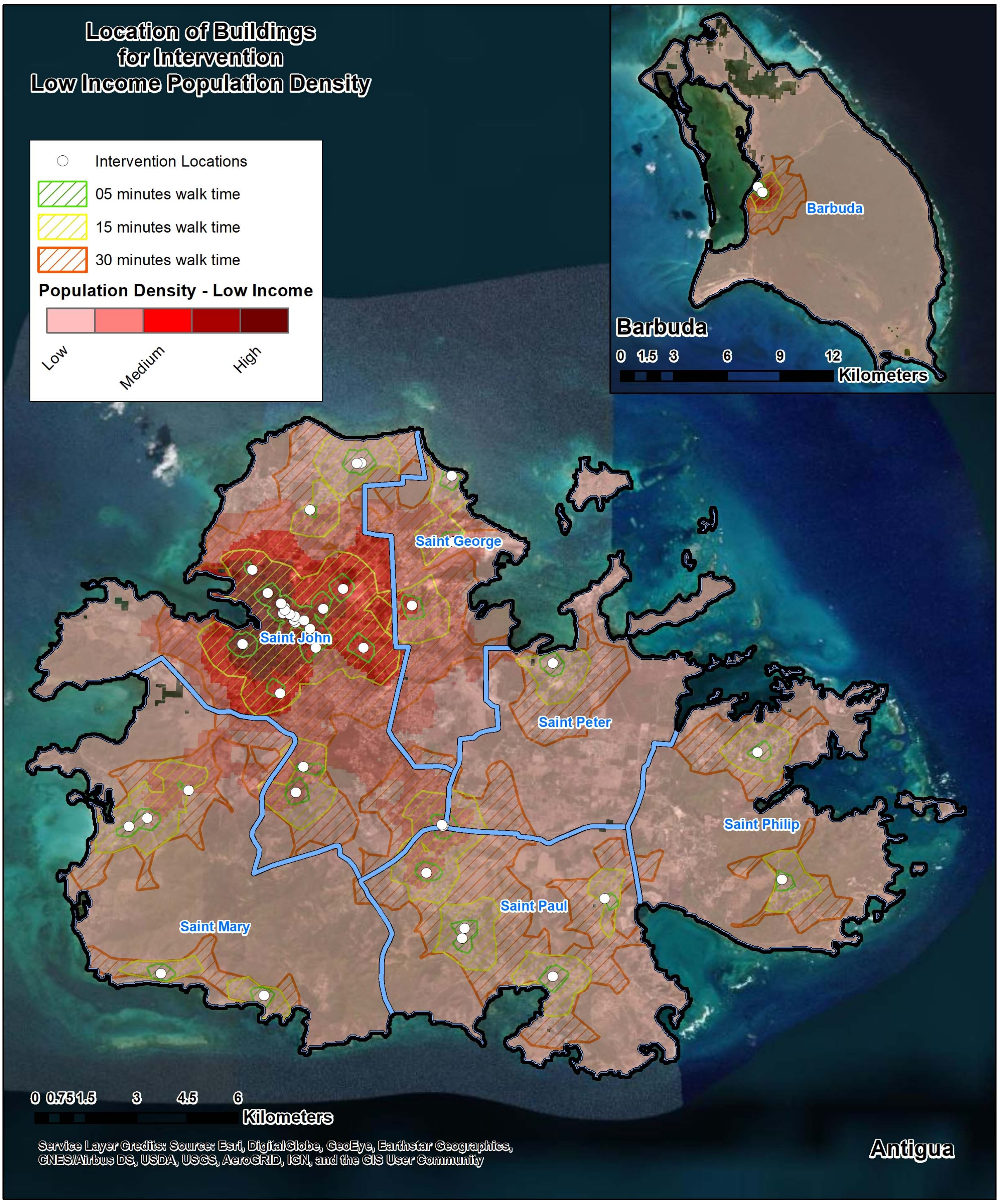


Figure 36. Distribution of project intervention sites within lower income areas with higher climate vulnerability.

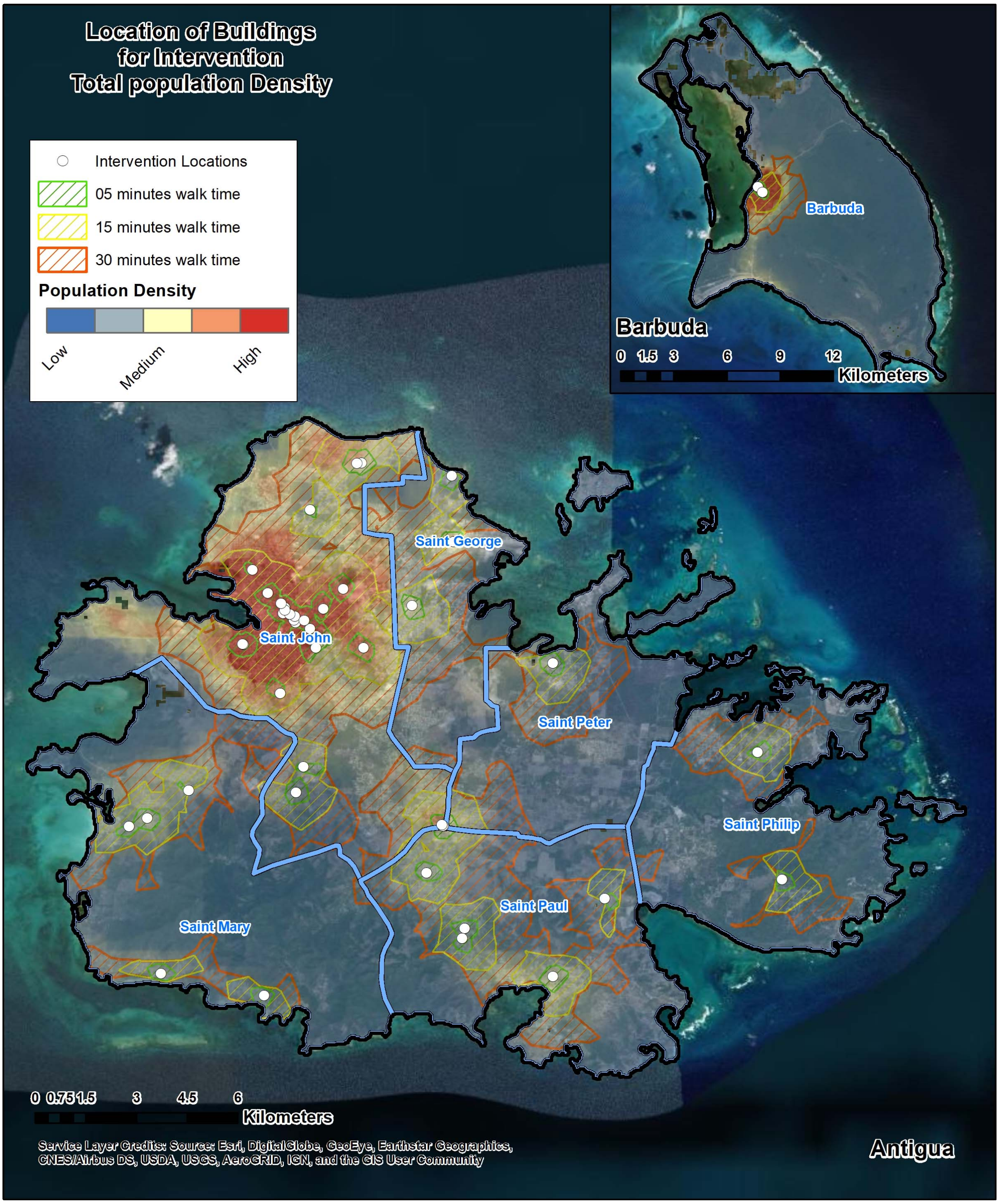


Figure 37. Distribution of project intervention sites to cover areas of higher population density.

Table 11. Walk-time analysis conducted to determine the coverage of project interventions.

Walk time	Population served	Population served (%)	Low income Population served (%)
5 minutes	10,512	11%	17%
15 minutes	45,923	47%	62%
30 minutes	73,216	76%	89%

The majority of the selected project intervention sites are located in areas of higher elevation, outside of the potential inundation areas from extreme downpours associated with hurricanes, as noted during Hurricane Irma. Nine sites are located within 10 m of the flood inundation zones, five are within 30 m, five within 50 m, 12 within 100 m and 16 sites are located further than 100 m away from these inundation zones. 60% of the project intervention sites are therefore located 50 m or more away from potential flood-inundation zones. For this reason, climate change adaptation measures to be implemented on target critical infrastructure will be designed and installed to primarily reduce the impacts of high wind speeds associated with Category 4 and 5 hurricanes, which is the main climate threat to these critical buildings in Antigua and Barbuda. A map showing the spatial distribution of the priority buildings to receive climate-proofing interventions under the proposed project are presented in Figures 38 and 39 below.

Figure 38. Priority buildings selected on Antigua island to receive climate-proofing measures under the proposed project. A) the spatial distribution of all priority buildings across Antigua island; and B) the spatial distribution of priority buildings in St. John's.

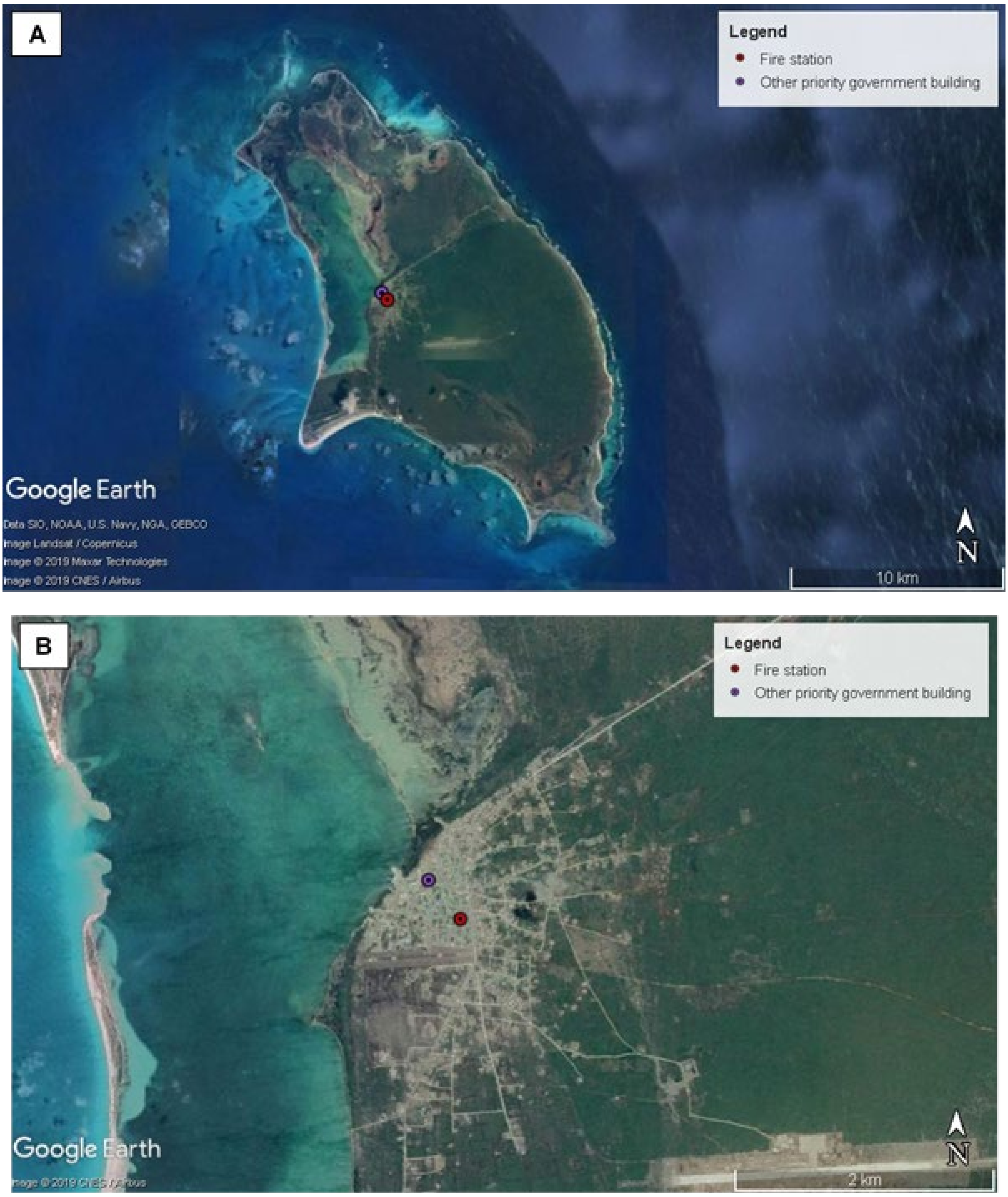


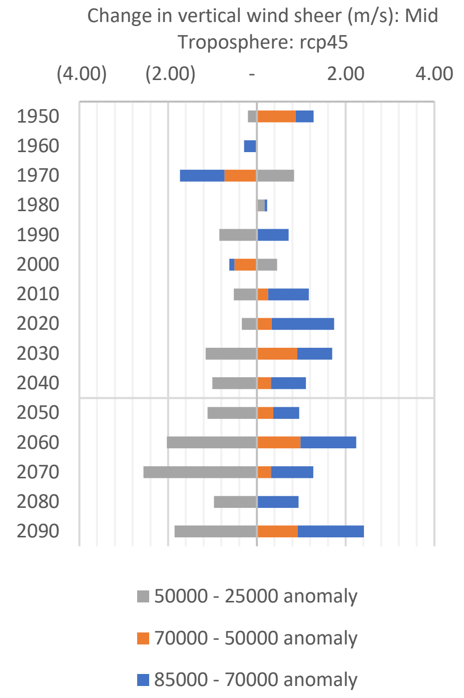
Figure 39. Priority buildings selected on Barbuda island to receive climate-proofing measures under the proposed project. A) the spatial distribution of all priority buildings across Barbuda island; and B) the spatial distribution of priority buildings in Codrington.

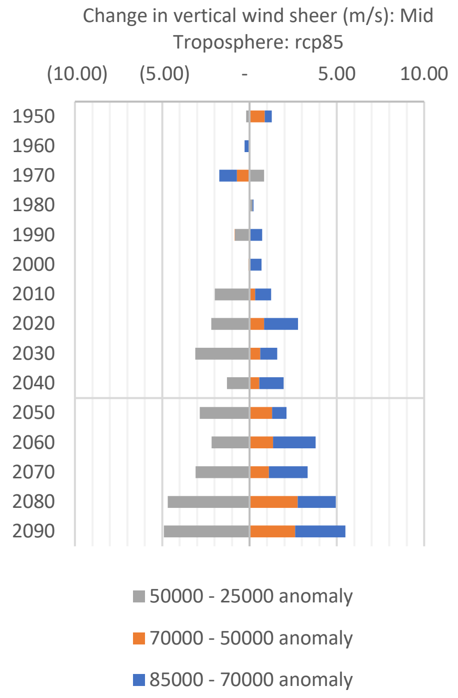
11. Appendices

11.1. Appendix 1. Monthly vertical wind shear (VWS) assessment for the lower-, mid-, and upper-troposphere

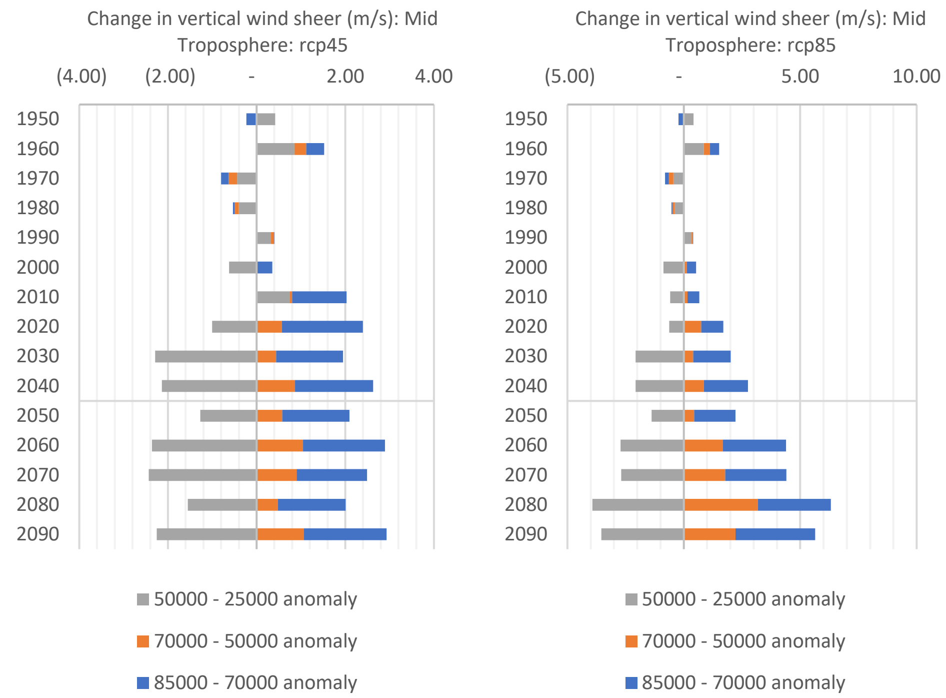
MDR 1

July

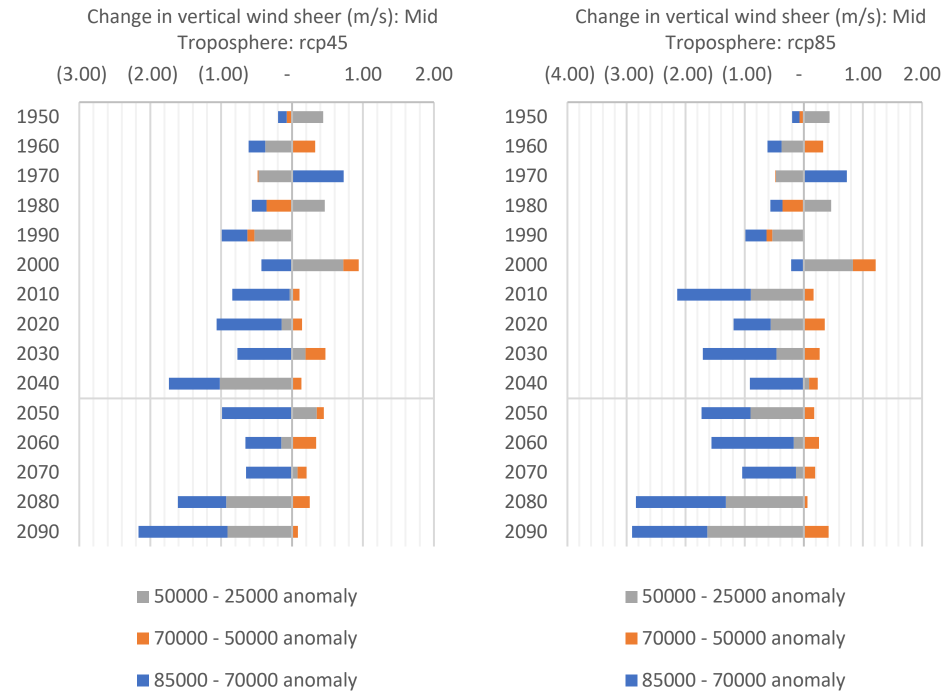




August



September



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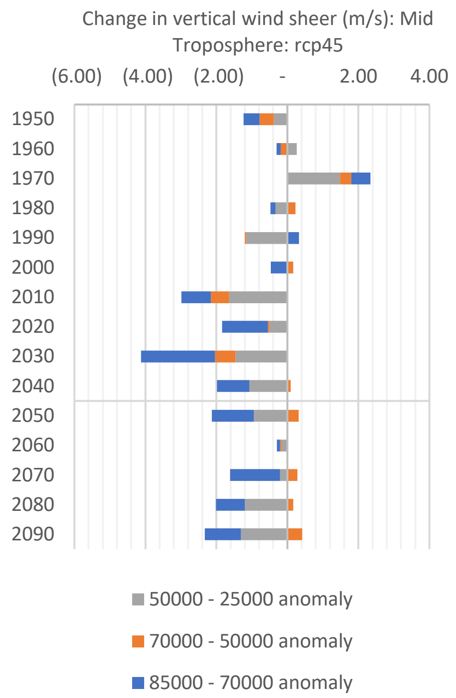
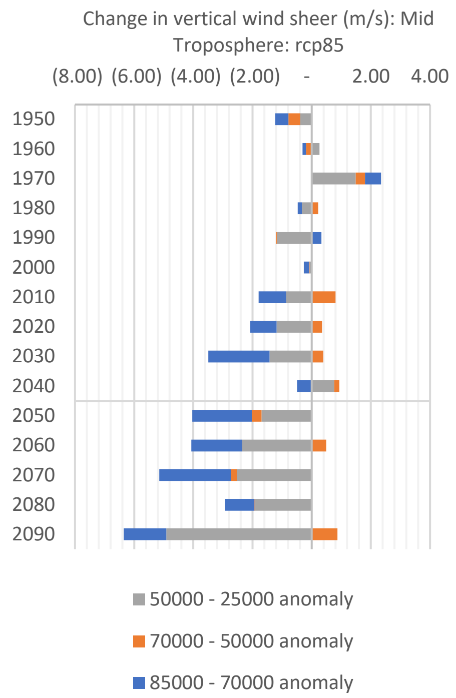
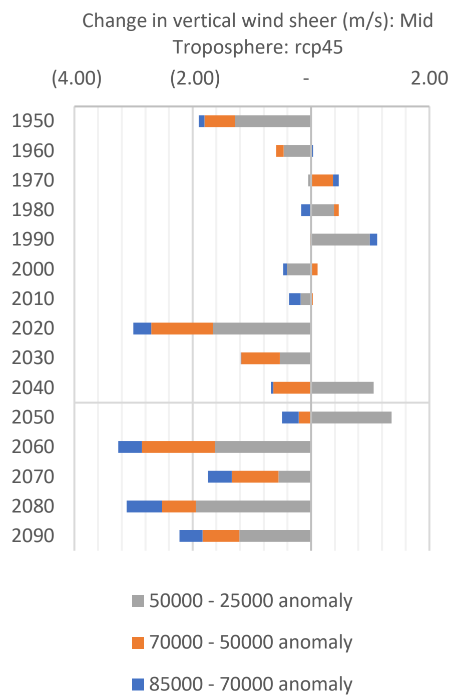
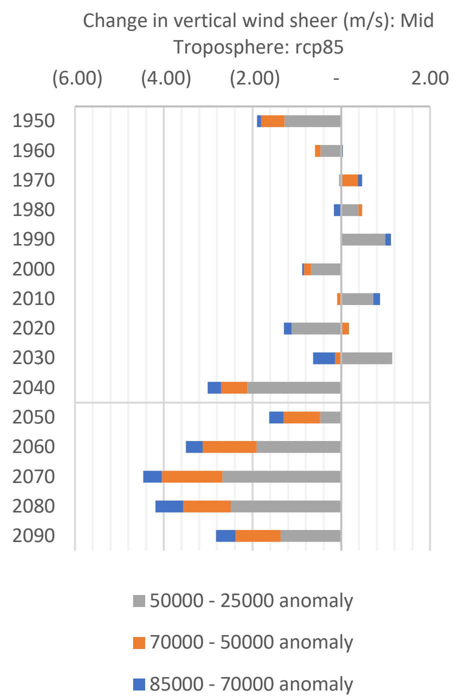




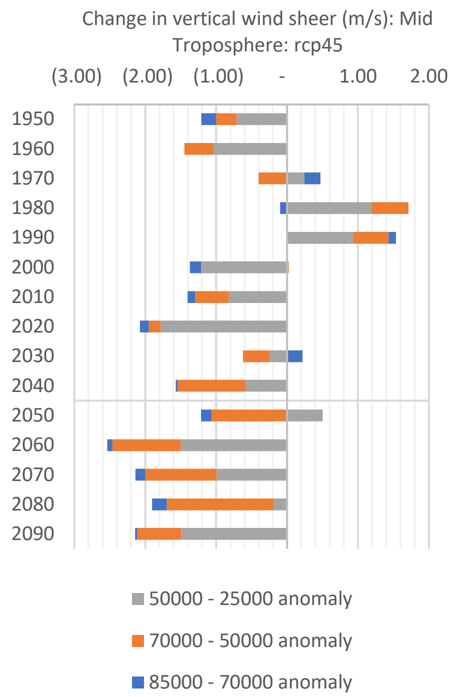
MDR 2

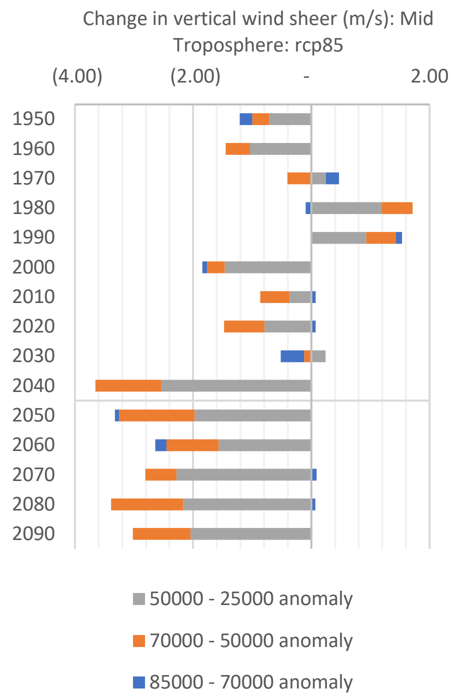
July





August





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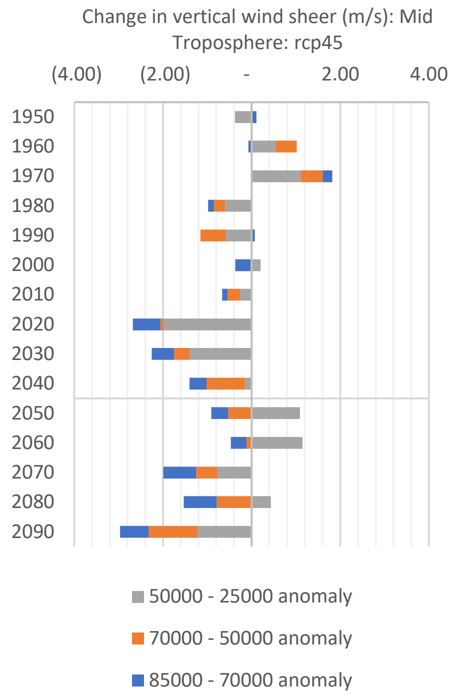

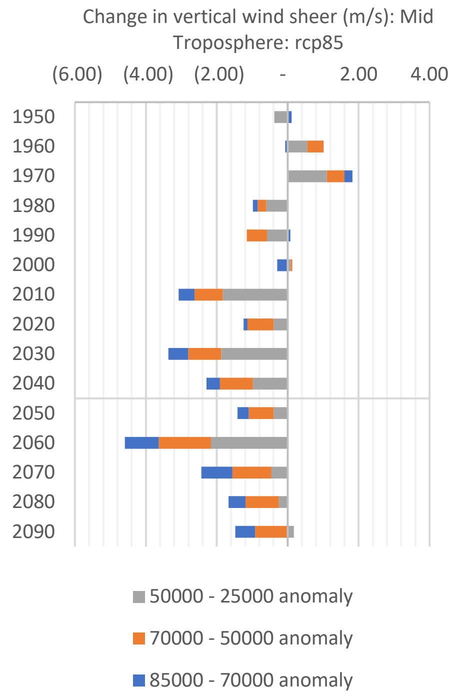

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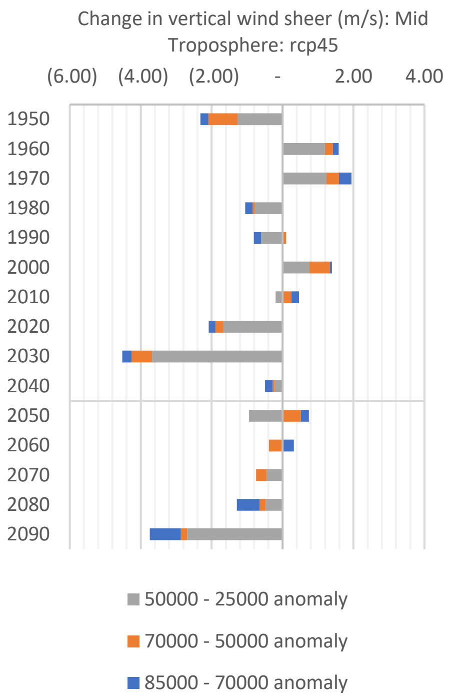
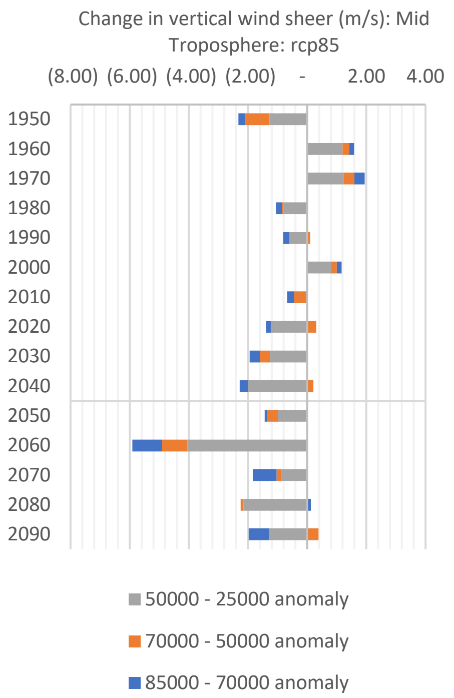
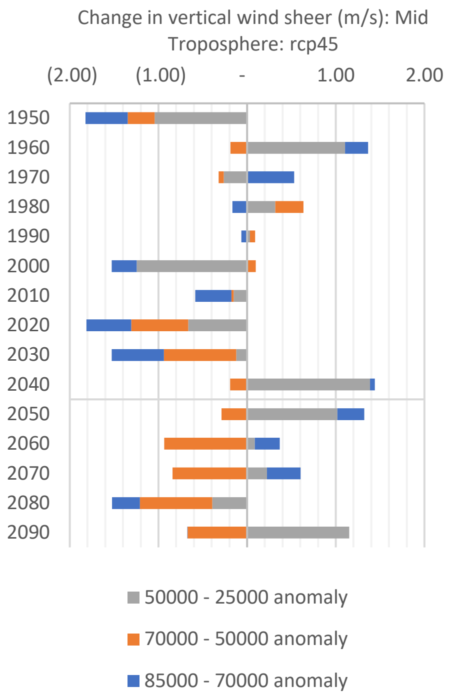
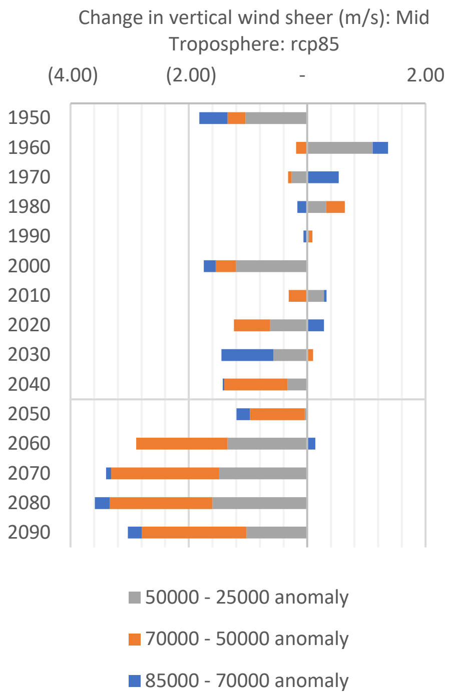




MDR 3

July





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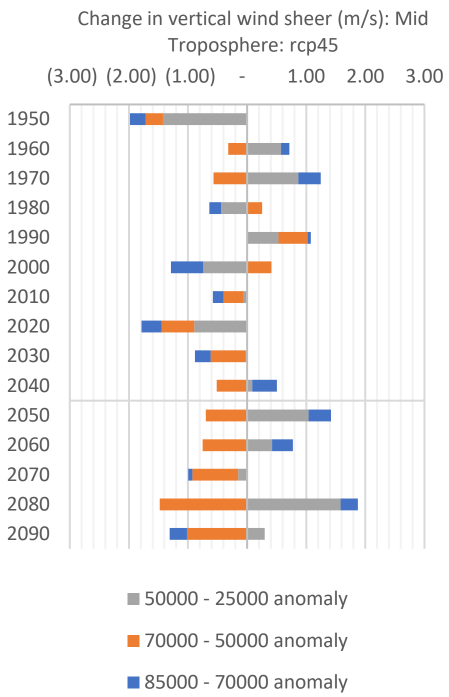

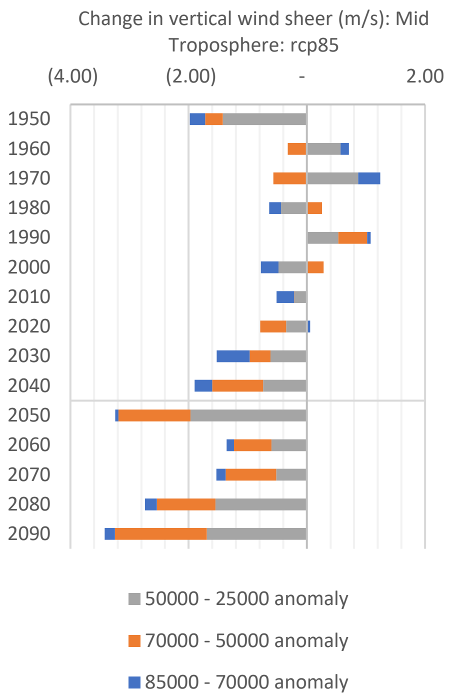

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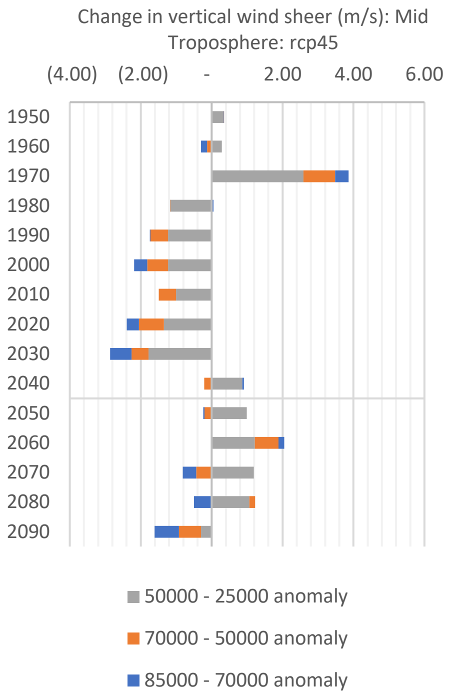
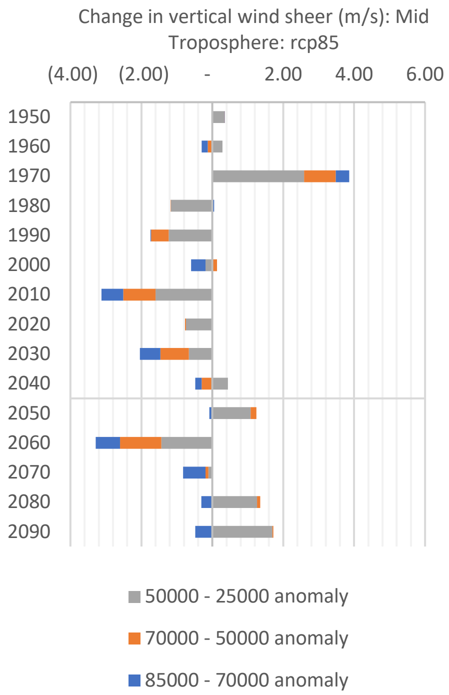
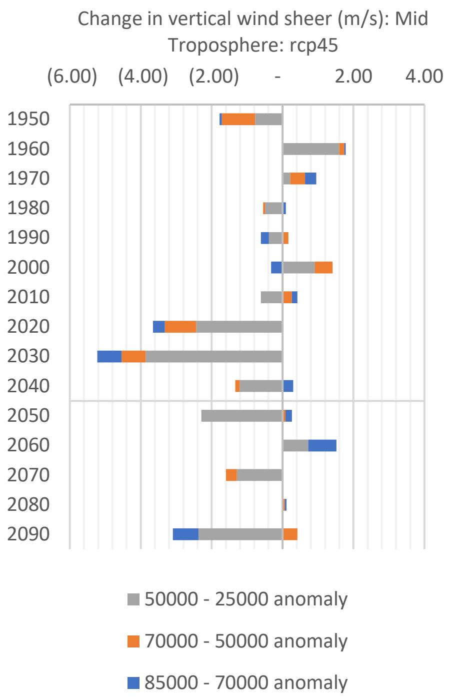
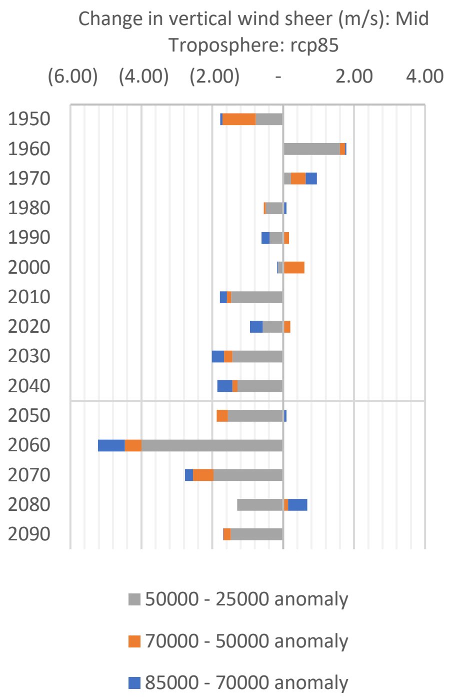


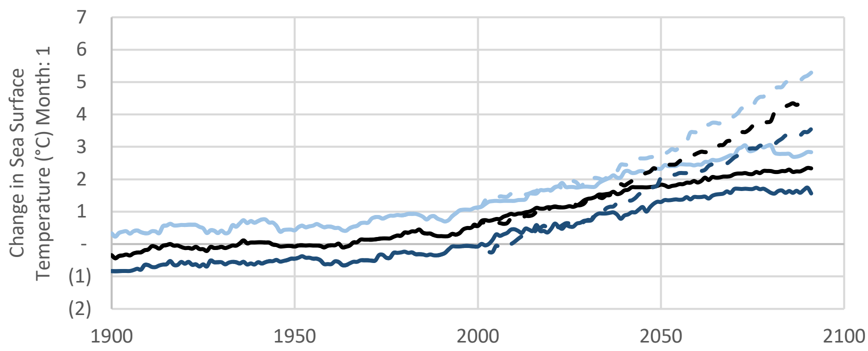


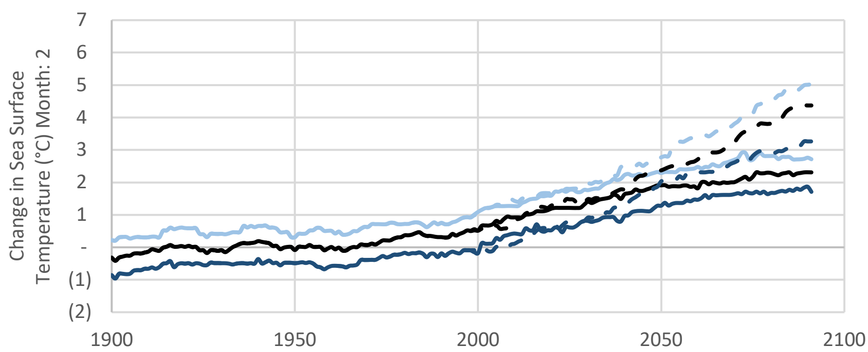
October

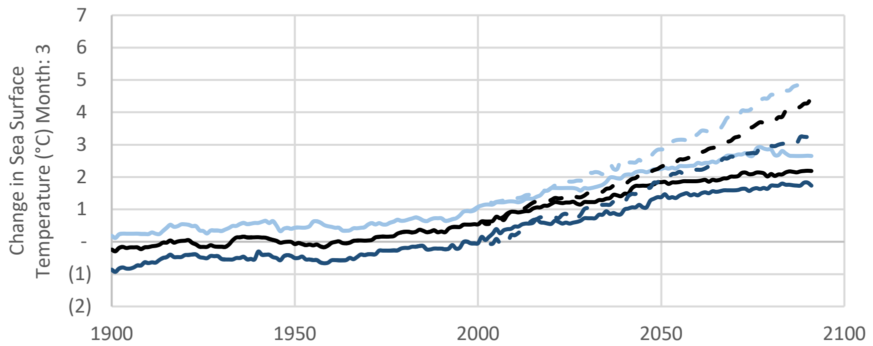


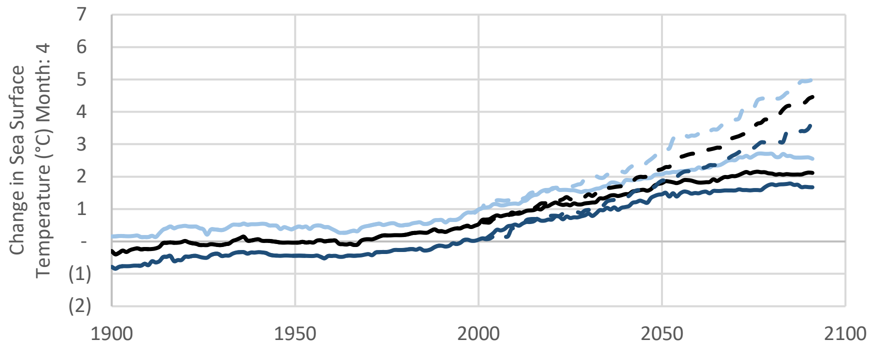


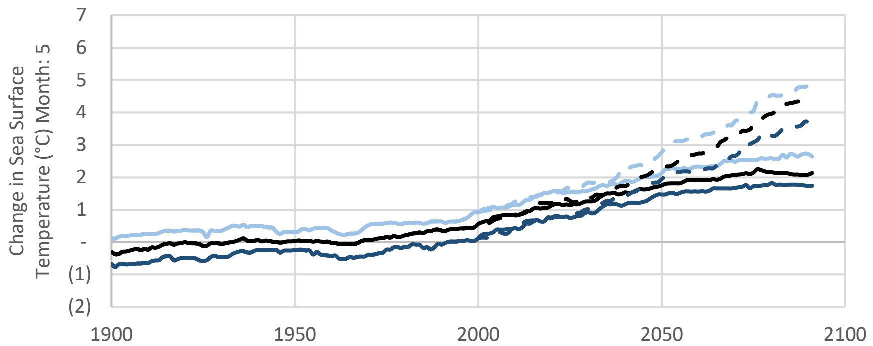
11.2. Appendix 2. Monthly sea surface temperature (SST)

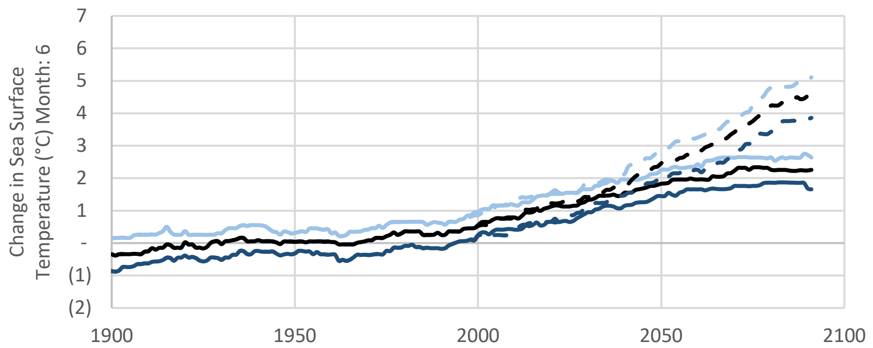


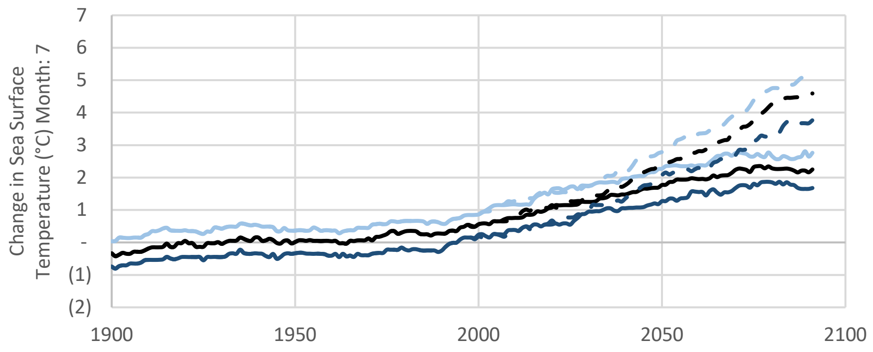


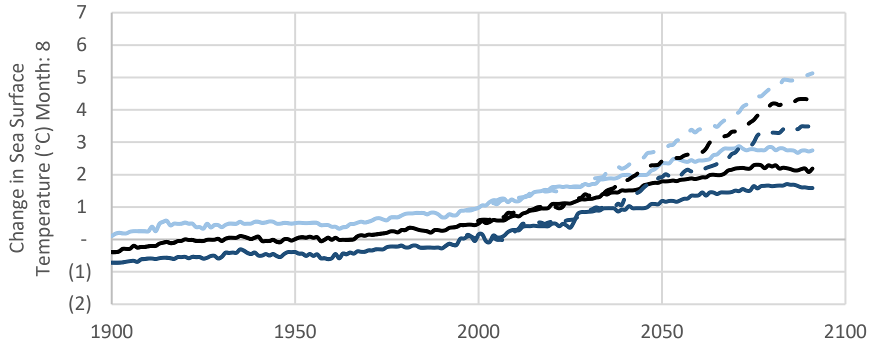

Change in Sea Surface Temperature (°C) Month: 3
7
6
5
4
3
2
1
-
(1)
(2)
1900
1950
2000
2050
2100

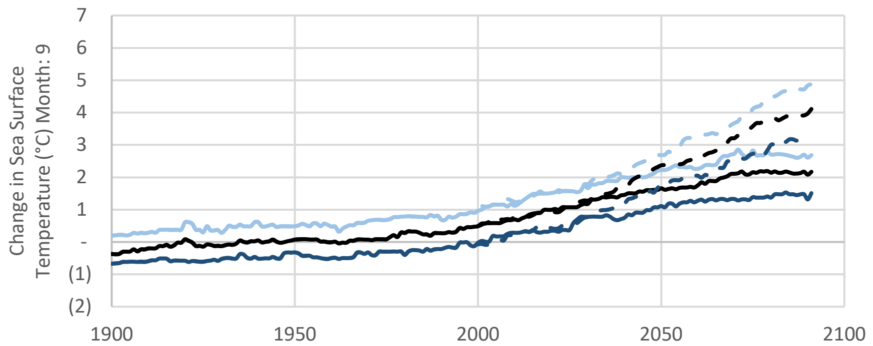

Change in Sea Surface Temperature (°C) Month: 4
7
6
5
4
3
2
1
-
(1)
(2)
1900
1950
2000
2050
2100

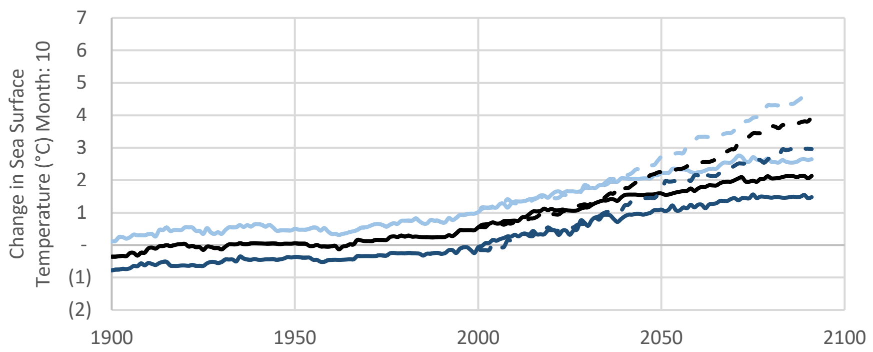

Change in Sea Surface Temperature (°C) Month: 5
7
6
5
4
3
2
1
-
(1)
(2)
1900
1950
2000
2050
2100

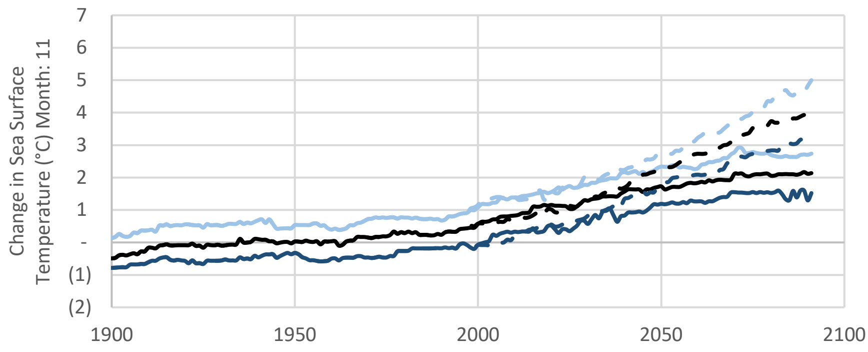

Change in Sea Surface Temperature (°C) Month: 6
7
6
5
4
3
2
1
-
(1)
(2)
1900
1950
2000
2050
2100


Change in Sea Surface Temperature (°C) Month: 7
7
6
5
4
3
2
1
-
(1)
(2)
1900
1950
2000
2050
2100

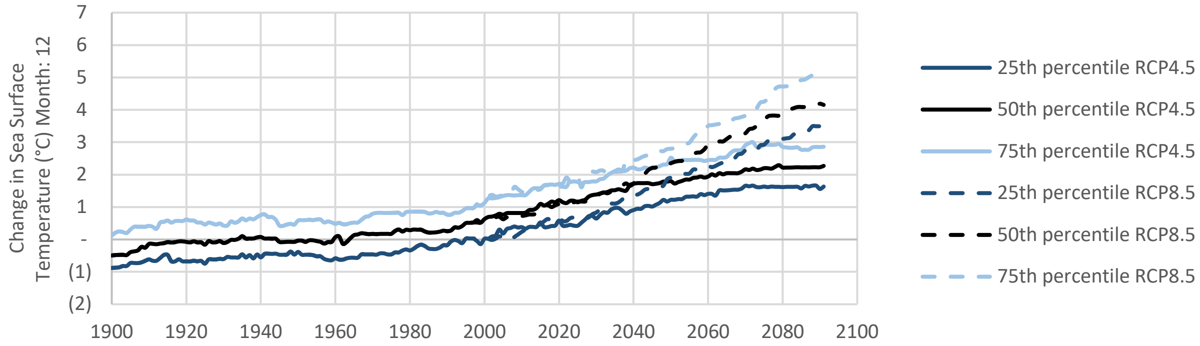

Change in Sea Surface Temperature (°C) Month: 8
7
6
5
4
3
2
1
-
(1)
(2)
1900
1950
2000
2050
2100


Change in Sea Surface Temperature (°C) Month: 9
7
6
5
4
3
2
1
-
(1)
(2)
1900
1950
2000
2050
2100


Change in Sea Surface Temperature (°C) Month: 10
7
6
5
4
3
2
1
-
(1)
(2)
1900
1950
2000
2050
2100



Change in Sea Surface Temperature (°C) Month: 11
7
6
5
4
3
2
1
-
(1)
(2)
1900
1950
2000
2050
2100



Change in Sea Surface Temperature (°C) Month: 12
7
6
5
4
3
2
1
-
(1)
(2)
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100
25th percentile RCP4.5
50th percentile RCP4.5
75th percentile RCP4.5
25th percentile RCP8.5
50th percentile RCP8.5
75th percentile RCP8.5