Building a More Resilient and Low-Carbon Caribbean

Report 1 - Climate Resiliency and Building Materials in the Caribbean

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Infrastructure and Energy Sector

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REPORT 1 Climate Resiliency and Building Materials in the Caribbean

Jed Bailey, Paola Carvajal, Javier Garcia,
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IDB

Background

According to the 2020 United Nations Office for the Coordination of Humanitarian Affairs (OCHA) report "Natural Disasters in Latin America and the Caribbean", between 2000 and 2019, a total of 330 storms affected the Caribbean region, including 148 tropical storms and 181 hurricanes (an average of 17 hurricanes per year) of which 23 reached category 5, impacting a total of 34 million people during that period. The 2017 hurricane season was the third worst on record in terms of the number of disasters and countries affected, as well as the magnitude of damage. The 2020 Atlantic hurricane season was the most active and fifth costliest in history. It was also the fifth consecutive above-average Atlantic hurricane season since 2016. There is a trend for which the storms affecting Central America and the Caribbean are becoming more powerful and producing more rainfall with greater frequency, reducing the time for recovery between events in the affected countries.

These events are particularly adverse for the island nations of the Caribbean, which are especially vulnerable due to their geographic and socioeconomic characteristics. In 2019, for example, Hurricane Dorian became the most powerful Atlantic hurricane to directly impact a landmass on record. In the Bahamas alone (one of the most affected countries) it caused USD 2.5 billion in losses. According to the United Nations report "Global Assessment for Disaster Risk Reduction" of 2015, on average the Caribbean has losses in infrastructure due to natural disasters (hurricanes, earthquakes, tsunamis and floods) for 12.5 billion dollars each year.

Within this context of high vulnerability, that's only going to worsen by the effects of Climate Change (CC), building resiliency should become a priority for the Caribbean countries.

The series "Building a more resilient and low-carbon Caribbean", focuses on the resiliency, sustainability and decarbonization of the construction industry in the Caribbean.

It's the result of a close collaboration between the IDB Social Infrastructure Unit (SIU), a team of architects and engineers that provide specialized technical support to programs that includes social infrastructure components, and the IDB Energy Division (ENE), that works in projects addressing the sustainability and decarbonization pathways of infrastructure projects.

The first three reports of the series[1] analyze the economic losses caused by climate related events, the benefits of improving building resiliency to reduce those economic losses and the benefits of subsidized financing for resilient buildings in the Caribbean. The results show that increasing building resiliency is economically viable for the high-risk islands of the Caribbean, generating long term savings and increasing the infrastructure preparedness to the impacts of CC.

These reports were based on a study, "Responsible infrastructure development for a Resilient Caribbean" initiated in 2019, developed by the consultant Jed Bailey with the support of the IDB team composed by: Paola Carvajal Blanco (INE/INE), Javier Garcia (INE/ENE), Christiaan Gischler (INE/ENE), Carlos Henriquez (INE/INE), Livia Minoja (SCL/SCL) and Mariana Silva Zúñiga (CSD/CCS).

This publication - Report 1: Climate Resiliency and Building Materials in the Caribbean - was made possible thanks to the valuable contributions and revisions from Claudia Alcaraz-Irazarry, Sasha Baxter and Alan Mentis(CCB/CCB), Wilhelm Dalaison and Ashley Morales (INE/INE), and Mariel Juarez Olivera (CSD/CCS).

1 Report 1: Climate Resiliency and Building Materials in the Caribbean

Report 2: Analysis of the benefits from resilient building materials and construction methods in the Caribbean

Report 3: Impact of subsidized financing to support resilient buildings in the Caribbean

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Executive Summary

The objective of this report is to present a quantification of the economic losses caused by climate impact events, in this case mostly hurricanes, in the Caribbean Region and to correlate these figures with the most common construction materials, typically used in each of the countries' building typologies. First, the report assesses the Caribbean region's vulnerability to climate impacts and highlights how these have affected the region's economic development in the last decades by presenting figures on impact on GDP and several annual average loss (AAL) comparisons to put it in perspective. It then analyzes what type of buildings are more impacted among housing, education, health and energy & telecommunication facilities, and what structural aspects present the weakest response to the impact of hurricanes. The report continues reviewing the different construction materials used in residential dwellings in the region and their characteristics, finally demonstrating the correlation between using more resilient materials and reduced economic losses. This work is the first part (Report 1) of a series that continue analyzing in detail the materials used in several typologies of buildings in the Caribbean (Report 2) and the economic benefits of using resilient materials in this region (Report 3).

The Caribbean islands are among the 25 most-vulnerable nations in terms of disasters per-capita or land area, and climate change is only expected to intensify these vulnerabilities. Only in 2020, there were 13 hurricanes in the Atlantic: this figure is the second highest on record. In addition to human lives losses, these disasters take a deep toll on economic growth for the Caribbean countries: in 2019, hurricane Dorian caused in Bahamas approximately US$2.5 billion in losses, while in 2017, Maria, caused in Dominica almost US$1.0 billion in losses.

The loss caused by climate events drags the ability of the Caribbean countries to invest in infrastructure and social programs, contributing to slower productivity growth, poorer health outcomes, and lower standards of living. The economic impact of hurricanes can be measured by loss of annual GDP and put into perspective using the Annual Average Loss (AAL) as share of the country's capital stock losses, the annual capital formation, and the annual social expenditure. The analysis carried out in this report shows that Caribbean countries would need to fully replace their capital stock every 50 years on average owing to damage from climate events; though countries at the higher end, would need to do so every 20 years—well below the expected useable life of most infrastructure. The analysis also shows how climate events place an ongoing economic drag on the region by shortening the useful life of infrastructure and diverting investment away from more productive economic and social uses. Across the Caribbean, the AAL is 30% of gross fixed capital investment, impacting the ability of countries to maintain infrastructure or build new one, and 76% of annual social expenditures (but reaches nearly 300% in the Bahamas and is more than 250% in Antigua and Barbuda) -including health, education, and social protection- showing the consequent drain of resources that could otherwise be spent on social programs, contributes to slower productivity growth, poorer health outcomes, and lower standards of living.

The losses caused by hurricanes concentrate mostly in the residential infrastructure and are mainly caused by weaknesses in roofs and their connection to the walls. When comparing the impact of hurricanes by typology of building on housing, education, health, and energy & telecommunication facilities, it is shown that the housing sector concentrates almost half of the total losses. Also, the damage to building roofs and their connection to the walls was the most widely reported type of building damage, as well as the main factor for water and wind penetrating the building envelop and damaging furniture, equipment, and supplies inside.

The analysis shows that countries with higher share of concrete outer walls and roofs, particularly for residential dwellings, present smaller values of AAL. Overall, resilient materials such as concrete and stone are used in 67% of all dwellings, with 30% built with wood and just 3% with other materials, with the share of dwellings made of concrete and stone increasing with average income. In Low-income countries, the share averages 59%, rising to 69% in Middle-income countries, and 85% in High-income countries. When assessing the correlation of materials used and impact of climate events in countries with similar locations, it is observed how countries where residential buildings use more frequently concrete as a material for the outer walls and roofs, present lower AAL levels. **The analysis suggests that improving the resiliency of outer walls and roofs in the Caribbean could significantly reduce the region's vulnerability to hurricanes and other climate impacts.**

Reports 2 and 3

The use of more resilient materials and construction techniques is economically beneficial and provides savings in total ownership costs cost over the life of the building, despite the initial higher investment needs. The analysis shows that, although the initial cost to build a resilient structure is generally higher compared to standard building options, the total ownership costs over the life of the building—including annual maintenance costs, energy costs, and hazard costs—were, generally lower. These economic benefits stem from the reduced hazard loss from using more resilient materials and construction methods, as well as from reduced energy use and CO_2 emissions from improving the building's insulation and using greener concrete options with less embedded CO_2.

Although the lifetime benefits from reduced hazard costs and, potentially, reduced energy costs, are much greater, the higher initial construction cost can deter project developers and building owners from investing in more resilient options. Providing low-cost finance to project developers (in the form of subsidized construction loans), to building owners (in the form of subsidized mortgages), or both can reduce the initial cost for more resilient buildings and incentivize developers and building owners, allowing them to reach reductions in ownership costs that can reach almost 50%.

1. Introduction

This report brings together different methods to assess the Caribbean region's vulnerability to climate impacts, and hurricanes in particular, with a review of construction materials used in buildings in the region. The aim of the report is to highlight how climate impacts have affected the region's economic development, and how building with resilient construction materials may help mitigate those impacts.


Source: IDB

2. Assessing the Impact of Hurricanes in the Caribbean

According to the OCHA "Natural disasters in Latin America and the Caribbean" report of 2020, between the years 2000 and 2019, a total of 330 storms affected the Caribbean region, including 148 tropical storms and 181 hurricanes (an average of 17 hurricanes per year) out of which, 23 reached Category 5, affecting a total of 34 Million people during that period. The storms impacting Central America and the Caribbean[2] are becoming increasingly more powerful, producing increased rainfall and higher storm surge due to climate change. More frequent and intense storms in the region means there is less time for recovery between events. Some facts to better illustrate the situation:

- The 2017 hurricane season is the third worst on record in terms of number of disasters and countries affected as well as the magnitude of damage.
- In 2019, Hurricane Dorian became the strongest Atlantic hurricane on record to directly impact a landmass.
- The 2020 Atlantic hurricane season was the most active and the fifth costliest Atlantic hurricane season on record. In addition, it was the fifth consecutive above average Atlantic hurricane season from 2016 onward. The season featured a total of 31 (sub)tropical cyclones, all but one of which became a named storm. Of the 30 named storms, 13 developed into hurricanes, and six further intensified into major hurricanes, with one, Hurricane Iota, attaining Category 5 strength on the Saffir–Simpson scale[3].

This section reviews three approaches to quantify the climate impact risks in the Caribbean through the lens of hurricanes and major tropical storms. Climate change is expected to increase the frequency and strength of tropical storms in the future. Understanding the economic and social impact of these climate events can help quantify the value of investing in climate resiliency.

The first approach shows the historical frequency and strength of storms in the region by comparing the damage that a country sustained from hurricanes (expressed as a share of GDP) with the country's historical economic growth (expressed as the percent annual increase in GDP).

The second approach uses statistical analysis of past storms to calculate the expected average annual loss (AAL) from hurricanes for each country. This AAL is then compared to various economic metrics, such as fixed capital and social expenditures.

The third approach focuses on the impact that hurricanes have had on specific sectors in the region, including direct damage, economic losses, and the cost to rebuild.

Together, these approaches highlight the ongoing drag on economic and social development that hurricanes impose on the countries in the Caribbean.

2 Within the IDB countries of the Caribbean region, only Guyana and Suriname are not prone to hurricanes.

3 Natural Disasters in Latin America and the Caribbean" OCHA 2020

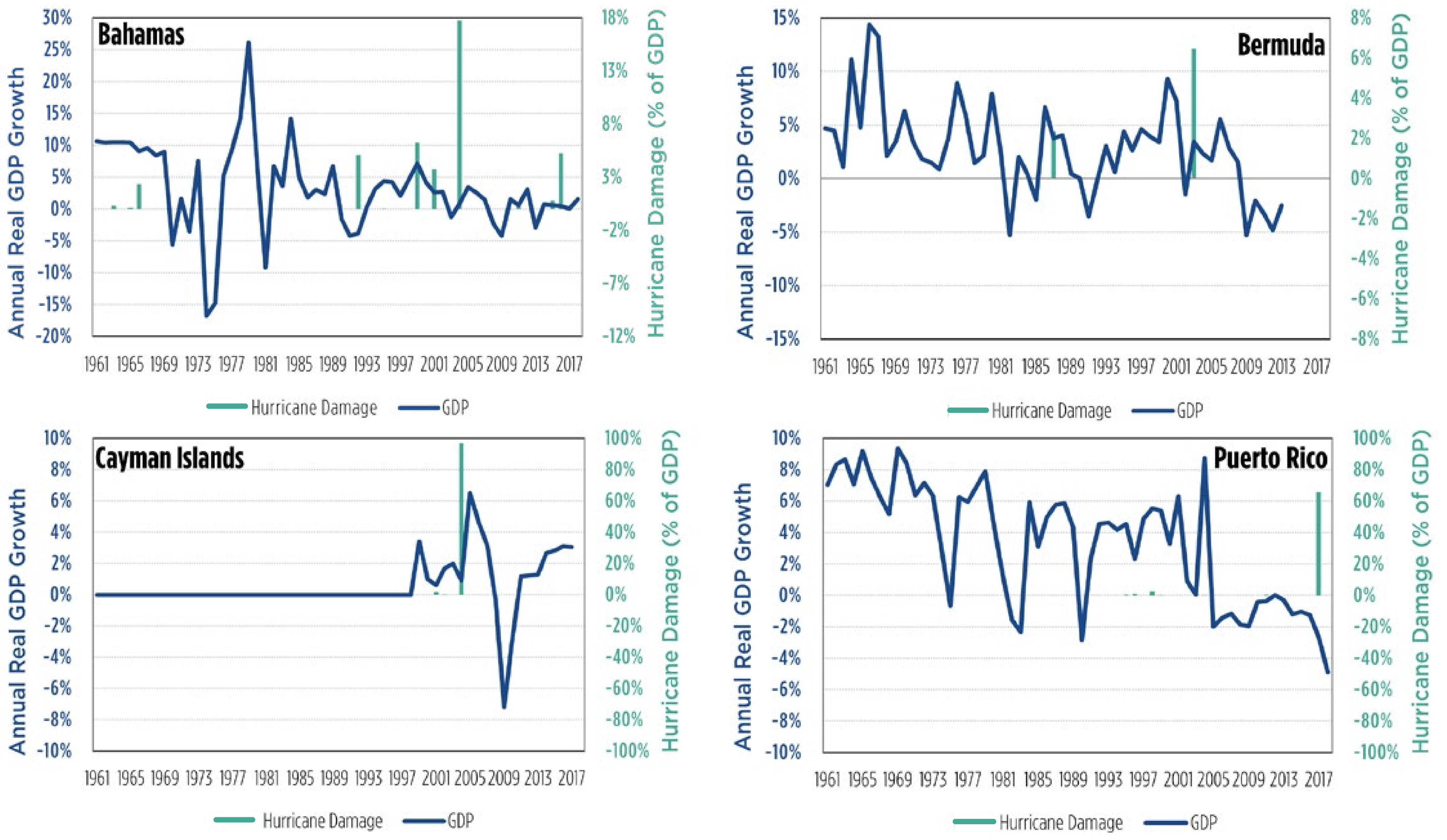
2.1. Hurricane Frequency and Impact on Total GDP

Figures 2.1, 2.2, and 2.3 highlight the frequency of, and damage from, hurricanes in the Caribbean. Each figure compares hurricane damage as a share of GDP with annual GDP growth for 15 Caribbean nations. Data for each country's annual GDP growth rate is from the 2020 edition of the World Bank's World Development Indicators (WDI) database. Data for historical hurricane damage as a share of GDP was calculated from historical GDP from the WDI database and hurricane damage data from the Emergency Events Database (EM-DAT) that is maintained by the Centre for Research on the Epidemiology of Disasters (CRED).

The figures are grouped by the relative wealth of each country, separated into High-income countries with a GDP per capita greater than US$20,000, Middle-income countries with a GDP per capita between US$10,000 and US$20,000 and Low-income countries with a GDP per capita below US$10,000.

The four countries in the High-Income grouping have seen less impact from hurricanes than other countries in the region. Only two Hurricanes created damage greater than 20% of GDP (Hurricane Ivan in the Cayman Islands in 2004 and Hurricane Maria in Puerto Rico in 2017). The Bahamas has seen multiple hurricanes strikes over the years, but few have caused more than a few percent of GDP in damage.

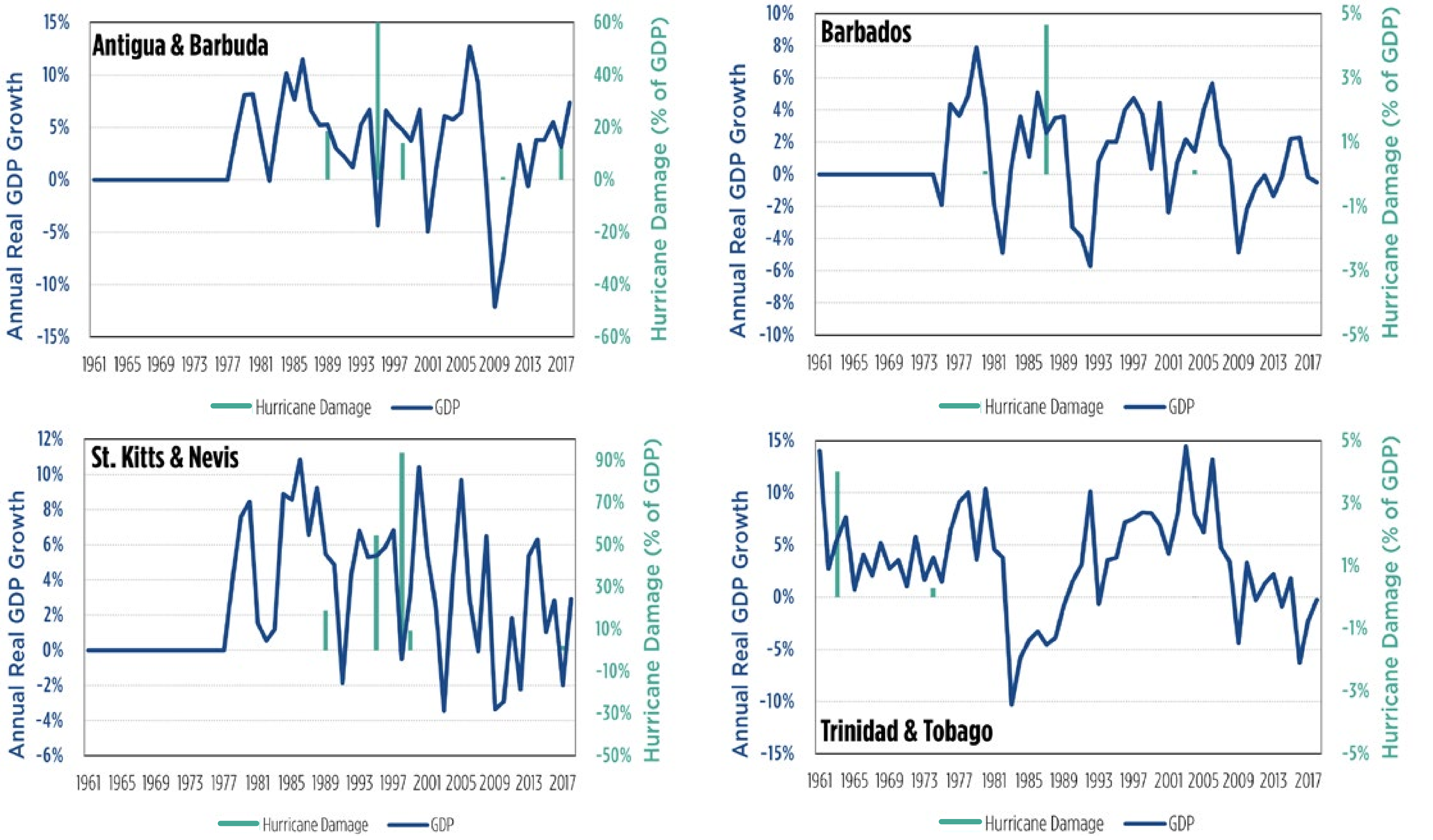
Figure 2.1. Hurricane damage and GDP growth impact, High-income Countries (Per Capita GDP > US$20,000).



Source: Energy Narrative based on data from the World Bank WDI dataset and the Centre for Research on the Epidemiology of Disasters EM-DAT database

The four countries in the Middle-Income group show a clear divergence from the countries in the northern part of the Lesser Antilles (Antigua & Barbuda and St. Kitts & Nevis) and those further south (Barbados and Trinidad & Tobago). The southern countries have seen little hurricane related damage, with no storm causing more than 5% of GDP in damage since the 1960s. The northern two have suffered from multiple storms, particularly between 1985 and 2000, with several causing damage equal to 20% or more of GDP.

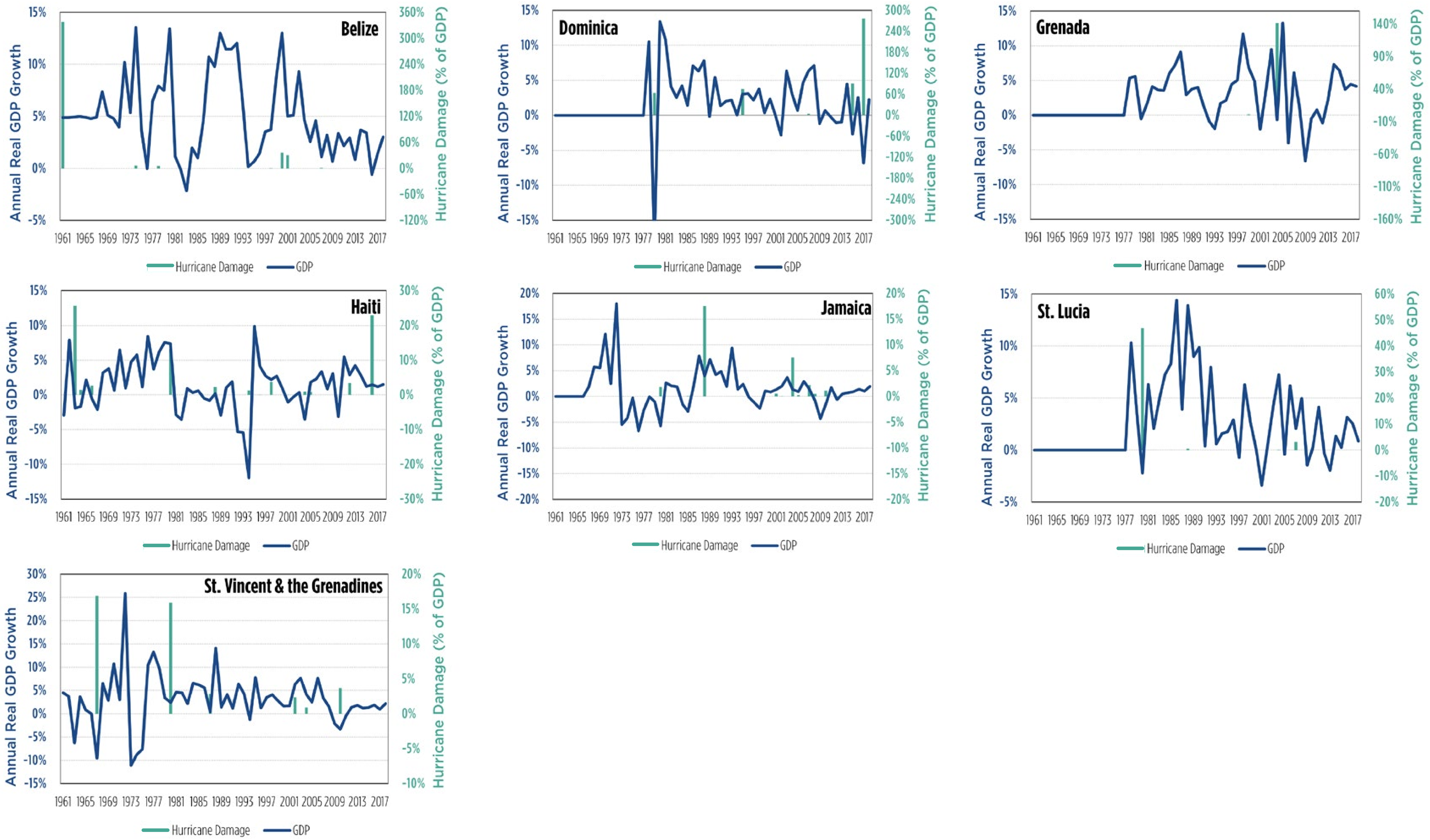
Figure 2.2. Hurricane damage and GDP growth impact, Middle-income Countries (Per Capita GDP US$10,000 to US$20,000).



Source: Energy Narrative based on data from the World Bank WDI dataset and the Centre for Research on the Epidemiology of Disasters EM-DAT database

The seven countries within the Low-Income group show a range of susceptibility to hurricanes and related damages. All have been struck by hurricane causing more than 15% of GDP in damage, with some suffering catastrophic events in excess of 100% of GDP (Belize – 330%; Dominica – 250%, and Grenada – 140%). Countries in this group are also more likely to see a significant impact on GDP growth from a major hurricane strike.

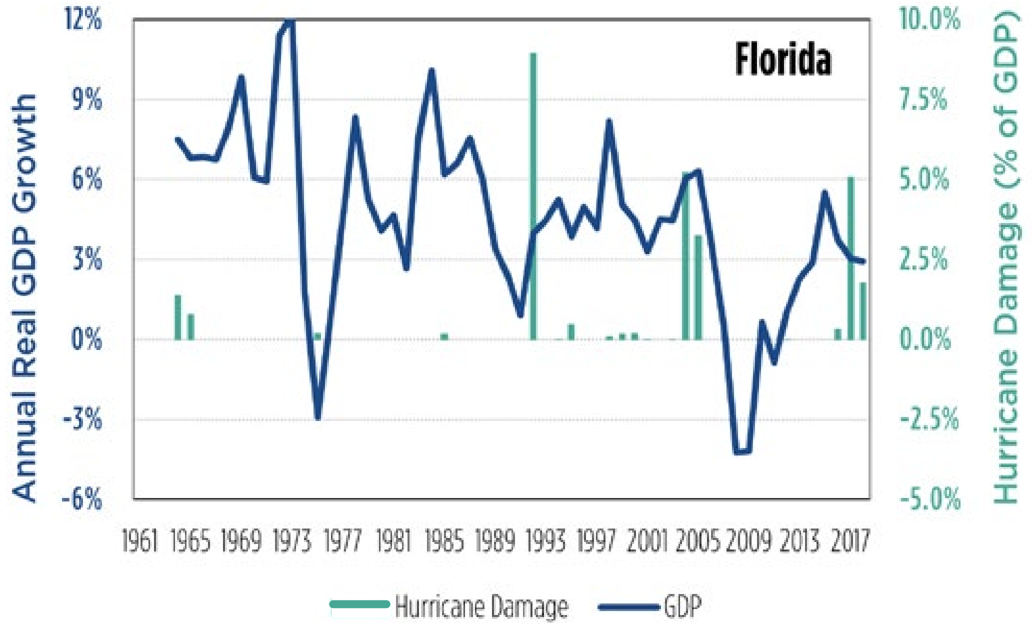
Figure 2.3. Hurricane damage and GDP growth impact, Low-income Countries (Per Capita GDP < US$10,000).



Source: Author based on data from the World Bank WDI dataset and the Centre for Research on the Epidemiology of Disasters EM-DAT database

Figure 2.4 shows the same analysis for the state of Florida. Although Florida is also frequently struck by major hurricanes, the damage as a share of GDP and impact on GDP growth is much lower. Of more than a dozen major hurricane strikes, only one (Hurricane Andrew in 1992) caused damage that was valued at more than 5% of GDP. In addition, hurricane strikes in Florida have less impact on GDP growth than was noted in many Caribbean countries.

Figure 2.4. Hurricane damage and GDP growth impact, Florida.



Source: Author based on data from US Bureau of Economic Analysis and the Centre for Research on the Epidemiology of Disasters EM-DAT database

2.2. Average Annual Loss Assessment

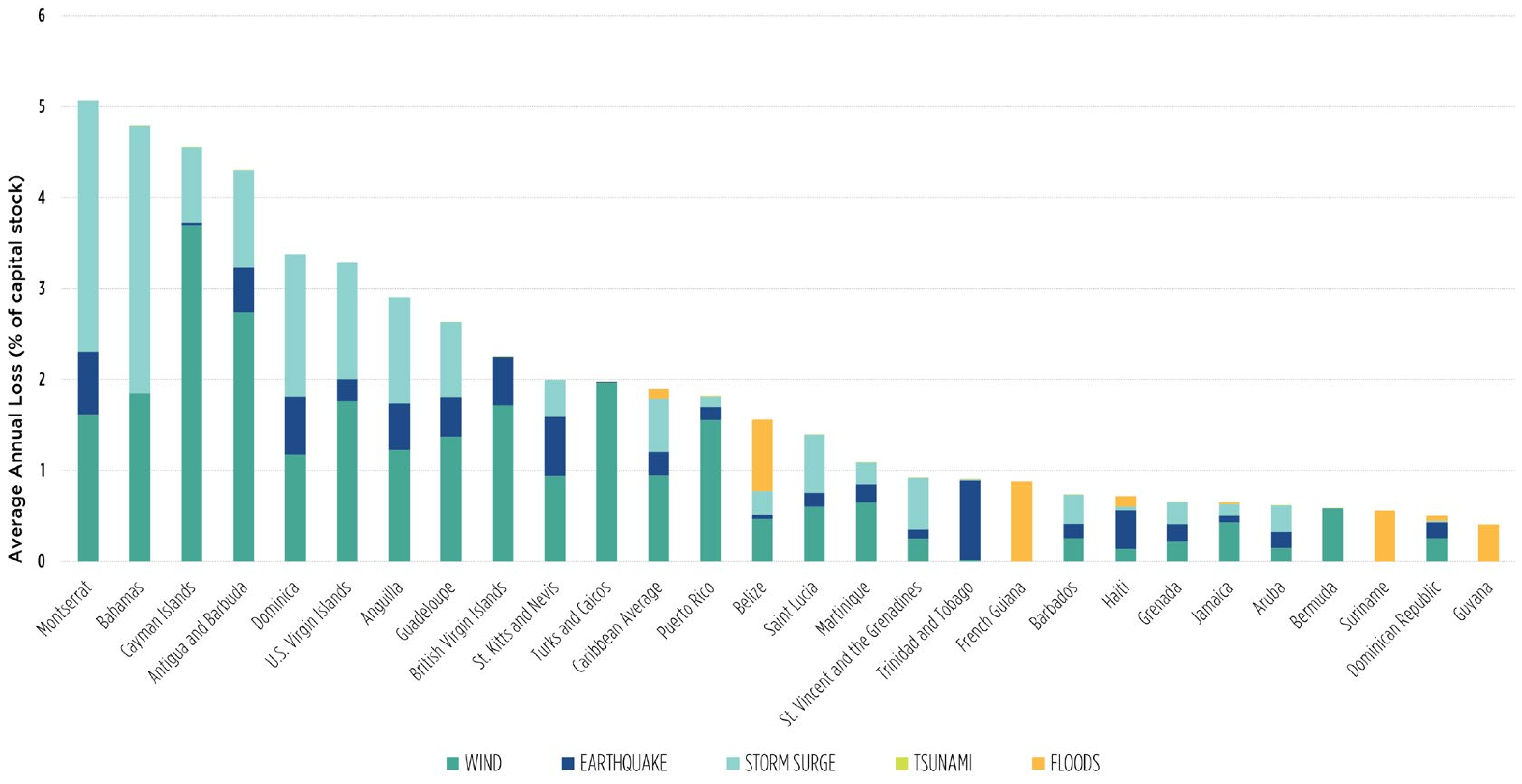
The economic toll of climate impacts in the Caribbean region is also reflected in data compiled for the 2015 UN Global Assessment Report on Disaster Risk Reduction (GAR 2015). This report analyzed the historical frequency and severity of tropical storms and other climate impacts to calculate their effect on economic and social development worldwide. This historical data was used to estimate the expected average annual loss from each type of event. That is, the expected total sum of economic losses over a long-term horizon was divided by the number of years in the forecast period to arrive at a levelized annual value.

This average annual loss (AAL) was compared to three macroeconomic metrics for each country: total capital stock, gross fixed capital formation, and social expenditure. The ratio of the AAL to fixed capital stock gives an indication of how the useful life of fixed capital assets, such as buildings and infrastructure, is shortened owing to hurricane damage. This shortened useful life in turn increases the investment needed just to maintain a country's capital stock and reduces the economic value of investing in capital stock. The ratio of the AAL to fixed capital formation shows the "tax" that hurricanes place on economic development in a country. Essentially, the share of fixed capital formation that is lost to hurricane damage each year represents money that could have been invested more productively if not for the hurricane risk. Finally, the ratio of the AAL to social expenditures highlights the same "tax" inflicted by hurricane risk but applied to the country's social spending. This represents the greater investment in the country's population that could be made in the absence of the hurricane risk.

2.2.1. Impact on Capital Stock

Figure 2.5 shows the calculated average annual loss from climate impacts in the Caribbean as a share of each country's existing capital stock. Capital stock is defined as the total value of a country's means of production of goods and services (that is, tools and infrastructure). This includes durable assets such as buildings, equipment, vehicles, infrastructure, and land improvements. Capital stock is a critical component of the production process, along with labor, energy, and materials. When capital stock is destroyed (for example, if a house is destroyed in a hurricane, or the machinery in a plant is destroyed in a fire), the country's ability to produce goods and services (in these cases, housing services for the affected family and the products made in the damaged factory) is reduced. Comparing the annual average loss from climate impacts as a share of capital stock gives a sense of the vulnerability of each country's economy and the ongoing cost to return to the previous state of productive capacity after each event.

Figure 2.5. Average annual impact of climate impacts as a share of total capital stock, by type of event.



Throughout the Caribbean, the main threat is from wind and storm surges that accompany hurricanes, although some countries in the region face earthquake and flood risks as well. The GAR 2015 database did not include damage assessments from volcanoes which are also active in the region.

The range of potential impacts ranges from 5% of the total capital stock in Montserrat to less than 0.5% in Guyana, with the region averaging 1.9%. This implies that Caribbean countries would need to fully replace their capital stock every 50 years on average owing to damage from climate events. Countries at the higher end would need to do so every 20 years—well below the expected useable life of most infrastructure.

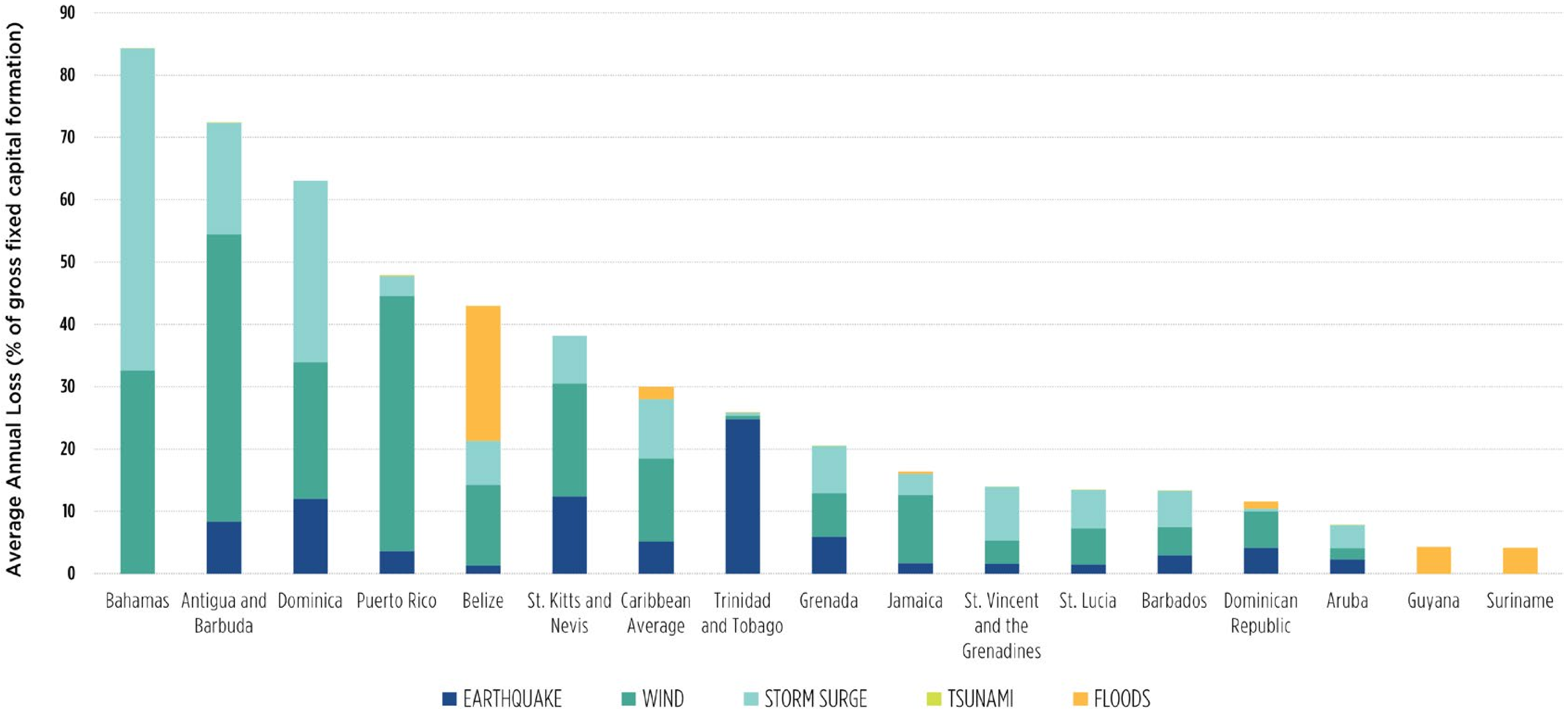
Country	AAL/Capital stock [%]						
	Earthquake	Wind	Storm surge	Tsunami	Floods	Volcano	Multi-hazard
Montserrat	0.69	1.62	2.76	0.00	0.00	0.00	5.07
Bahamas	0.00	1.85	2.94	0.00	0.00	0.00	4.79
Cayman Islands	0.04	3.69	0.83	0.00	0.00	0.00	4.56
Antigua and Barbuda	0.49	2.74	1.07	0.00	0.00	0.00	4.30
Dominica	0.64	1.18	1.56	0.00	0.00	0.00	3.38
U.S. Virgin Islands	0.24	1.76	1.29	0.00	0.00	0.00	3.29
Anguilla	0.51	1.23	1.16	0.00	0.00	0.00	2.91
Guadeloupe	0.44	1.37	0.83	0.00	0.00	0.00	2.64
British Virgin Islands	0.53	1.72	0.00	0.00	0.00	0.00	2.25
St. Kitts and Nevis	0.65	0.95	0.40	0.00	0.00	0.00	2.00
Turks and Caicos	0.01	1.96	0.00	0.00	0.00	0.00	1.97
Caribbean Average	**0.26**	**0.95**	**0.58**	**0.00**	**0.10**	**0.00**	**1.90**
Puerto Rico	0.14	1.56	0.12	0.00	0.00	0.00	1.82
Belize	0.05	0.47	0.26	0.00	0.79	0.00	1.56
Saint Lucia	0.15	0.61	0.63	0.00	0.00	0.00	1.39
Martinique	0.20	0.65	0.24	0.00	0.00	0.00	1.09
St. Vincent and the Grenadines	0.11	0.25	0.57	0.00	0.00	0.00	0.93
Trinidad and Tobago	0.87	0.02	0.02	0.00	0.00	0.00	0.90
French Guiana	0.00	0.00	0.00	0.00	0.88	0.00	0.88
Barbados	0.16	0.25	0.32	0.00	0.00	0.00	0.74
Haiti	0.42	0.14	0.04	0.00	0.12	0.00	0.72
Grenada	0.19	0.22	0.24	0.00	0.00	0.00	0.65
Jamaica	0.07	0.43	0.13	0.00	0.01	0.00	0.65
Aruba	0.18	0.15	0.29	0.00	0.00	0.00	0.62
Bermuda	0.00	0.59	0.00	0.00	0.00	0.00	0.59
Suriname	0.00	0.00	0.00	0.00	0.56	0.00	0.56
Dominican Republic	0.18	0.25	0.02	0.00	0.05	0.00	0.50
Guyana	0.00	0.00	0.00	0.00	0.41	0.00	0.41

Source: Author based on data from the UN Global Assessment Report on Disaster Risk Reduction 2015

2.2.2. Impact on Gross Fixed Capital Formation

Figure 2.6 shows the average annual loss as a share of gross fixed capital formation. This measure shows the amount of capital investment each year, on average, that would be directed toward repairing or replacing infrastructure that was damaged by climate impacts rather than in expanding the country's stock of fixed capital (that is, new buildings, equipment, and other infrastructure).

Figure 2.6. Average annual loss from climate impacts as a share of average annual gross fixed capital formation, by type of event.



At the higher end, nearly 85% of annual gross fixed capital investment in the Bahamas is lost to wind and storm surge damage from hurricanes on average over the long term. Across the Caribbean, the average annual loss is 30%, primarily from wind, storm surges, and earthquakes. For higher income countries like the Bahamas that already have high levels of capital stock, the high ratio of hurricane damage to gross fixed capital formation represents an elevated cost to maintain the country's existing infrastructure. For lower income countries that do not have the same level of capital stock, a higher share of hurricane damage to gross fixed capital formation acts as a drag on the country's ability to develop as only a fraction of the money spent on new infrastructure results in a long-term increase in the country's fixed capital stock.

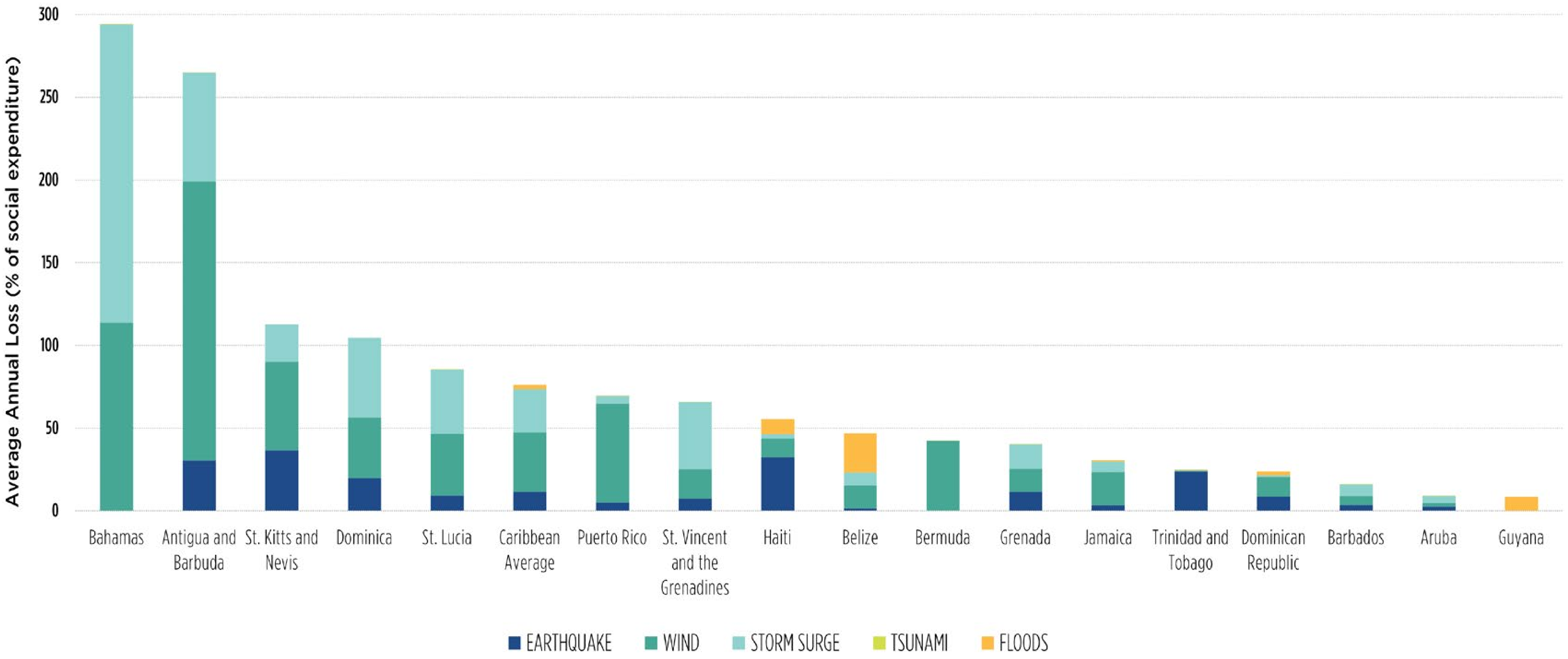
Country	AAL/GFCF [%]					
	Earthquake	Wind	Storm surge	Tsunami	Floods	Multi-hazard
Bahamas	0.00	32.58	51.73	0.00	0.00	84.31
Antigua and Barbuda	8.32	46.13	17.94	0.02	0.00	72.40
Dominica	12.01	21.92	29.10	0.00	0.00	63.03
Puerto Rico	3.59	40.95	3.25	0.04	0.10	47.93
Belize	1.35	12.91	7.04	0.00	21.67	42.98
St. Kitts and Nevis	12.42	18.11	7.69	0.00	0.00	38.21
Caribbean Average	**5.16**	**13.30**	**9.55**	**0.01**	**1.99**	**30.00**
Trinidad and Tobago	24.82	0.53	0.47	0.00	0.04	25.85
Grenada	5.95	7.00	7.57	0.01	0.00	20.53
Jamaica	1.73	10.89	3.38	0.00	0.37	16.37
St. Vincent and the Grenadines	1.59	3.74	8.59	0.01	0.00	13.93
St. Lucia	1.45	5.86	6.10	0.00	0.00	13.41
Barbados	2.93	4.56	5.81	0.01	0.00	13.31
Dominican Republic	4.16	5.82	0.46	0.00	1.15	11.59
Aruba	2.26	1.86	3.64	0.00	0.00	7.76
Guyana	0.01	0.00	0.00	0.00	4.30	4.31
Suriname	0.00	0.00	0.00	0.00	4.14	4.14

Source: Author based on data from the UN Global Assessment Report on Disaster Risk Reduction 2015

2.2.3. Impact on Social Expenditures

Figure 2.7 compares the average annual loss to each country's annual social expenditures, including health, education, and social protection. This measure highlights the ways in which climate impacts reduce the amount of government or donor funds that are available for social development and wellbeing.

Figure 2.7. Average annual loss from climate impacts as a share of average annual social expenditure, by type of event.



Here again, the Bahamas' high vulnerability to hurricanes results in the expected average annual loss reaching nearly three times the country's annual social expenditures. The Caribbean average is 76%, driven primarily by hurricane damage. This ongoing drain contributes to slower productivity growth, poorer health outcomes, and lower standards of living.

Country	AAL/Social expenditure [%]					
	Earthquake	Wind	Storm surge	Tsunami	Floods	Multi-hazard
Bahamas	0.00	113.66	180.46	0.00	0.00	294.13
Antigua and Barbuda	30.41	168.68	65.59	0.06	0.00	264.74
St. Kitts and Nevis	36.59	53.37	22.65	0.00	0.00	112.61
Dominica	19.92	36.35	48.25	0.00	0.00	104.53
St. Lucia	9.27	37.39	38.91	0.02	0.00	85.58
Caribbean Average	**11.54**	**35.77**	**26.20**	**0.02**	**2.59**	**76.12**
Puerto Rico	5.22	59.51	4.72	0.05	0.15	69.65
St. Vincent and the Grenadines	7.49	17.66	40.56	0.03	0.00	65.75
Haiti	32.52	11.06	2.86	0.03	8.91	55.39
Belize	1.48	14.08	7.68	0.00	23.64	46.88
Bermuda	0.00	42.28	0.00	0.05	0.00	42.33
Grenada	11.65	13.71	14.84	0.01	0.00	40.21
Jamaica	3.22	20.31	6.30	0.01	0.68	30.52
Trinidad and Tobago	23.77	0.50	0.45	0.00	0.04	24.77
Dominican Republic	8.53	11.93	0.94	0.01	2.36	23.77
Barbados	3.49	5.43	6.93	0.01	0.00	15.86
Aruba	2.62	2.16	4.23	0.00	0.00	9.01
Guyana	0.02	0.00	0.00	0.00	8.30	8.31

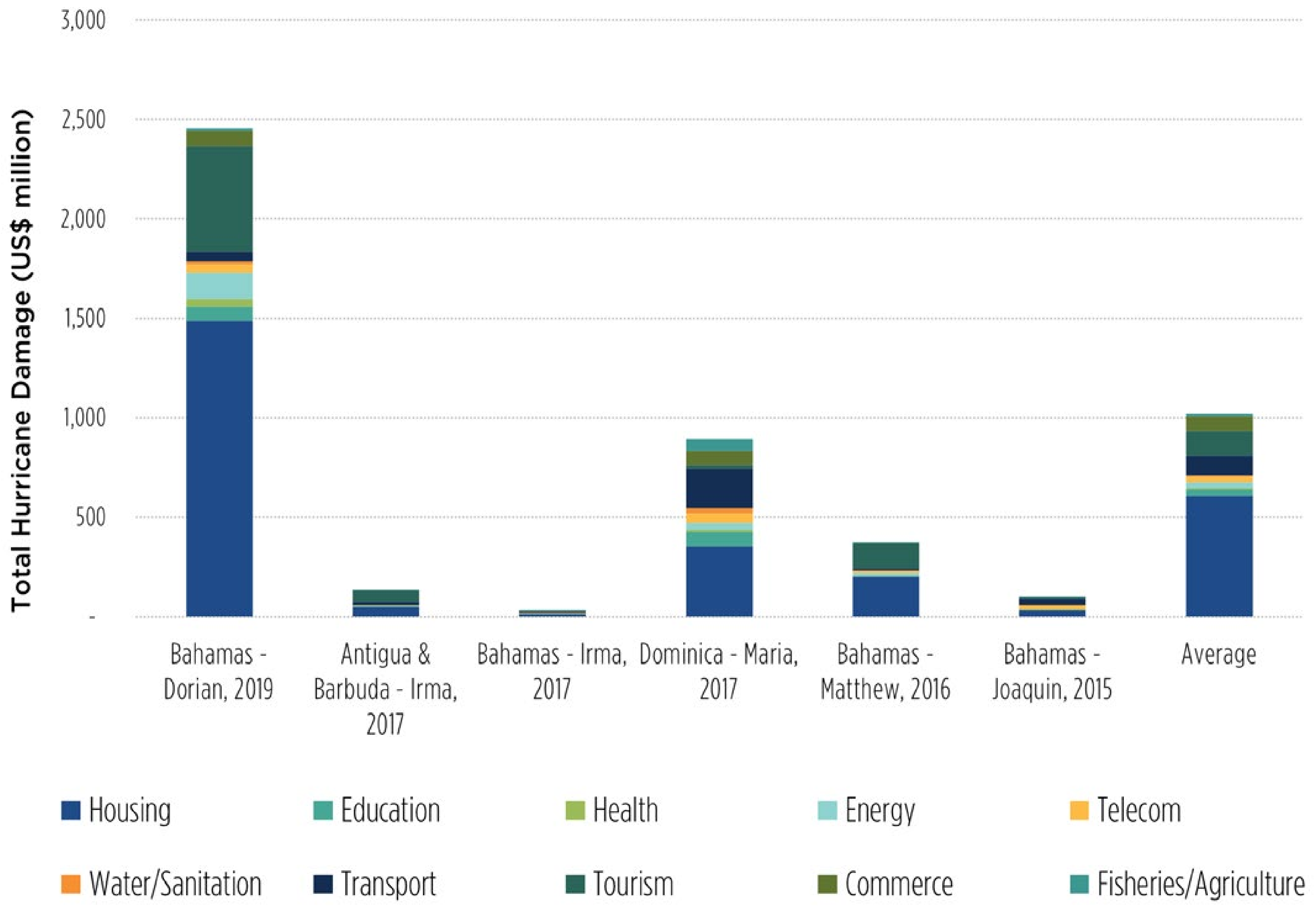
Source: Author based on data from the UN Global Assessment Report on Disaster Risk Reduction 2015

2.3. Sector Specific Effects of Climate Impacts Across the Region

This section extends the analysis above to examine the impact of hurricanes in specific sectors, including housing, education, health, energy and telecommunications. The analysis compiles damage assessment reports for recent hurricanes in the Caribbean region. The assessments include five country assessments related to Hurricane Irma and Hurricane Maria (including the US Virgin Islands, Antigua & Barbuda, the Bahamas, Dominica, and St. Maarten), and assessments for three other hurricane strikes to the Bahamas: Joaquin in 2015, Matthew in 2016, and Dorian in 2019. All of the countries and storms included in the assessment are relatively recent to ensure that the assessed impacts are relevant to each country's current state. The assessment included a large number of countries affected by the same storms (Hurricane Irma and Hurricane Maria) to highlight the range of impacts that a single storm can cause. In addition, multiple storms that affected the Bahamas were included to highlight the range of storm variability through the experience of a single island.

Figures 2.8 shows the reported damage by sector from recent hurricane strikes in the Caribbean in total dollar value terms.

Figure 2.8. Assessed damage by sector from recent hurricanes (US$ million).



	Bahamas - Dorian, 2019	Antigua & Barbuda - Irma, 2017	Bahamas - Irma, 2017	Dominica - Maria, 2017	St. Maartin - Irma & Maria, 2017	Bahamas - Matthew, 2016	Bahamas - Joaquin, 2015	Weighted average
Housing	1,487	50	15	354	442	200	33	369
Education	72	3	2	74	60	3	1	31
Health	38	2	1	11	4	1	2	8
Energy	131	3	1	33	6	16	2	27
Telecom	42	1	2	48	51	10	21	25
Water and Sanitation	15	0	0	24	7	1	1	7
Transport	51	16	8	201	382	11	32	100
Tourism	530	59	1	20	0	129	11	107
Commerce	78	0	0	70	0	0	0	21
Fisheries and Agriculture	14	0	1	58	0	1	1	11
Total	**2,458**	**134**	**31**	**893**	**952**	**372**	**104**	**706**

Source: Author based on data from individual hurricane damage assessments

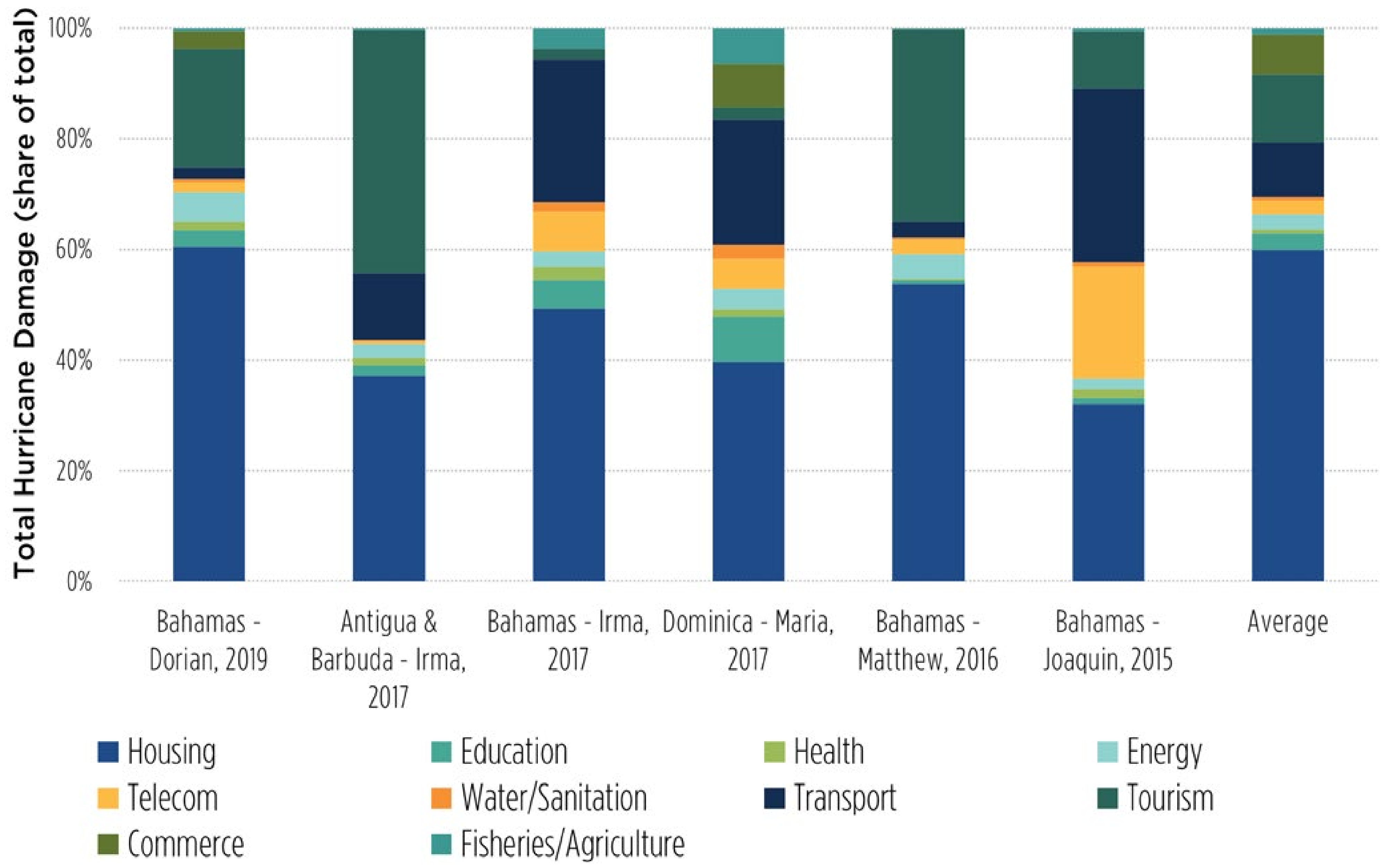
Hurricane Dorian's strike on the Bahamas in 2019 did the most damage of the hurricanes assessed in the graphic, causing almost US$2.5 billion in damage or more than double the next largest (Hurricane Maria's strike to Dominica and Hurricane's Maria and Irma's combined damage to St. Maartin in 2017). All other hurricanes caused less than US$1 billion in damage.

Figure 2.9 shows the same sector level hurricane damage data as a share of the total damage.

On average, damage to the housing sector accounted for 46% of the total damage from the hurricanes that were analyzed. The next most affected sectors were transport (20%) and tourism (16%). Housing sector damage was consistently large across all reports, ranging from 30-60% of the total. Damage to the tourism and transport sectors was more varied, with tourism damage ranging between 2-35% and transport ranging between 2-40% of the total.

Damage to other sectors, such as education, health, energy, and telecommunications, were typically lower. However, losses from these sectors create knock-on effects that can exacerbate rescue and recovery efforts and reduce the country's economic growth potential over the longer term.

Figure 2.9. Assessed damage by sector from recent hurricanes (share of total).



	Bahamas - Dorian, 2019	Antigua & Barbuda - Irma, 2017	Bahamas - Irma, 2017	Dominica - Maria, 2017	St. Maartin - Irma & Maria, 2017	Bahamas - Matthew, 2016	Bahamas - Joaquin, 2015	Regional weighted average
Housing	61%	37%	49%	40%	46%	54%	32%	52%
Education	3%	2%	5%	8%	6%	1%	1%	4%
Health	2%	1%	2%	1%	0%	0%	2%	1%
Energy	5%	2%	3%	4%	1%	4%	2%	4%
Telecom	2%	1%	7%	5%	5%	3%	20%	4%
Water and Sanitation	1%	0%	2%	3%	1%	0%	1%	1%
Transport	2%	12%	26%	23%	40%	3%	31%	14%
Tourism	22%	44%	2%	2%	0%	35%	10%	15%
Commerce	3%	0%	0%	8%	0%	0%	0%	3%
Fisheries and Agriculture	1%	0%	4%	6%	0%	0%	1%	2%

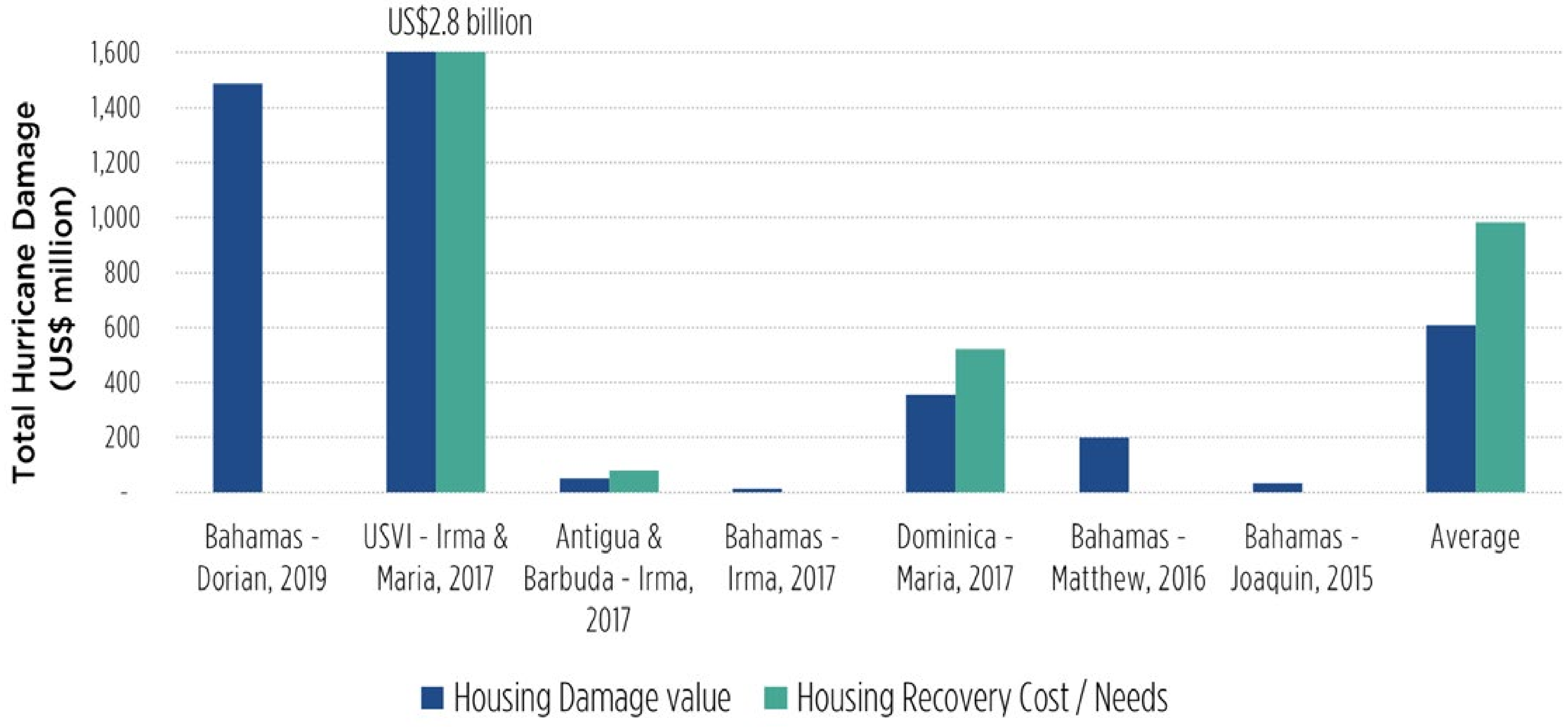
Source: Author based on data from individual hurricane damage assessments

2.3.1. Housing

Figure 2.10 shows the reported damage and estimated recovery costs for the housing sector from recent hurricane strikes in the Caribbean.

Across the region, residential sector recovery programs consistently cost more than the estimated hurricane damage. This higher cost reflects a philosophy to "build back better"; in each hurricane, older and lower quality buildings suffered the greatest damage. Replacing these buildings with higher quality construction, built to current building code requirements, results in a building with higher value than the original structure.

Figure 2.10. Assessed housing sector damage and recovery need from recent hurricanes (US$ million).



	Bahamas - Dorian, 2019	USVI- Irma & Marta, 2017	Antigua & Barbuda - Irma, 2017	Bahamas - Irma, 2017	Dominica - Maria, 2017	St. Maartin - Irma & Maria, 2017	Bahamas - Matthew, 2016	Bahamas - Joaquin, 2015	Average
Damage	1,487	2,300	50	15	354	442	200	33	610
Recovery Cost/Needs		2,800	80		520	534			983

Source: Author based on data from individual hurricane damage assessments

Table 2.1 below summarizes common contributing factors to housing sector damage as reported in each hurricane damage report.

Common contributing factors include:

- **Older housing not upgraded to meet current building codes.** Although many countries update building codes to reflect advances in building materials and techniques, or to address changing risks, few countries require existing buildings to be updated to meet the new code.
- **Poor roof-wall connections.** Even well-constructed buildings with resilient walls and roofs were badly damaged when the roof was lifted off the building by the hurricane winds, allowing wind and rain to enter the building and damage the interior.
- **Poor construction and enforcement of building codes.** Several damage assessments noted that the buildings most affected were poorly built or not built as required by building codes that were in force at the time of construction.

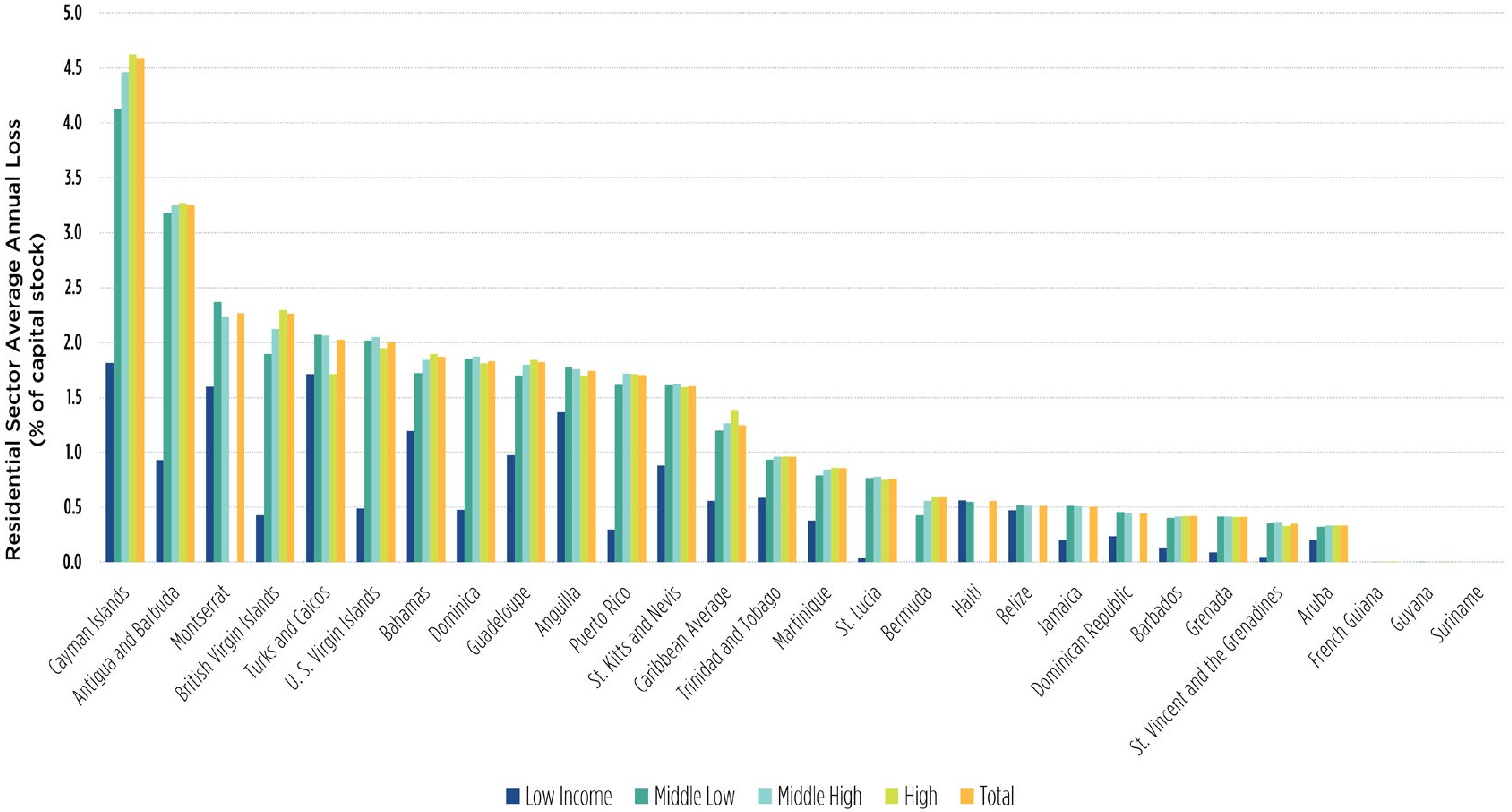
Table 2.1. Reported contributing factors to housing damage from recent hurricanes.

Contributing Factors - Housing	Bahamas - Dorian, 2019	USVI - Irma & Maria, 2017	Antigua & Barbuda - Irma, 2017	Bahamas - Irma, 2017	Dominica - Maria, 2017	St. Maartin - Irma & Maria, 2017	Bahamas - Matthew, 2016	Bahamas - Joaquin, 2015
Older buildings not up to Cat 5 code		X					X	X
Wind speed was higher than required wind speed protection for housing				X				
Loss of roof and damage to windows/doors major cause of housing damage				X	X		X	X
Poor roof - wall connections				X	X		X	X
Poor enforcement of building codes		X		X	X		X	
Poor quality building materials				X	X		X	
Lack of adequate maintenance				X			X	
Built with non-resilient materials					X			
Poor construction practices					X		X	

Source: Author based on data from individual hurricane damage assessments

Figure 2.11 shows the expected average annual loss as a share of residential capital stock by the income segments within each country, using the same assessment methodology as above.

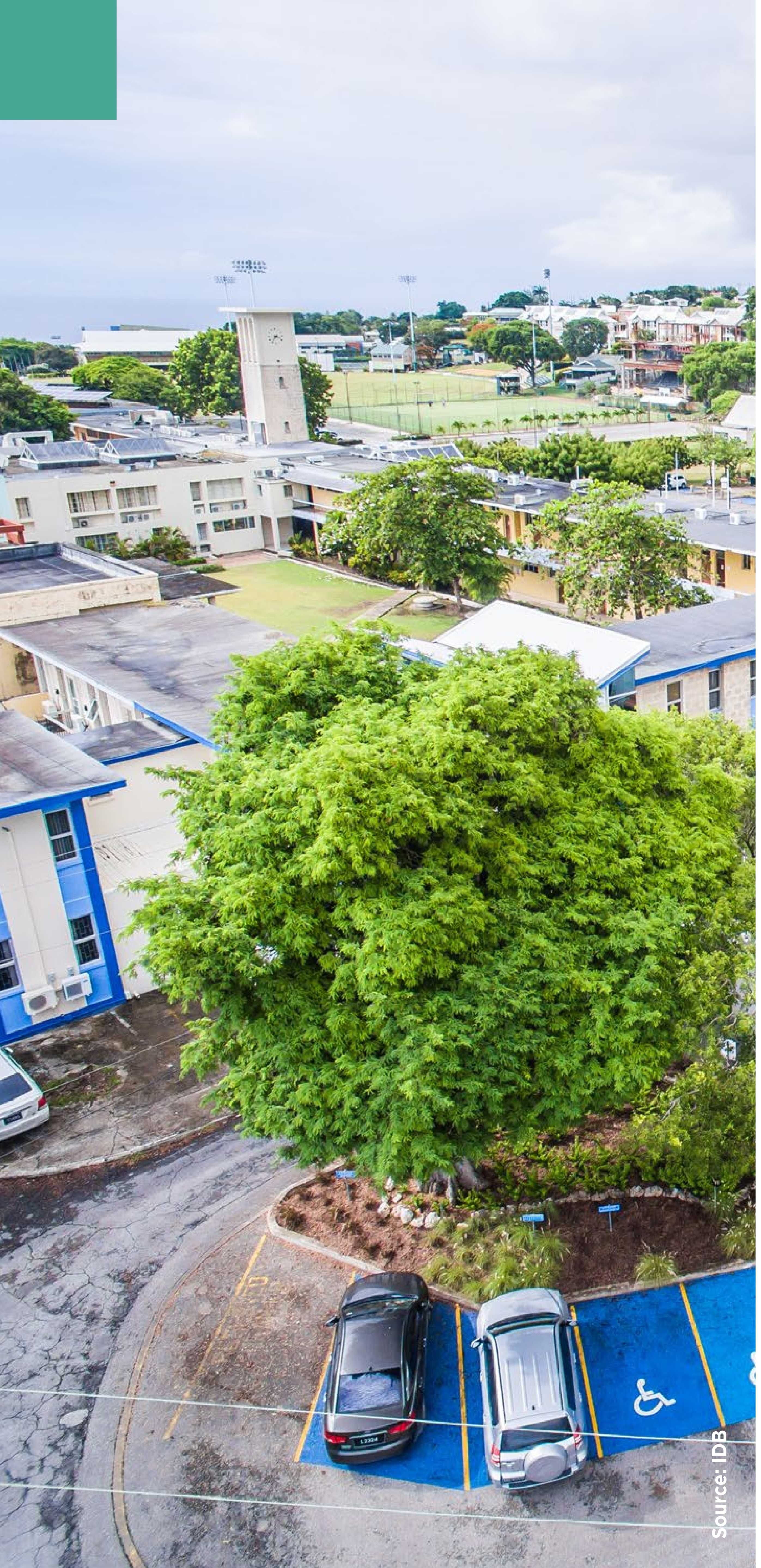
Figure 2.11. Average annual loss from climate impacts as a share of residential capital stock, by income level.



The average annual loss for residential buildings tends to be higher for High-income countries (such as the Cayman Islands, Virgin Islands, Turks and Caicos, etc.), as well as for higher income segments of each country's population. Across the Caribbean, the housing sectors average annual loss from climate impacts is estimated to be 1.3% of the housing sectors total value. For many countries, this value is more than 1.5%, reaching as high as 4.5% for the Cayman Islands.

Country	Residential AAL / Capital Stock by Income evel				
	Low Income	Middle Low	Middle High	High	Total
	[%]	[%]	[%]	[%]	[%]
Cayman Islands	1.81	4.13	4.46	4.63	4.59
Antigua and Barbuda	0.93	3.18	3.25	3.27	3.26
Montserrat	1.60	2.37	2.24		2.27
British Virgin Islands	0.43	1.90	2.12	2.29	2.26
Turks and Caicos	1.71	2.07	2.06	1.71	2.03
U. S. Virgin Islands	0.49	2.01	2.05	1.95	2.00
Bahamas	1.19	1.72	1.84	1.90	1.87
Dominica	0.47	1.85	1.87	1.81	1.83
Guadeloupe	0.98	1.70	1.80	1.84	1.82
Anguilla	1.36	1.77	1.76	1.70	1.74
Puerto Rico	0.30	1.62	1.71	1.71	1.70
St. Kitts and Nevis	0.88	1.61	1.62	1.60	1.60
Caribbean Average	**0.56**	**1.20**	**1.27**	**1.38**	**1.25**
Trinidad and Tobago	0.59	0.93	0.96	0.96	0.96
Martinique	0.38	0.79	0.84	0.86	0.85
St. Lucia	0.04	0.77	0.78	0.75	0.76
Bermuda	0.00	0.43	0.56	0.59	0.59
Haiti	0.56	0.55			0.56
Belize	0.47	0.52	0.51		0.52
Jamaica	0.20	0.52	0.51		0.50
Dominican Republic	0.24	0.46	0.44		0.44
Barbados	0.13	0.41	0.42	0.42	0.42
Grenada	0.09	0.42	0.42	0.41	0.41
St. Vincent and the Grenadines	0.05	0.36	0.37	0.33	0.35
Aruba	0.20	0.32	0.33	0.33	0.33
French Guiana	0.00	0.00	0.00	0.00	0.00
Guyana	0.00	0.00	0.00		0.00
Suriname	0.00	0.00	0.00	0.00	0.00

Source: Author based on data from the UN Global Assessment Report on Disaster Risk Reduction 2015

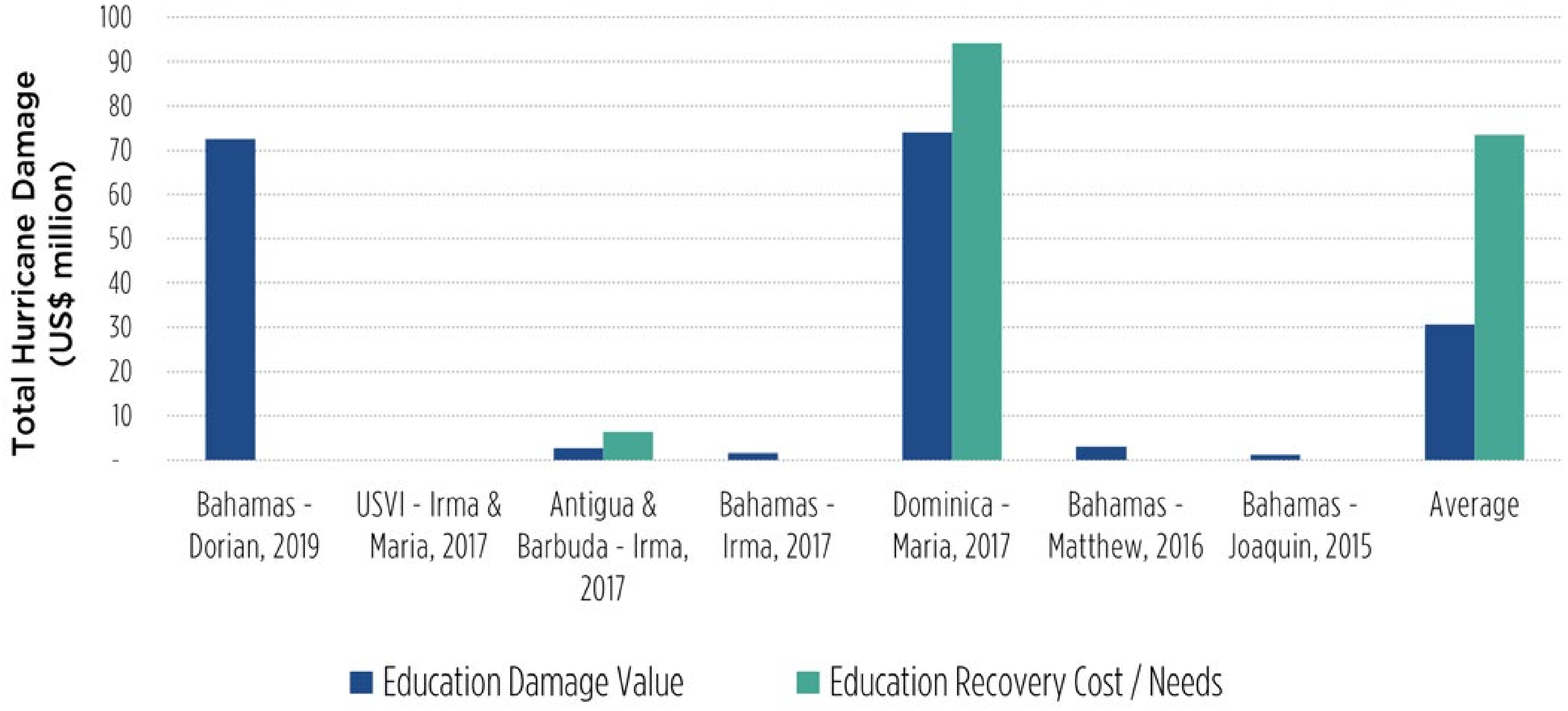


2.3.2. Education

Figure 2.12 shows the reported damage and estimated recovery costs for the education sector from recent hurricane strikes in the Caribbean.

As with the housing sector, the cost for education sector recovery after a hurricane is estimated to be much higher than the actual damage that was caused. This is primarily due to plans to rebuild damaged buildings to a higher standard with stronger materials and more resilient construction practices.

Figure 2.12. Assessed education sector damage and recovery need from recent hurricanes (US$ million).



	Bahamas - Dorian, 2019	USVI- Irma & Marta, 2017	Antigua & Barbuda - Irma, 2017	Bahamas - Irma, 2017	Dominica - Maria, 2017	St. Maartin - Irma & Maria, 2017	Bahamas - Matthew, 2016	Bahamas - Joaquin, 2015	Average
Damage	72		3	2	74	60	3	1	31
Recovery Cost/Needs			6		94	120			73

Source: Author based on data from individual hurricane damage assessments

Table 2.2 below summarizes common contributing factors to damage in the education sector as reported in each hurricane damage report.

Common contributing factors include:

- **Roofs, windows, and doors were the weakest link.** The majority of the reported damage to education infrastructure came from damage to roofs and subsequent water intrusion. In some instances, damage to windows and doors also allowed wind and water to enter the buildings.
- **Water damage to equipment and supplies.** Flooding and wind/rain was the major cause of damage to equipment and supplies stored in the educational buildings. Protocols to cover and protect sensitive equipment such as computers and using storage rooms without windows could reduce these risks.

Table 2.2. Reported contributing factors to education sector damage from recent hurricanes.

Contributing Factors - Education	Bahamas - Dorian, 2019	USVI - Irma & Maria, 2017	Antigua & Barbuda - Irma, 2017	Bahamas - Irma, 2017	Dominica - Maria, 2017	St. Maartin - Irma & Maria, 2017	Bahamas - Matthew, 2016	Bahamas - Joaquin, 2015
Damage to roof or windows/doors was main cause of building damage		x	x	x	x		x	x
Water damage to equipment / supplies		x			x		x	x
Lack of adequate maintenance				x				
Lack of funding slowed repairs and delayed reopening				x				
Loss of teaching time was major factor in losses				x				

Source: Author based on data from individual hurricane damage assessments

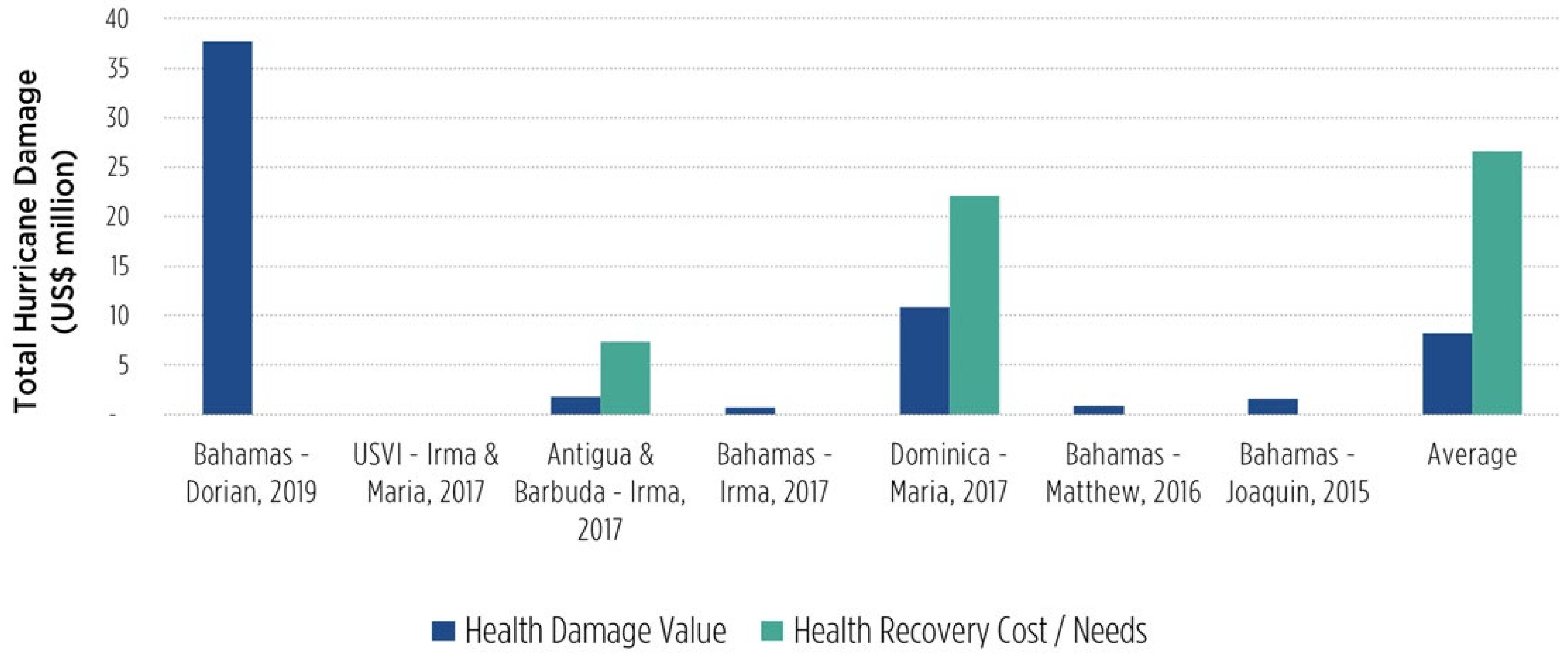
Source: IDB

2.3.3. Health

Figure 2.13 shows the reported damage and estimated recovery costs for the health sector from recent hurricane strikes in the Caribbean.

As with the housing and education sectors, the cost for health sector recovery after a hurricane is estimated to be much higher than the actual damage that was caused. This is primarily due to plans to "build back better" and replace damaged buildings with more resilient structures. The difference was particularly striking in Sint Maarten where the expected cost to rebuild was almost 10x the damage caused by Hurricanes Maria and Irma.

Figure 2.13. Assessed health sector damage and recovery need from recent hurricanes (US$ million).



	Bahamas - Dorian, 2019	USVI- Irma & Marta, 2017	Antigua & Barbuda - Irma, 2017	Bahamas - Irma, 2017	Dominica - Maria, 2017	St. Maartin - Irma & Maria, 2017	Bahamas - Matthew, 2016	Bahamas - Joaquin, 2015	Average
Damage	38		2	1	11	4	1	2	8
Recovery Cost/Needs			7		22	50			26

Source: Author based on data from individual hurricane damage assessments

Table 2.3 below summarizes common contributing factors to damage in the health sectors as reported in each hurricane damage report.

Common contributing factors include:

- **Roofs, windows, and doors were the weakest link.** The majority of the reported damage to health infrastructure came from damage to roofs and subsequent water intrusion. In some instances storm surges also resulted in flooding. Relocating facilities to higher ground can help reduce this risk.
- **Water damage to equipment and supplies.** Flooding and wind/rain was the major cause of damage to equipment and supplies stored in the educational buildings. In some clinics, roof damage was minimal, but enough to allow water leaks to damage sensitive medical equipment. Protocols to cover and protect vulnerable equipment and using storage rooms without windows could reduce these risks.
- **Insufficient back-up generation.** Several reports noted that health systems were compromised when the power distribution grid failed and on-site back-up generation was unable to fully compensate. While most critical care facilities did have back up generation ready, the generators were not equipped to operate for long periods. In addition, fuel supplies were often insufficient and securing additional fuel was complicated by hurricane damage to streets and ports.

Table 2.3. Reported contributing factors to health sector damage from recent hurricanes.

Contributing Factors - Health	Bahamas - Dorian, 2019	USVI - Irma & Maria, 2017	Antigua & Barbuda - Irma, 2017	Bahamas - Irma, 2017	Dominica - Maria, 2017	St. Maartin - Irma & Maria, 2017	Bahamas - Matthew, 2016	Bahamas - Joaquin, 2015
Backup generators were faulty or lacked sufficient fuel		x			x			x
Damage to roof was a major cause of building damage		x	x	x	x		x	x
Flooding was a major cause of building damage								x
Workers were unable to reach health facilities to report to work		x					x	x
Service disruption was main factor in losses		x		x				x
Flooding damaged equipment and supplies	x				x		x	x

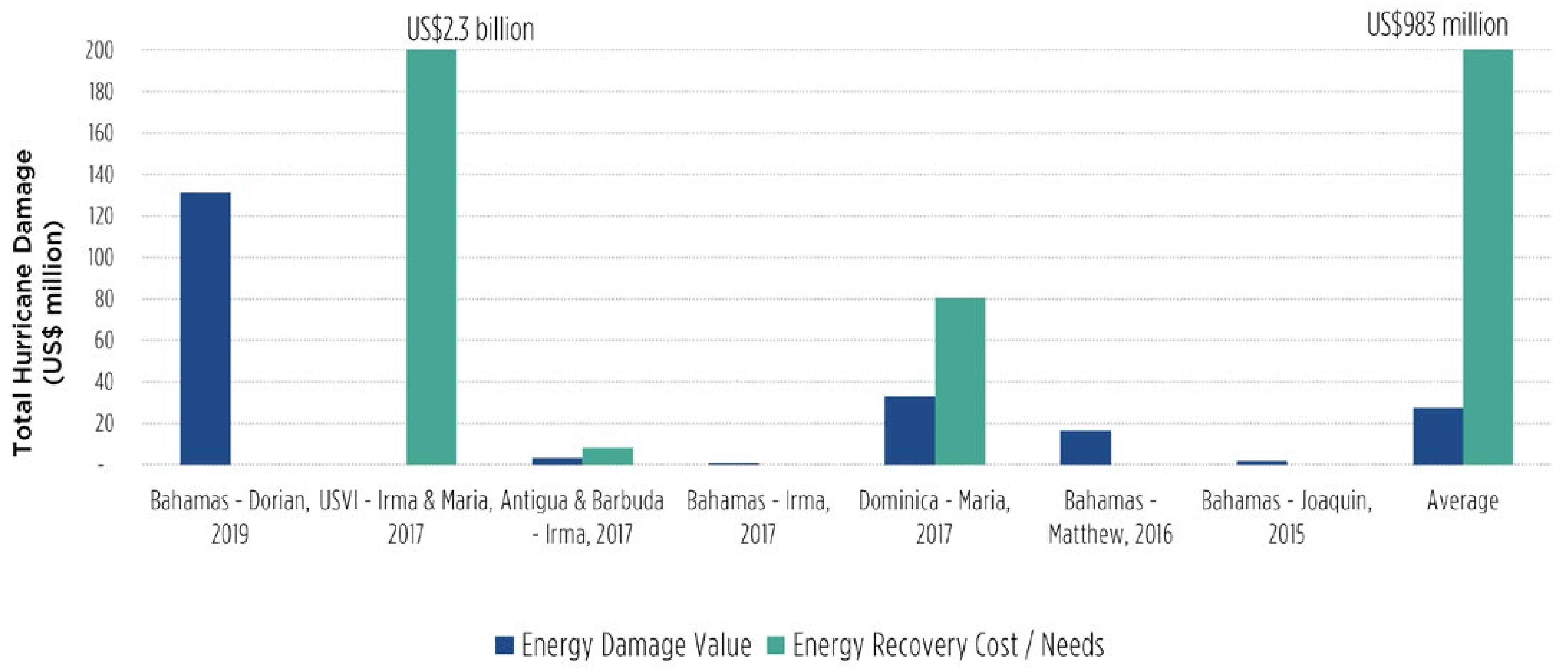
Source: Author based on data from individual hurricane damage assessments

2.3.4. Energy and Telecommunications

Figure 2.14 shows the reported damage and estimated recovery costs for the energy sector from recent hurricane strikes in the Caribbean.

As with the housing sector, the cost for energy sector recovery after a hurricane is estimated to be much higher than the actual damage that was caused. This is primarily due to plans to move overhead electricity distribution wires underground to protect the system from wind and falling trees, as putting distribution wires underground is more expensive than replacing overhead wires.

Figure 2.14. Assessed energy sector damage and recovery need from recent hurricanes (US$ million).



	Bahamas - Dorian, 2019	USVI- Irma & Marta, 2017	Antigua & Barbuda - Irma, 2017	Bahamas - Irma, 2017	Dominica - Maria, 2017	St. Maartin - Irma & Maria, 2017	Bahamas - Matthew, 2016	Bahamas - Joaquin, 2015	Average
Damage	131		3	1	33	6	16	2	27
Recovery Cost/Needs		2,300	8		81	57			611

Source: Author based on data from individual hurricane damage assessments

Figure 2.15 shows the reported damage and estimated recovery costs for the telecommunications sector from recent hurricane strikes in the Caribbean.

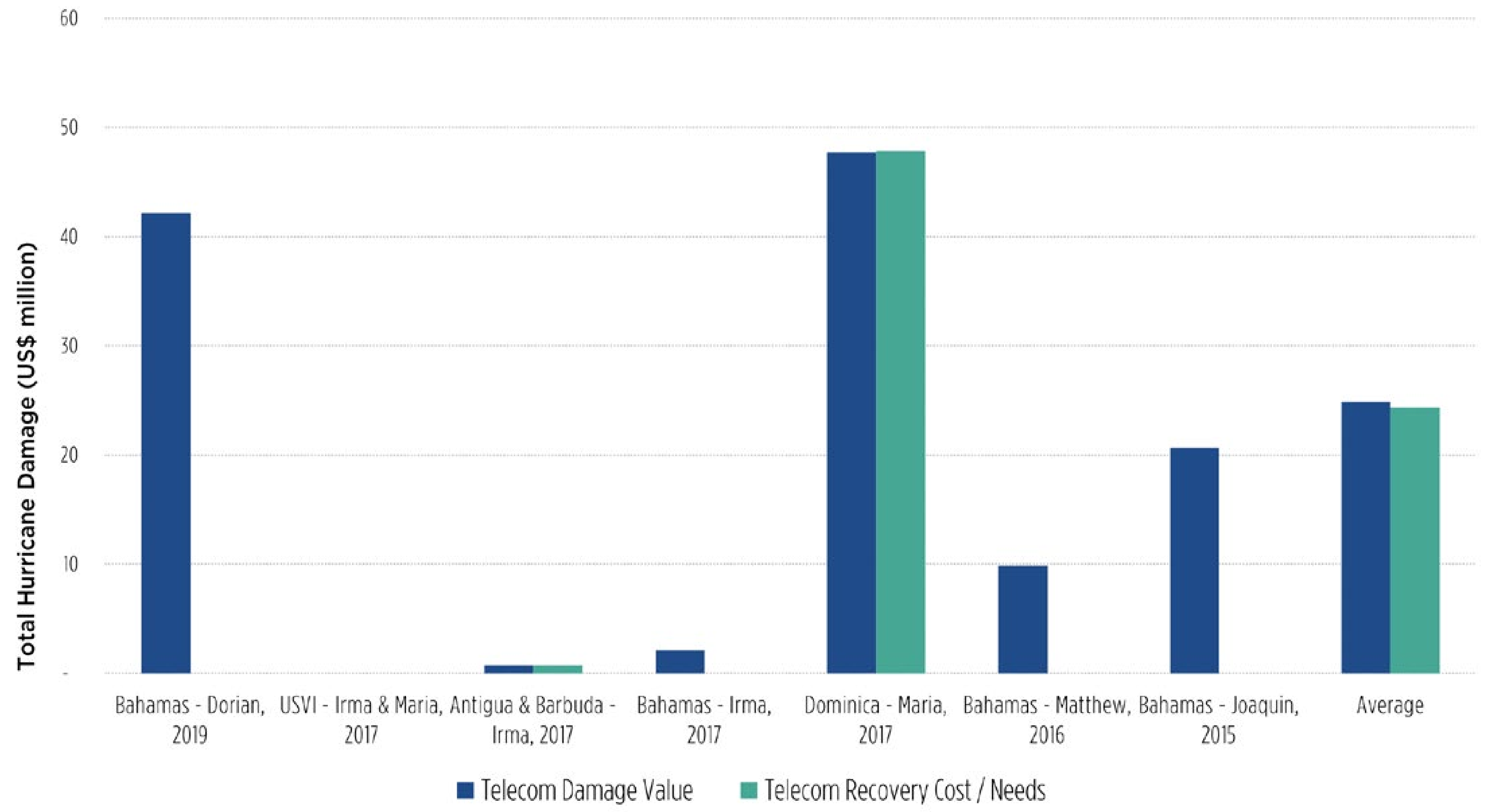
Unlike for other sectors, the cost for telecommunications sector recovery after a hurricane is estimated to be roughly the same or less than the actual damage that was caused. This is primarily due allocating the cost of burying telecommunication lines to the electricity distribution wires that will also be buried (as telephone lines typically use electricity distribution poles in agreement with the power utility). Other telecom infrastructure, such as cell phone towers, is less affected by changing building codes and any replacement infrastructure is typically of similar value to the original infrastructure it replaces.

Table 2.4 below summarizes common contributing factors to damage in the energy and telecommunications sectors as reported in each hurricane damage report.

Common contributing factors include:

- **Electricity distribution and telecommunications lines located above ground.** The majority of the reported damage to energy and telecommunications infrastructure came from downed distribution lines. In some instances the damage was exacerbated by old or wooden poles, but in most cases the lines were downed by falling trees and flying debris. In these cases, stronger poles made with concrete or composite materials would not have helped reduce the damage caused to the distribution grid.
- **Flooding damage to buildings and buried lines.** Flooding was the major cause of damage to buildings and power generation infrastructure, and was also an issue for buried electricity and telecommunications lines in one report. Relocating generators away from the coast and improving the site preparations and building integrity would help minimize this risk.
- **Insufficient back-up generation.** Several reports noted that telecommunications systems were compromised when the power distribution grid failed and key equipment did not have on-site back-up generation. Other reports from wealthier countries noted that many residencies and businesses did not have back-up generation on site. Those that did were not equipped to operate for long periods (having insufficient fuel on site or insufficient capacity to fully replace the main electricity service).

Figure 2.15. Assessed telecommunications sector damage and recovery need from recent hurricanes (US$ million).



	Bahamas - Dorian, 2019	USVI- Irma & Marta, 2017	Antigua & Barbuda - Irma, 2017	Bahamas - Irma, 2017	Dominica - Maria, 2017	St. Maartin - Irma & Maria, 2017	Bahamas - Matthew, 2016	Bahamas - Joaquin, 2015	Average
Damage	42		1	2	48	51	10	21	25
Recovery Cost/Needs			1		48	25			24

Source: Author based on data from individual hurricane damage assessments

Table 2.4. Reported contributing factors to energy and telecommunications sector damage from recent hurricanes.

Contributing Factors - Energy	Bahamas - Dorian, 2019	USVI - Irma & Maria, 2017	Antigua & Barbuda - Irma, 2017	Bahamas - Irma, 2017	Dominica - Maria, 2017	St. Maartin - Irma & Maria, 2017	Bahamas - Matthew, 2016	Bahamas - Joaquin, 2015
Electricity Distribution wires and wired telecom above ground	X	X	X	X		X	X	X
Old Electricity distribution poles (wooden)		X					X	
Power / telecom lines downed by falling trees				X			X	X
Back up generators not designed to run for long periods		X						
Utility scale PV panels improperly mounted		X						
Debris damanged utility scale PV panels		X						
Buried lines damaged by flooding	X							
Generators / buildings flooded	X				X			X
Contributing Factors - Telecom	**Bahamas - Dorian, 2019**	**USVI - Irma & Maria, 2017**	**Antigua & Barbuda - Irma, 2017**	**Bahamas - Irma, 2017**	**Dominica - Maria, 2017**	**St. Maartin - Irma & Maria, 2017**	**Bahamas - Matthew, 2016**	**Bahamas - Joaquin, 2015**
Electricity Distribution wires and wired telecom above ground	X	X	X	X		X	X	X
Lack of telecom backup		X						
Buried lines damaged by flooding	X							
Loss of power to telecom system		X			X		X	X

Source: Author based on data from individual hurricane damage assessments

3. Construction Materials Used in the Caribbean

This section analyzes the construction materials that are used in the outer walls and roofs of buildings in the Caribbean. The analysis is built up from population and housing census data from 20 Caribbean countries. The majority of the census surveys were taken in 2010 or 2011, but they represent the most recent available data on housing numbers and materials. These census surveys typically include data on the type of outer wall material and the type of roofing material used for dwellings. Some census data include information on the dwelling's floor type, age (based on year built), and general condition.

This data was aggregated into groupings of more climate-resilient materials (such as concrete) and less climate-resilient materials (such as wood). The data was then analyzed to identify trends in the types of materials used based on a country's wealth. This analysis suggests that higher income countries tend to have more residential buildings built with resilient materials. Finally, the data was compared with the average annual loss data for each country to identify any correlation between the reduction in hurricane risk and greater use of resilient materials.

Although census data is not available for the materials used in other building types, such as hotels, hospitals, or schools, the insights gained from the analysis of residential buildings are extended to other building types.

3.1. Outer Wall Construction Materials

Of the twenty country census surveys that were analyzed, thirteen (Anguilla, Antigua & Barbuda, Barbados, Belize, British Virgin Islands, Dominican Republic, Grenada, Guyana, Jamaica, Montserrat, St. Lucia, St. Vincent & the Grenadines and Trinidad & Tobago) include details on the type of building material used for the outer walls of each dwelling.

The building materials that were reported included:

- Concrete in various forms, such as formed concrete, concrete blocks, fiber-cement panels, and concrete with stone and bricks.
- Stone and brick
- Wood and plywood
- Wood sticks, including palmetto, yagua, and shingles
- Wood with concrete, stone, or brick
- Sheet metal
- Stucco and adobe
- Makeshift
- Other

Table 3.1 below summarizes the data provided by the thirteen countries census reports, grouped by typical building material types.

Table 3.1. Caribbean Dwellings by Outer Wall Building Material and Country.

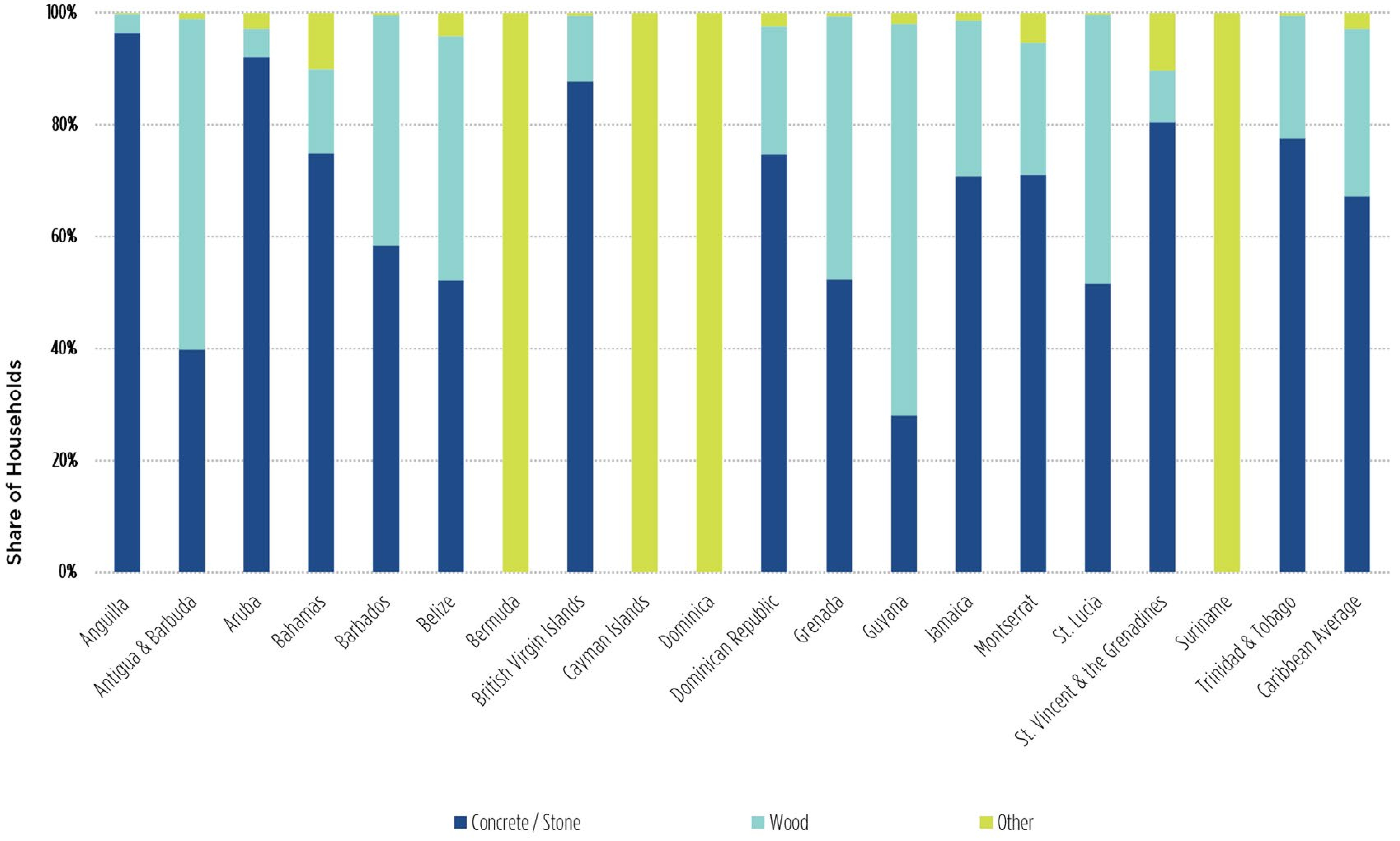
Country	Mineral		Wood					Other			Total
	Concrete (all forms)	Stone / Brick	Wood	Other wood	Wood w/ Mineral	Wood w/ other	Sheet metal	Stucco / Adobe	Makeshift	Other / Unknown	
Anguilla	4,749	7	82	0	91	0	0	0	0	6	4,935
Antigua & Barbuda	11,898	133	12,584	0	0	5,295	0	0	15	288	30,213
Aruba	32,105	0	1,746	0	0	0	210	0	0	784	34,845
Bahamas	77,069	0	15,414	0	0	0	0	0	0	10,276	102,758
Barbados	52,305	2,645	17,365	0	21,529	0	0	0	0	329	94,173
Belize	41,367	205	26,781	5,748	2,227	0	1,806	804	230	490	79,658
Bermuda	NA	NA	NA	NA	NA	NA	NA	NA	NA	28,192	28,192
British Virgin Islands	9,366	134	732	0	413	128	0	0	0	57	10,830
Cayman Islands	NA	NA	NA	NA	NA	NA	NA	NA	NA	22,760	22,760
Dominica	NA	NA	NA	NA	NA	NA	NA	NA	NA	31,352	31,352
Dominican Republic	2,294,249	0	573,175	130,425	0	0	0	0	0	73,887	3,071,736
Grenada	18,844	78	10,214	2,090	4,653	0	0	0	94	138	36,111
Guyana	55,599	1,652	92,958	0	50,553	0	463	1,355	729	1,389	204,698
Jamaica	499,659	3,605	128,711	0	69,815	0	0	0	0	9,541	711,331
Montserrat	1,657	4	362	0	175	11	114	0	3	9	2,335
St. Lucia	30,069	69	11,324	7,243	9,528	0	0	1	80	61	58,375
St. Vincent & the Grenadines	28,772	870	0	0	2,857	523	0	36	0	3,771	36,829
Suriname	NA	NA	NA	NA	NA	NA	NA	NA	NA	134,329	134,329
Trinidad & Tobago	308,392	322	46,518	0	36,295	4,780	0	878	0	1,056	398,241
Total	**3,097,209**	**8,459**	**879,761**	**138,263**	**149,281**	**5,423**	**2,479**	**2,159**	**1,068**	**179,489**	**4,463,592**

Source: Energy Narrative based on individual country 2010 or 2011 census data

The table highlights the broad range in population and, by extension, the number of total dwellings in each country. The Dominican Republic has the most total dwellings with roughly 3 million, or nearly 60% of the total dwellings reported across the thirteen countries. Montserrat is the smallest, reporting only 2,355 total dwellings. The data also shows the wide range in types of building materials used across the region, with more than 25 different categories listed in the country census surveys. These categories were consolidated to ten in the table, and further consolidated into three main groups in the charts below.

Figure 3.1 highlights this trend showing the share of each building material used in the outer walls of dwellings for each country.

Figure 3.1. Share of Caribbean Dwellings by Outer Wall Building Material and Country.



In every country except Antigua & Barbuda and Guyana at least half of the dwellings were built of concrete in one form or another. Seven of the thirteen countries used concrete for at least 70% of dwellings, and in Anguilla the share was over 90%. Wood was the second most used building material, accounting for virtually all dwellings that were not built using concrete. Only Barbados and St. Vincent & the Grenadines used stone for a noticeable share of their dwellings. The countries showing "Other / Not Stated" are primarily households that did not provide data, with the exception of Belize and Montserrat where 2% and 5%, respectively, of dwellings use sheet metal for the outer wall. Data on outer wall construction materials was not available for Bermuda, Dominica, and Suriname.

Country	Concrete / Stone	Wood	Other
Anguilla	96%	4%	0%
Antigua & Barbuda	40%	59%	1%
Aruba	92%	5%	3%
Bahamas	75%	15%	10%
Barbados	58%	41%	0%
Belize	52%	44%	4%
Bermuda	0%	0%	100%
British Virgin Islands	88%	12%	1%
Cayman Islands	0%	0%	100%
Dominica	0%	0%	100%
Dominican Republic	75%	23%	2%
Grenada	52%	47%	1%
Guyana	28%	70%	2%
Jamaica	71%	28%	1%
Montserrat	71%	23%	5%
St. Lucia	52%	48%	0%
St. Vincent & the Grenadines	80%	9%	10%
Suriname	NA	NA	100%
Trinidad & Tobago	78%	22%	0%
Caribbean Average	**67%**	**30%**	**3%**

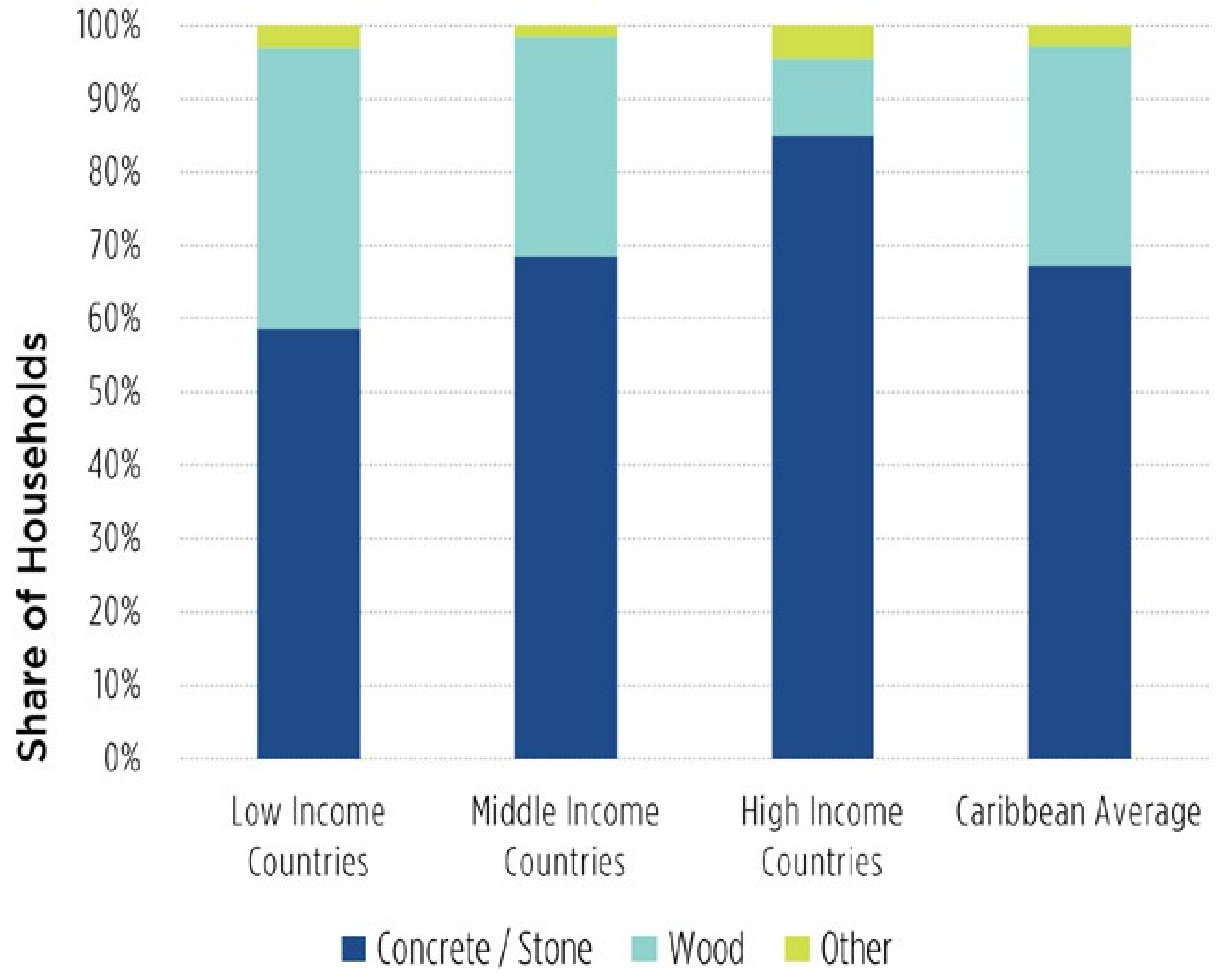
Source: Energy Narrative based on individual country 2010 or 2011 census data

The hurricane damage reports described in section 2.3 above suggest that buildings in the education and health sectors (schools, clinics, and hospitals) are more likely to be built with concrete than individual houses. Hurricane damage in these sectors was almost entirely owing to roof damage and water entry via the roof, doors, and windows, rather than structural damage to the outer walls. This suggests that the buildings in these sectors are generally built with outer walls that are more climate resilient.

Figure 3.2 summarizes the average share of each outer wall material used in the Caribbean for Low-income (GDP per capita below US$10,000), Middle-income (GDP per capita between US$10,000 and US$20,000), and High-income countries (GDP per capita greater than US$20,000), as well as the overall average for the region.

Overall, resilient materials such as concrete and stone are used in 67% of all dwellings, with 30% built with wood and just 3% with other materials. The share of dwellings made of concrete and stone increases with average income. In Low-income countries, the share averages 59%, rising to 69% in Middle-income countries, and 85% in High-income countries.

Figure 3.2. Average Caribbean Dwellings Outer Wall Building Material by Country Income Levels.



	Concrete / Stone	Wood	Other
Low-income Countries	59%	38%	3%
Middle-income Countries	69%	30%	1%
High-income Countries	85%	11%	4%
Caribbean Average	**67%**	**30%**	**3%**

Source: Energy Narrative based on individual country 2010 or 2011 census data

3.2. Roofing Materials

Of the twenty country census surveys that were analyzed, nine include details on the type of building material used for the roof of each dwelling (Anguilla, British Virgin Islands, Grenada, and Jamaica reported outer wall building material but not roofing material). These roofing materials included:

- Concrete
- Sheet metal
- Shingles, including tile, asphalt, wood, and other
- Rubber
- Asbestos
- Thatch
- Makeshift /Tarpulin
- Other

Table 3.2 summarizes the data provided by the nine countries census reports, grouped by typical roofing material types.

Table 3.2. Caribbean Dwellings by Roofing Material and Country.

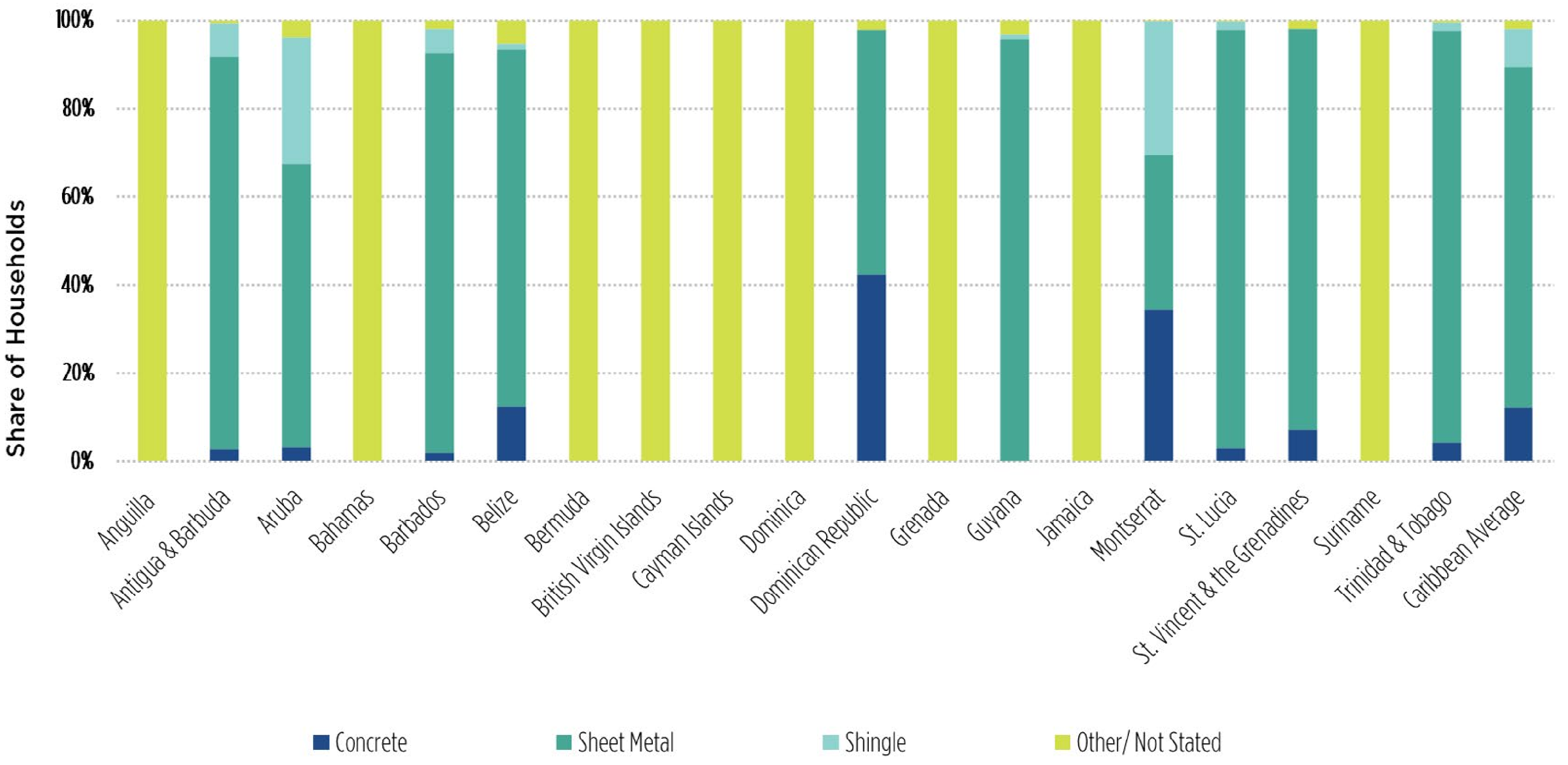
Country	Concrete, Sheet metal		Shingle				Other					Total
	Concrete	Sheet metal	Tile	Asphalt	Wood	Other	Rubber	Asbestos	Thatch	Makeshift / Tarpulin	Other / Unknownn	
Anguilla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4,935	4,935
Antigua & Barbuda	794	26,939	108	1,040	276	844	0	0	0	31	181	30,213
Aruba	1,088	22,466	4,448	5,566	0	0	0	275	0	0	1,002	34,845
Bahamas	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	102,758	102,758
Barbados	1,763	85,513	1,246	2,992	938	0	0	0	0	0	1,721	94,173
Belize	9,979	64,518	192	652	267	0	346	125	3,114	46	420	79,658
Bermuda	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	28,192	28,192
British Virgin Islands	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10,781	10,781
Cayman Islands	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	22,760	22,760
Dominica	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10,830	10,830
Dominican Republic	1,298,309	1,709,782	0	0	0	0	0	23,815	0	0	39,830	3,071,736
Grenada	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	36,111	36,111
Guyana	202	196,115	121	314	1,614	67	0	0	5,304	527	434	204,698
Jamaica	0	0	0	0	0	0	0	0	0	0	711,331	711,331
Montserrat	804	821	0	546	153	7	0	0	0	4	0	2,335
St. Lucia	1,661	55,537	74	688	219	46	0	0	0	11	139	58,375
St. Vincent & the Grenadines	2,688	33,452	0	0	0	0	0	0	0	0	689	36,829
Suriname	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	134,329	134,329
Trinidad & Tobago	17,501	371,428	672	2,396	4,425	0	0	0	0	0	1,819	398,241
Total	**1,312,135**	**2,105,333**	**6,115**	**10,564**	**3,095**	**911**	**346**	**24,215**	**8,418**	**604**	**259,955**	**3,731,690**

Source: Energy Narrative based on individual country 2010 or 2011 census data

The table highlights the broad range in the types of roofing materials used across the region, with more than 14 different categories listed in the country census surveys. These categories were consolidated into four main groups in Figure 3.3.

In every reporting country except Belize, the Dominican Republic, and Montserrat, at least 90% of the dwellings had sheet metal roofs. Only the Dominican Republic and Montserrat had a sizeable share using concrete (42% and 34%, respectively), with Belize reporting 12%. Shingled roofs accounted for 30% of the total in Montserrat, but only 8% in Antigua & Barbuda and 5% in Barbados, the two countries with the next highest shares. The countries showing "Other / Not Stated" are entirely households that did not provide data, with the exception of the Dominican Republic where 1% of dwellings reported using asbestos roofing.

Figure 3.3. Share of Caribbean Dwellings by Roofing Material and Country.



Data from the hurricane damage reports described in section 2.3 above suggest that buildings in the education and health sectors (schools, clinics, and hospitals) are also likely to be built with sheet metal and other materials with limited resiliency. Hurricane damage reported in these sectors was largely related to roof damage and water entry via the roof. This suggests that the buildings in these sectors face similar challenges with climate resiliency as residential buildings.

Country	Concrete	Sheet Metal	Shingle	Other/ Not Stated
Anguilla	NA	NA	NA	100%
Antigua & Barbuda	3%	89%	8%	1%
Aruba	3%	64%	29%	4%
Bahamas	NA	NA	NA	100%
Barbados	2%	91%	5%	2%
Belize	13%	81%	1%	5%
Bermuda	NA	NA	NA	100%
British Virgin Islands	NA	NA	NA	100%
Cayman Islands	NA	NA	NA	100%
Dominica	NA	NA	NA	100%
Dominican Republic	42%	56%	0%	2%
Grenada	NA	NA	NA	100%
Guyana	0%	96%	1%	3%
Jamaica	NA	NA	NA	100%
Montserrat	34%	35%	30%	0%
St. Lucia	3%	95%	2%	0%
St. Vincent & the Grenadines	7%	91%	0%	2%
Suriname	NA	NA	NA	100%
Trinidad & Tobago	4%	93%	2%	0%
Caribbean Average	**12%**	**77%**	**9%**	**2%**

Source: Author based on individual country 2010 or 2011 census data

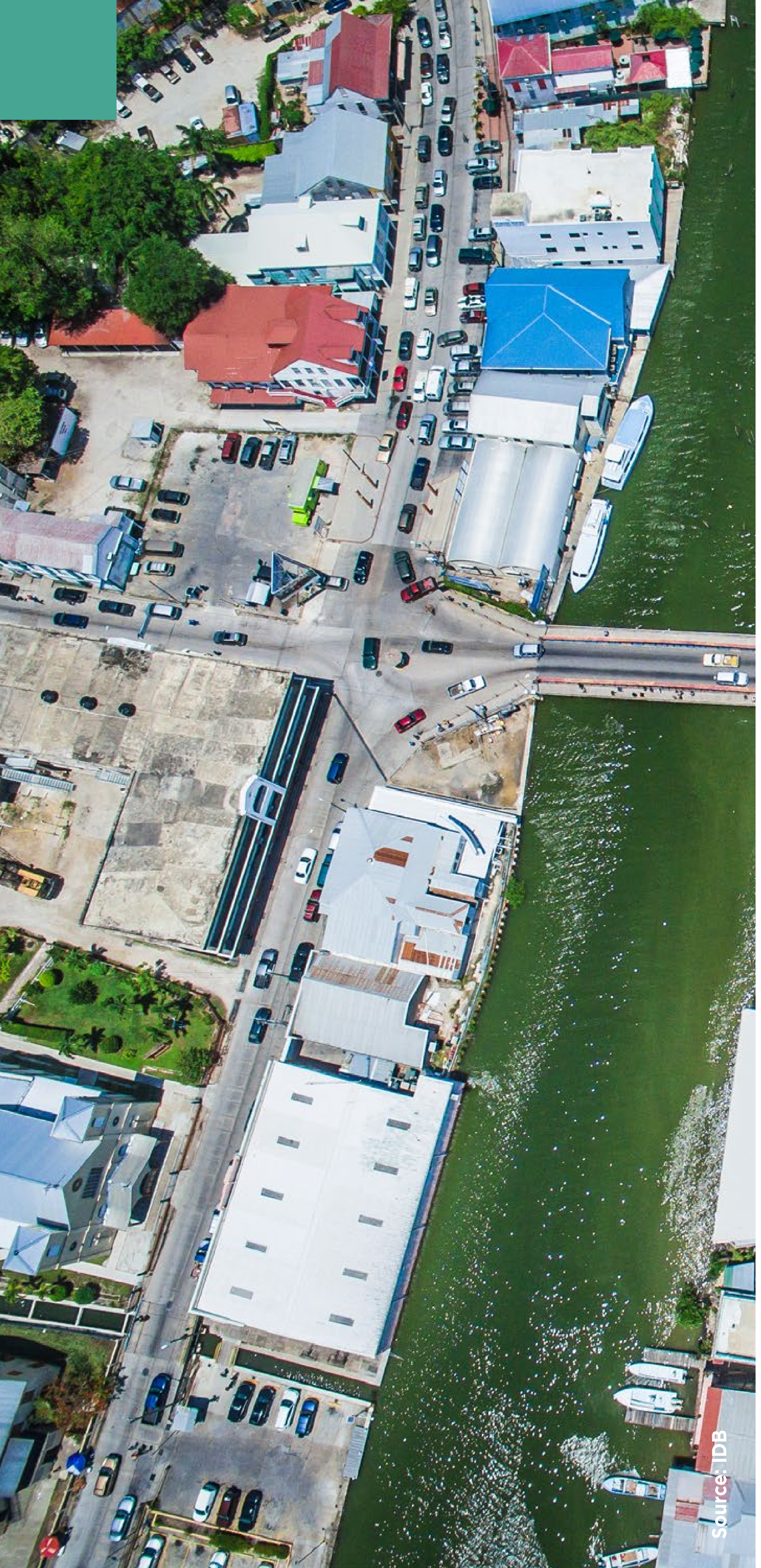
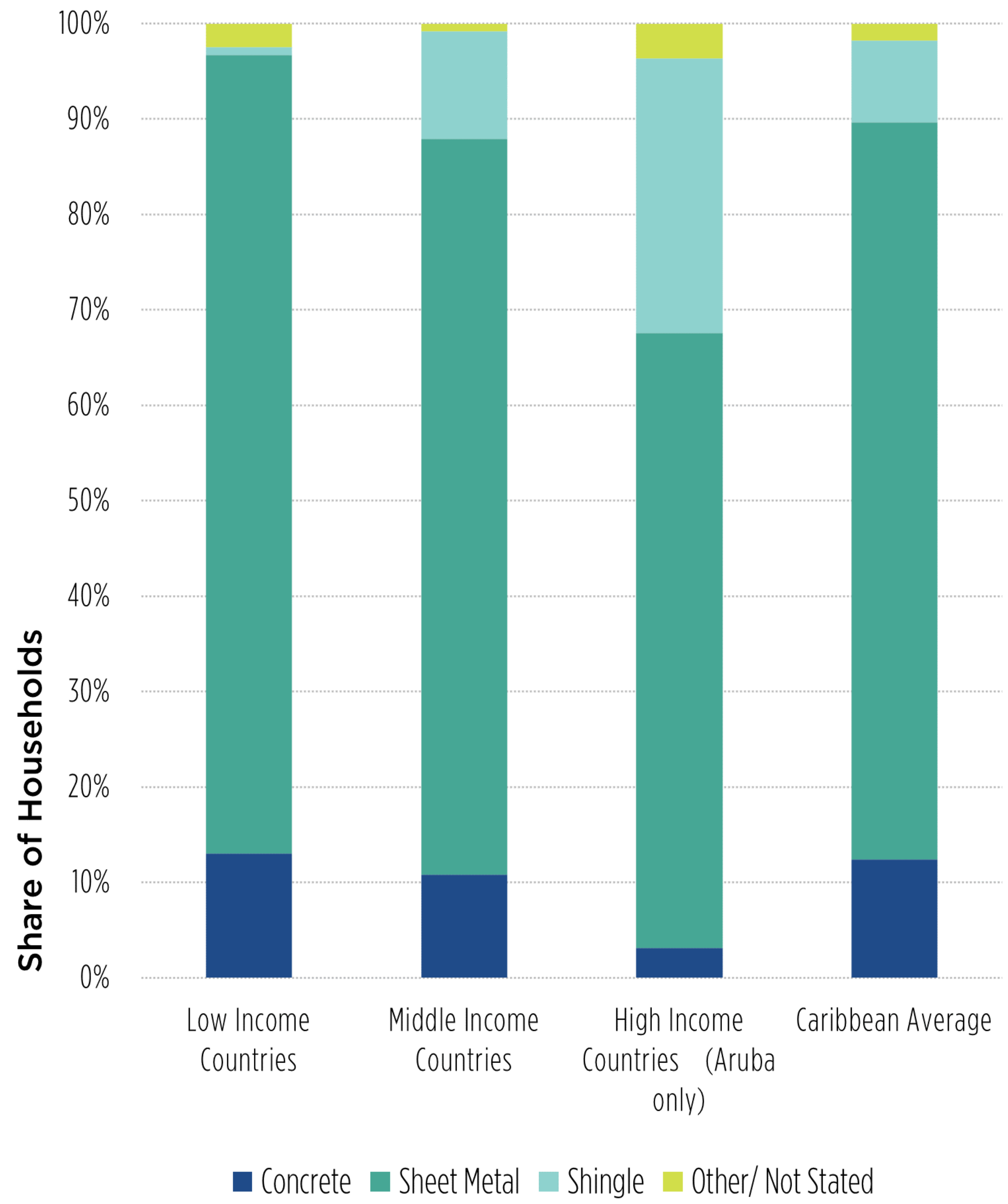


Figure 3.4 summarizes the average share of each roofing material used in the Caribbean for Low-income (GDP per capita below US$10,000), Middle-income (GDP per capita between US$10,000 and US$20,000), and High-income countries (GDP per capita greater than US$20,000), as well as the overall average for the region.

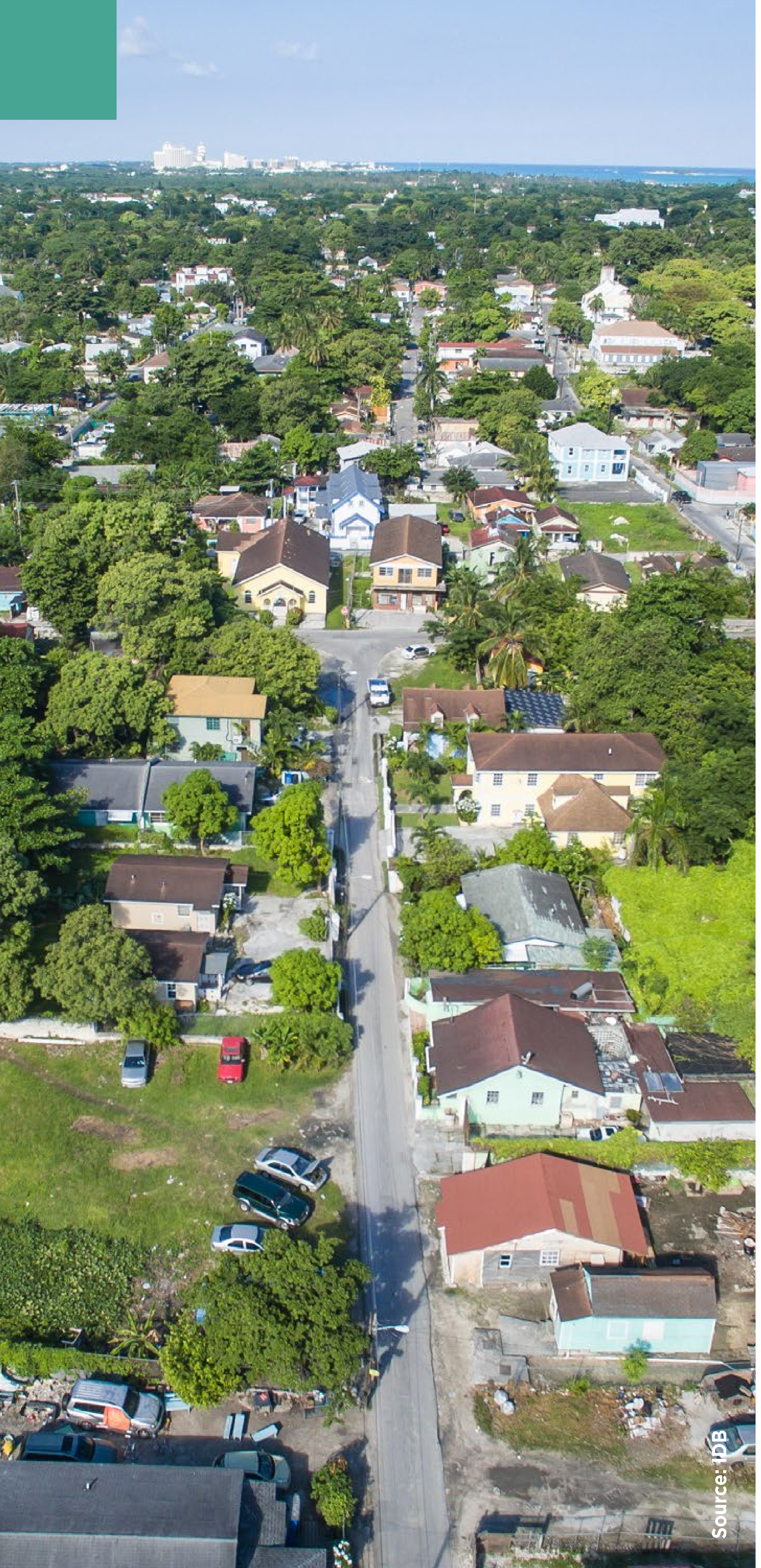
Overall, concrete and sheet metal are used in 90% of all dwellings (with sheet metal alone accounting for 77% of the total), 9% built with shingles, and just 1% with other materials. The share of dwellings roofed with concrete and steel decreases with average income. In Low-income countries, the share averages 97%, falling to 88% in Middle-income countries, and to 68% in High-income countries. This trend could be influenced by the higher cost of shingles relative to sheet metal. It may also reflect the limited data available for High-income countries: only Aruba had data on dwelling roofing materials. Although Bermuda is known to have a high share of buildings with stone roofs, and concrete roofing is widely used in the Cayman Islands, hard data for each country was not available and is not included here.

Figure 3.4. Average Caribbean Dwellings Roofing Material by Country Income Level.



	Concrete	Sheet Metal	Shingle	Other/ Not Stated
Low-income Countries	13%	84%	1%	2%
Middle-income Countries	11%	77%	11%	1%
High-income Countries (Aruba only)	3%	64%	29%	4%
Caribbean Average	**12%**	**77%**	**9%**	**2%**

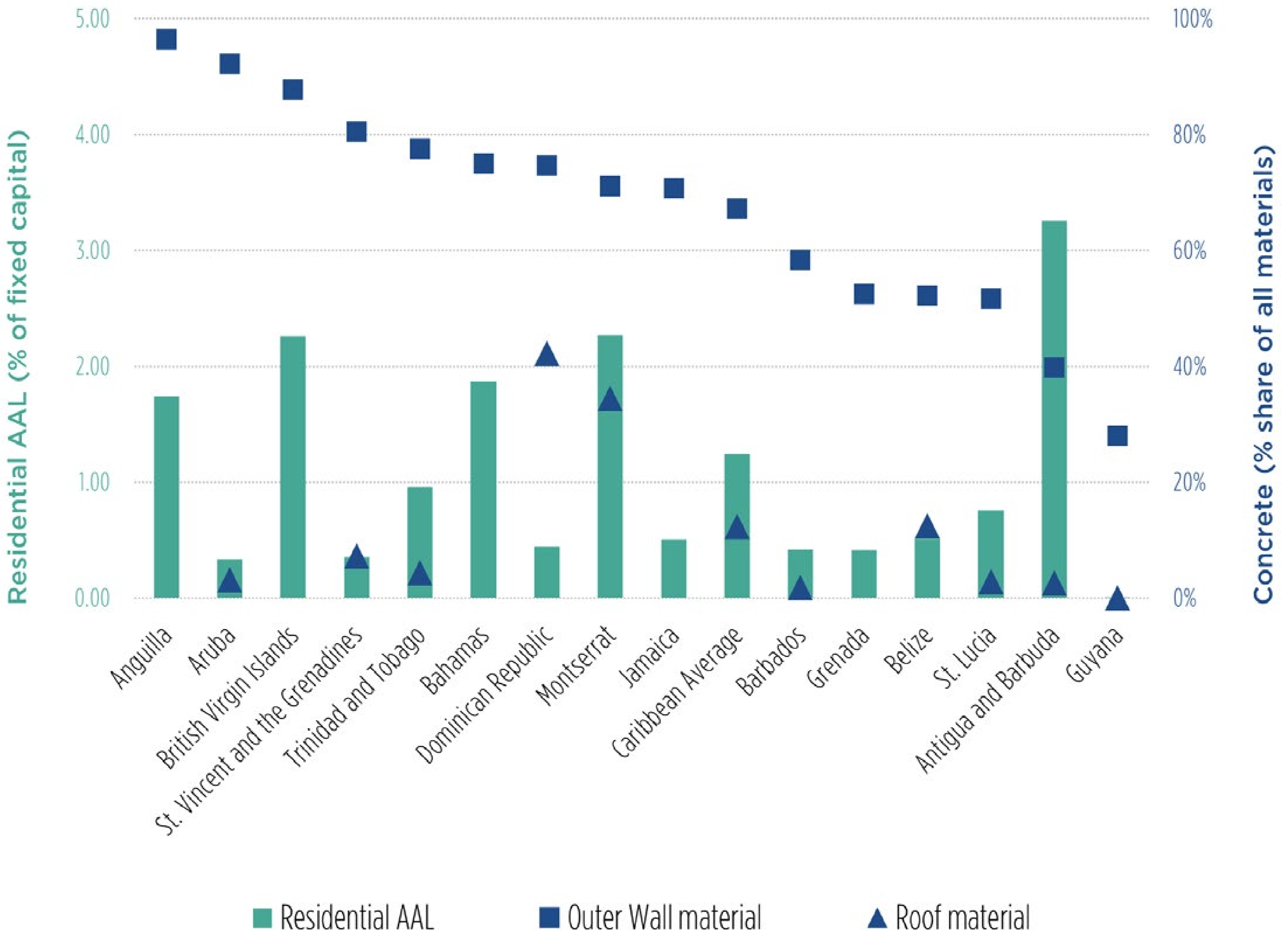
Source: Energy Narrative based on individual country 2010 or 2011 census data



4. Construction Materials and Climate Resiliency

Figure 4.1 compares the climate impact risk assessment for the residential sector from Section 2.2 with the census data on outer wall and roofing material use (ordered from lowest to highest share of concrete in the outer walls). This comparison illustrates any correlation between increased use of concrete and reduced disaster losses in the residential sector.

Figure 4.1. Comparison of residential average annual loss from climate impacts and concrete share of outer wall and roofing.



In order to assess the correlation of materials used and impact of climate events, countries with similar locations should be compared. For example, Anguilla, Antigua & Barbuda, and Montserrat are geographically very close to each other and have almost identical wealth (as measured by GDP per capita). Montserrat, with a higher share of concrete use in outer walls, shows an average annual loss for the residential sector that is a full percentage point less than Antigua & Barbuda. Anguilla, with the highest share of concrete use in outer wall construction in the dataset, has a half a percentage point lower average annual loss than Montserrat.

Country	Residential AAL	Outer Wall material	Roof material
Anguilla	1.74	96%	NA
Aruba	0.33	92%	3%
British Virgin Islands	2.26	88%	NA
St. Vincent and the Grenadines	0.35	80%	7%
Trinidad and Tobago	0.96	78%	4%
Bahamas	1.87	75%	NA
Dominican Republic	0.44	75%	42%
Montserrat	2.27	71%	34%
Jamaica	0.50	71%	NA
Caribbean Average	**1.25**	**67%**	**12%**
Barbados	0.42	58%	2%
Grenada	0.41	52%	NA
Belize	0.52	52%	13%
St. Lucia	0.76	52%	3%
Antigua and Barbuda	3.26	40%	3%
Guyana	0.00	28%	0%

Source: Author based on data from the UN Global Assessment Report on Disaster Risk Reduction 2015 and country census reports.

Table 4.1 compares the AAL and the share of residential buildings with concrete, wood, or other outer wall building materials based on country census data for four pairs of neighboring countries: i) Montserrat and Antigua & Barbuda, ii) St. Vincent & the Grenadines and Grenada, iii) Anguilla and the British Virgin Islands, and iv) the Dominican Republic and Jamaica. These pairs were chosen based on their relative proximity and the availability of outer wall material data for each country.

The table supports the hypothesis that country with a higher share of residential buildings with concrete outer walls will have a lower AAL than neighboring countries (with a presumably similar hurricane risk exposure) with a lower share of concrete residential buildings. For each pair of countries located near to each other, the country with the higher share of residential buildings using concrete as an outer wall material also has the lower residential AAL, indicating a lower risk of damage from hurricanes.

Each country's overall residential sector AAL can therefore be expressed as the sum of the product of distinct AALs for concrete buildings and non-concrete buildings and each category's respective share of the total number of residential buildings in the country. This equation is shown below:

Country AAL = (Concrete building AAL) * (Share of Concrete Buildings) + Non-concrete building AAL) * (Share of non-concrete buildings)

For each country pair, the underlying hurricane risk is assumed to be the same, and therefore the average AAL for concrete buildings and the average AAL for non-concrete buildings should also be the same in each country. Using the country AAL data and share of concrete and non-concrete houses in each country, the concrete building AAL and non-concrete building AAL can be calculated. This calculation resulted in the outcomes for the various country pairs in the Caribbean shown in Table 4.2.

Table 4.1. Residential AAL and outer wall material comparison.

Country	Residential AAL %	Outer Wall Material		
		Concrete	Wood	Other/ Unknown
Montserrat	2.27%	71.1%	23.5%	5.4%
Antigua & Barbuda	3.26%	39.8%	59.2%	1.0%
St. Vincent & the Grenadines	0.35%	80.5%	9.2%	10.3%
Grenada	0.41%	52.4%	47.0%	0.6%
Anguilla	1.74%	96.4%	3.5%	0.1%
British Virgin Islands	2.26%	87.7%	11.8%	0.5%
Dominican Republic	0.44%	74.69%	22.91%	2.41%
Jamaica	0.50%	70.75%	27.91%	1.34%

Source: Author based on 2015 GAR and country census reports

Table 4.2. Residential AAL based on outer wall materials.

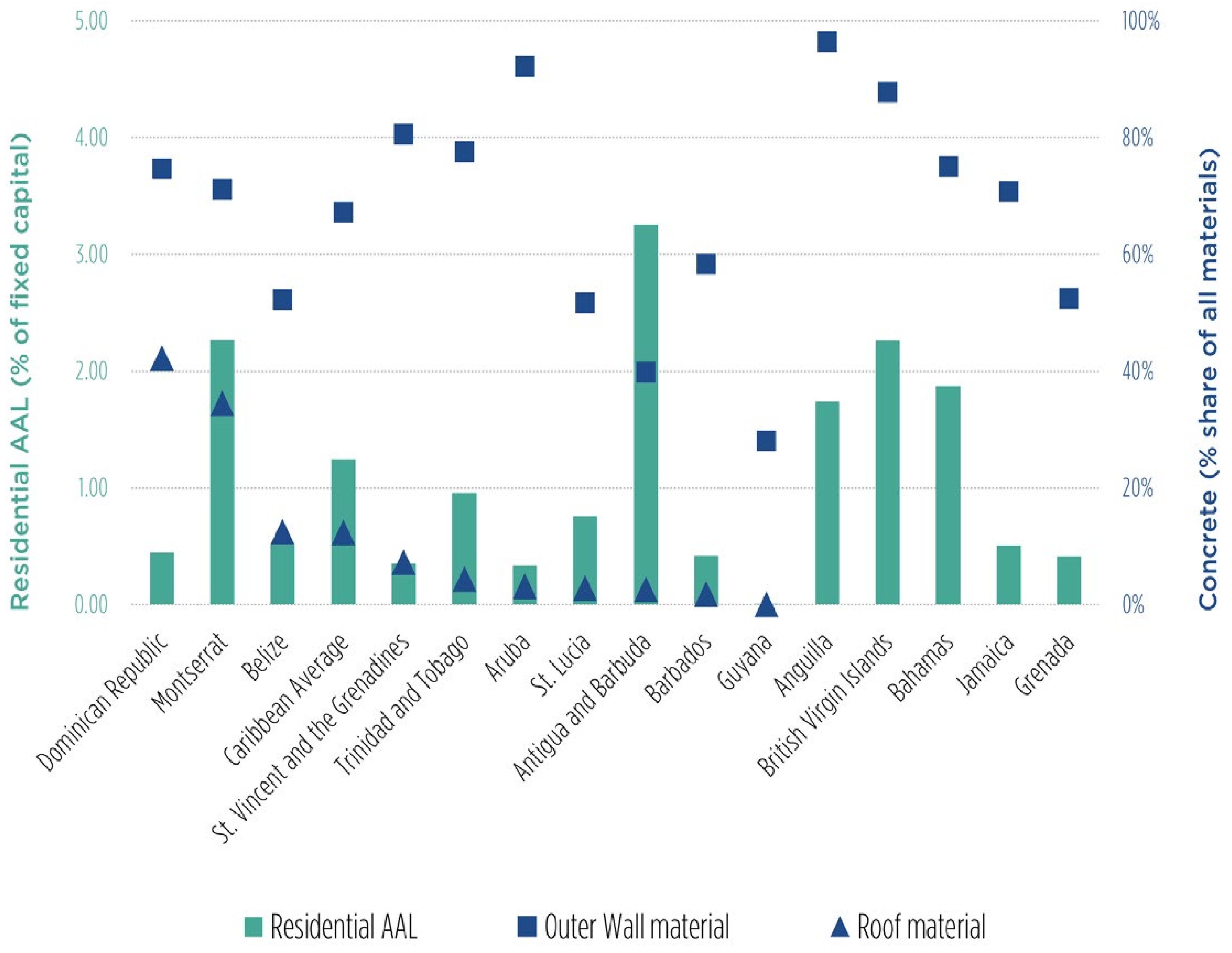
Country	Country Total AAL	Concrete Wall AAL%	Other Wall AAL%
Montserrat	2.27%	1.35%	4.52%
Antigua & Barbuda	3.26%	1.35%	4.52%
St. Vincent & the Grenadines	0.35%	0.31%	0.52%
Grenada	0.41%	0.31%	0.52%
Anguilla	1.74%	1.53%	7.50%
British Virgin Islands	2.26%	1.53%	7.50%
Dominican Republic	0.44%	0.05%	1.60%
Jamaica	0.50%	0.05%	1.60%

Source: Author calculations

The calculations showed that buildings using concrete had much smaller expected average annual losses than non-concrete buildings in all regions, with the largest difference in those regions with the highest overall AAL. That is, countries with a higher overall hurricane risk showed a wider range in vulnerability between concrete and non-concrete buildings. This outcome fits with experience in the region as those countries with the highest AAL also experience the strongest storms that are more likely to damage non-resilient buildings.

Figure 4.2 shows the same data sorted by the share of concrete used as a roofing material. In this analysis, the chart showing the average annual loss as a share of capital stock for each country has been sorted based on the estimated annual losses from wind, as this measure is most relevant to roof vulnerability to climate impacts.

Figure 4.2. Comparison of average annual loss from climate impacts as a share of fixed capital stock and roofing materials.




Source: IDB

Data is not available for the materials used in buildings other than the housing sector. This comparison is a rough proxy for buildings in other sectors, such as health and education. Based on regional hurricane damage reports, buildings in these sectors were most likely to be damaged from roof failures and leaks. If buildings in other sectors use similar roofing materials as the housing sector in each country, this comparison should illustrate any correlation between the increased use of resilient roof materials and reduced disaster losses in the health, education, and other sectors.

Country	Residential AAL	Outer Wall material	Roof material
Dominican Republic	0.44	75%	42%
Montserrat	2.27	71%	34%
Belize	0.52	52%	13%
Caribbean Average	**1.25**	**67%**	**12%**
Saint Vincent and the Grenadines	0.35	80%	7%
Trinidad and Tobago	0.96	78%	4%
Aruba	0.33	92%	3%
Saint Lucia	0.76	52%	3%
Antigua and Barbuda	3.26	40%	3%
Barbados	0.42	58%	2%
Guyana	0.00	28%	0%
Anguilla	1.74	96%	NA
British Virgin Islands	2.26	88%	NA
Bahamas	1.87	75%	NA
Jamaica	0.50	71%	NA
Grenada	0.41	52%	NA

Source: Author based on data from the UN Global Assessment Report on Disaster Risk Reduction 2015 and country census reports.

As with the analysis on outer wall materials, there is some evidence that increased use of concrete for roofing correlates with reduced risk of loss from climate impacts. For example, Antigua & Barbuda and Montserrat are geographically very close to each other and have almost identical wealth (as measured by GDP per capita). Montserrat, with a higher share of concrete use in roofs, shows an average annual loss from wind damage that is a full percentage point less than Antigua & Barbuda (although the risk from storm surge is much higher). The Dominican Republic, with the highest share of concrete roofs in the group, also shows a risk from wind damage well below the Caribbean average.

Table 4.3 shows the available census data on the share of buildings with roofs made of concrete and other materials compared to the country average AAL for the same four countries pairs that were analyzed for outer wall materials.

Fewer countries had census data showing residential buildings by roof material, but the two pairs of countries that did include such data follow the same pattern shown with the outer wall materials: countries with a higher share of concrete roofs have a lower total AAL than countries facing similar hurricane risks with lower shares of concrete roofs.

Based on this observation, the specific AAL for concrete roofs and non-concrete roofs was calculated for each region for which data was available using the same methodology as the outer wall material analysis. The resulting AAL for concrete and other roofs is shown in Table 4.4.

Here, the difference in AAL for concrete roofs and roofs made of other materials is even more striking than for the outer wall material analysis.

The above analysis suggests that improving the resiliency of outer walls and roofs in the Caribbean could significantly reduce the region's vulnerability to hurricanes and other climate impacts. Improving the resiliency of roofs in particular, such as by using concrete or stone, can reduce damage from high winds and subsequent damage to building interiors from leaking roofs.

In addition to using more resilient building materials, buildings can be made more resistant to climate impacts through enhanced construction practices. Analysis by the MIT Sustainable Concrete Lab highlighted the benefits of enhanced building techniques in reducing the expected hazard loss from hurricanes. The specific building enhancements that were investigated included:

Table 4.3. Residential AAL and roof material comparison.

Country	Residential AAL %	Roof			
		Concrete	Metal	Shingle	Other / Unknown
Montserrat	2.27%	34%	35%	30%	0%
Antigua & Barbuda	3.26%	2.6%	89.2%	7.5%	0.7%
St. Vincent & the Grenadines	0.35%	7.3%	90.8%	0.0%	1.9%
Barbados	0.42%	1.9%	90.8%	5.5%	1.8%
Anguilla	1.74%	NA	NA	NA	NA
British Virgin Islands	2.26%	NA	NA	NA	NA
Dominican Republic	0.44%	42%	56%	0%	2%
Jamaica	0.50%	NA	NA	NA	NA

Source: Author based on 2015 GAR and country census reports

Table 4.4. Residential AAL based on roof materials.

Country	Country Total AAL	Concrete Roof AAL%	Other Roof AAL%
Montserrat	2.27%	0.19%	3.35%
Antigua & Barbuda	3.26%	0.19%	3.35%
St. Vincent & the Grenadines	0.35%	0.02%	0.44%
Barbados	0.42%	0.02%	0.44%
Dominican Republic	0.44%	0.01%	1.76%
Jamaica	0.50%	0.01%	1.76%

Source: Author calculations

- **Roof straps.** These metal straps wrap around the rafters of a building's roof and securely fasten them to load bearing walls or columns that then connect directly to the foundation. The straps enhance the roofs' ability to withstand lifting force from hurricane winds and pressure differentials between the interior and exterior of the building, and improve the building's overall integrity by establishing a direct path for lifting forces to be transferred from the roof through the building structure and to the foundation.

- **Enhanced shingle and cladding connections.** The resiliency of roof shingles or other cladding materials, such as sheet metal, can be improved by using more resistant connectors (for example, screws instead of nails), more frequent connectors (placing screws or nails more closely together so more are used to hold down each square foot of shingle or cladding), or using specialized adhesives to augment or replace screw and nail connectors. These enhancements reduce the risk of individual shingles or cladding components from separating from the rest of the roofing assembly in high winds.

- **Window shutters and improved glass.** Adding higher strength windows, such as specially engineered glass or windows with multiple panes, and installing steel shutters that can be lowered during storms greatly reduce the risk of widows shattering in high winds or when struck by flying debris.

The MIT study estimated the break-even mitigation percent for applying enhanced construction methods to buildings built with wood, masonry, and concrete in Miami-Dade County, Florida (a region with similar hurricane exposure as the northern Lesser Antilles in the Caribbean). That is, the study calculated the incremental cost for enhanced construction that would be economically justified as a percentage of the original building cost. The analysis suggested that it was economically beneficial to spend up to 11.4% of the cost of a wooden building, 5.5% of the cost of a masonry building, and 4.2% of the cost of a concrete building to enhance the building's resilience to hurricanes.

These estimates were converted to an equivalent reduction in the AAL for the building by calculating the equivalent annual payment over a 50-year lifetime of the building and a discount rate of 12%. Essentially, the analysis calculated the annual amount that a building owner would be willing to pay for the enhanced construction, based on the breakeven analysis figure, expressed as a percentage of the building construction cost. Because the analysis is based on the break-even cost, this annual willingness to pay value is also equal to the reduction in expected annual losses from natural hazards, in other words, the reduction in the buildings AAL. The resulting calculations are shown in Table 3.8.

The reduction in AAL ranged from 0.51% for concrete buildings to 1.37% for wood buildings. Comparing the reduction to the baseline AAL for wood and concrete buildings that was calculated for Montserrat and Antigua & Barbuda above (the country pair with AALs closest to southern Florida), the reduction from enhanced construction practices was shown to be roughly 1/3 of the expected AAL of the material used.

Table 3.8. Residential AAL and outer wall material comparison.

Outer wall material	Breakeven mitigation %	Equivalent AAL% reduction	Baseline AAL% for wall type	% reduction from enhanced construction
Wood	11.40%	1.37%	4.50%	31%
Masonry	5.50%	0.66%	NA	NA
Concrete	4.20%	0.51%	1.40%	36%
				33%

Source: Author calculations

5. Conclusions

This report has highlighted the Caribbean region's vulnerability to hurricanes, and the high cost that hurricanes place on the region. Comparing hurricane damage to a country's GDP and GDP growth showed that there is a wide range in the frequency, strength, and impact of storms that have struck the region over the last 50 years. Hurricane damage (measured as a share of GDP) tended to be less in higher income countries than lower income countries. The average annual loss analysis also suggested that hurricanes place an ongoing economic drag on the region by shortening the useful life of infrastructure and diverting investment away from more productive economic and social uses.

The more detailed damage reports from individual storms suggested common areas of vulnerability. In particular, damage to building roofs and their connection to the walls was the most widely reported type of building damage, as well as the main factor for water and wind penetrating the building envelop and damaging furniture, equipment, and supplies inside.

Given this, the resiliency of the region's buildings and infrastructure, is of critical importance to minimize hurricane damage and losses. Census data from the region also showed that more resilient materials such as concrete and stone are used in the outer walls in less than 70% of the residential buildings in the region, and in less than 15% of the roofs. Higher income countries tend to have more residential buildings built with resilient materials. Although data is unavailable regarding the materials used for buildings in other sectors, hurricane damage reports suggest that education and health buildings are likely to have more resilient wall materials but are still vulnerable to roof damage.

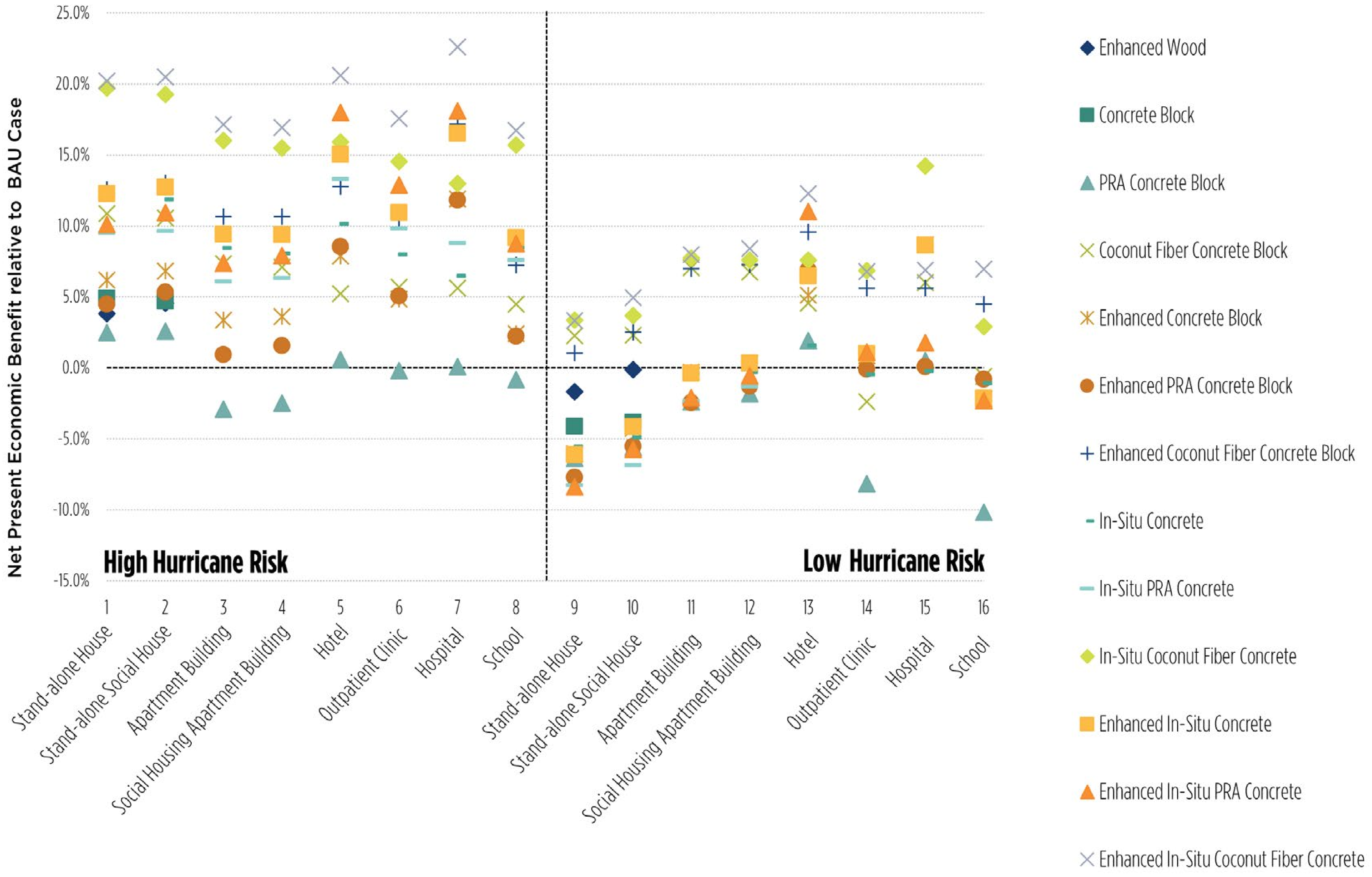
Comparing this data on building materials with the annual average loss data for neighboring countries (which are likely to have similar exposure to hurricane risks) showed that buildings with concrete outer wall and roofs have significantly lower expected AAL than non-concrete buildings.

This insight forms the basis for two subsequent technical reports: Report 2 analyzes the economic benefits of using resilient materials and construction techniques for different building categories in the Caribbean, and Report 3 examines the benefits of providing subsidized financing to promote resilient building development in the Caribbean.

Report 2 found that using resilient materials and construction methods in the Caribbean is economically beneficial across a wide range of building types and construction options. These economic benefits stem from the reduced hazard loss from using more resilient materials and construction methods, as well as from reduced energy use and CO2 emissions from improving the building's insulation and using greener concrete options with less embedded CO2. These benefits are therefore most notable in areas with high risk from climate impacts, high energy prices, and high CO2 content in the electricity mix.

Figure 5.1 summarize the economic benefits of all cases analyzed relative to the BAU case for eight building categories and two hurricane risk areas. In each summary, a positive figure indicates the option has a lower overall cost than the comparable BAU case (that is, it is economically beneficial to build the resilient alternative option rather than standard building practice). A negative figure indicates that the resilient alternative option is more expensive than the BAU option and is not economically beneficial to pursue.

Figure 5.1. Net Present Economic Benefit Relative to BAU Case (% of BAU Case).



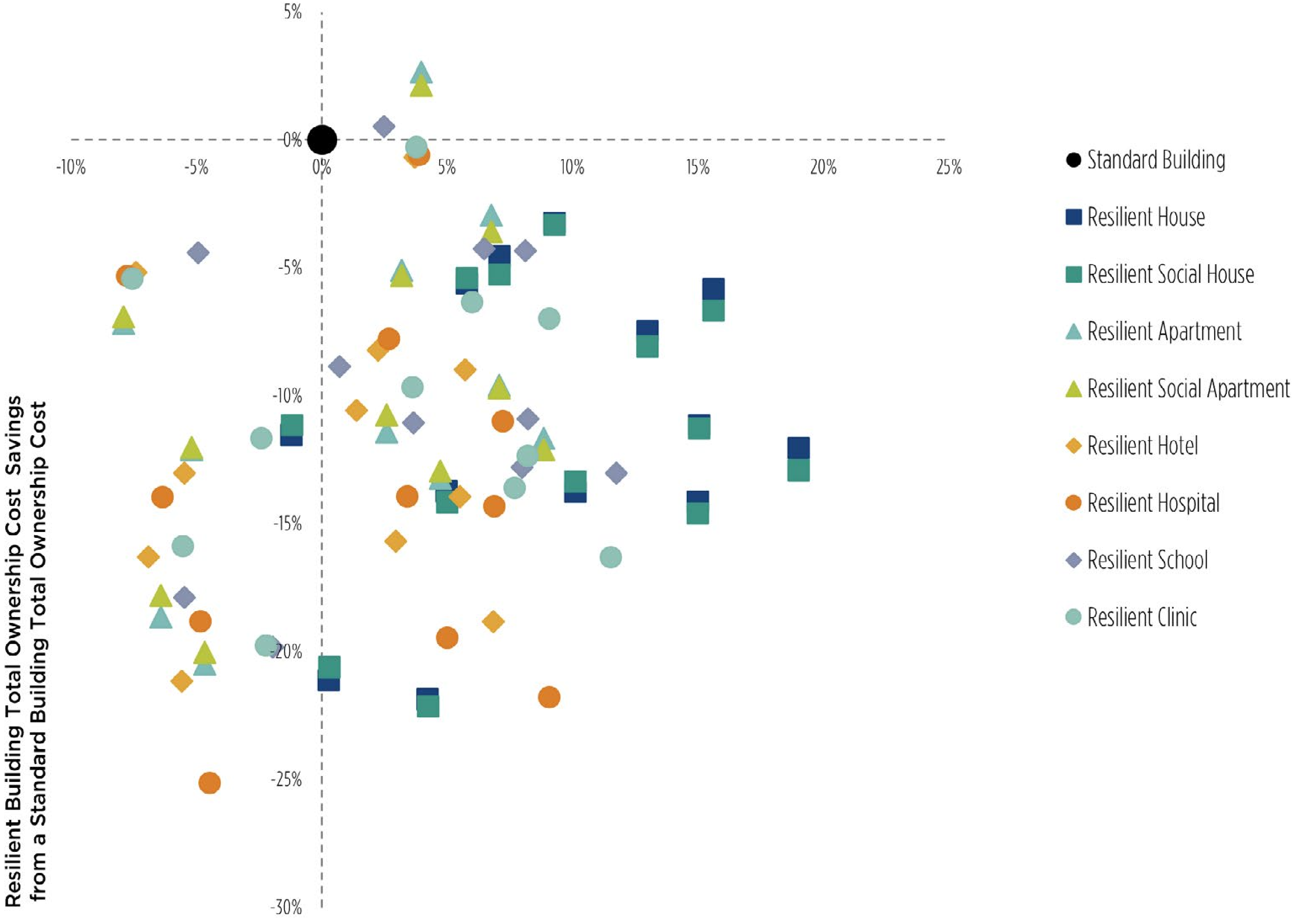
Source: Author calculations

The initial cost to build a structure using resilient building materials or construction techniques was found to be generally more expensive than standard building options, but the total ownership cost over the life of the building—including annual maintenance costs, energy costs, and hazard costs— was generally less. Total ownership costs for more resilient buildings were lower than standard buildings because of reduced energy costs (from better insulation) and reduced hazard costs (from the building's more resilient characteristics).

Figure 5.2 highlights this finding by plotting resilient building construction costs and total building ownership costs relative to standard building construction costs and total building costs for each building type and resilient material option that was analyzed in Report 2. In the figure, the horizontal axis shows the increase in construction costs for most resilient building options relative to standard buildings. The vertical axis shows the reduction in total ownership costs for most resilient building options relative to standard buildings.

The analysis modeled roughly a dozen variations in building materials and construction methods for each building category shown in the graphic.

Figure 5.2. Resilient building construction costs and total ownership costs relative to a standard building for all modeled building materials and construction methods across eight building categories.



Although the lifetime benefits from reduced hazard costs and, potentially, reduced energy costs, are much greater, the higher initial construction cost can deter project developers and building owners from investing in more resilient options. Providing low-cost finance to project developers (in the form of subsidized construction loans), to building owners (in the form of subsidized mortgages), or both can reduce the initial cost for more resilient buildings and incentivize developers and building owners. Report 3 examines the impact of providing low-cost financing on the cost to build resilient buildings and the overall cost to own resilient buildings in the Caribbean.

Resilient Building Category	Resilient Building Construction Cost Relative to Standard Building			Resilient Building Total Ownership Cost Relative to Standard Building		
	Min	Average	Max	Min	Average	Max
Stand-Alone House	-1.2%	9.1%	19.0%	-21.9%	-11.2%	-3.3%
Stand-Alone Social House	-1.2%	9.1%	19.0%	-22.2%	-11.5%	-3.3%
Apartment Building	-7.9%	1.2%	8.8%	-20.5%	-10.0%	2.6%
Social Apartment Building	-7.9%	1.2%	8.8%	-20.0%	-9.9%	2.1%
Hotel	-7.4%	0.3%	6.8%	-21.2%	-12.1%	-0.7%
Outpatient Clinic	-7.5%	2.9%	11.5%	-19.8%	-10.8%	-0.3%
Hospital	-7.7%	1.3%	9.1%	-25.1%	-13.8%	-0.6%
School	-5.5%	2.3%	11.7%	-19.8%	-11.3%	-4.3%
Overall	**-7.9%**	**3.8%**	**19.0%**	**-25.1%**	**-11.1%**	**2.6%**

Source: Author based on calculations from Report 2

Figure 5.3 compares the building purchase price and the total lifetime building ownership costs for resilient buildings across all building categories and construction archetypes that were analyzed under the different financial subsidy options—roughly 100 variations were modeled for each financial subsidy option. The resilient building costs are presented relative to the costs for a standard building of each category with standard financing.

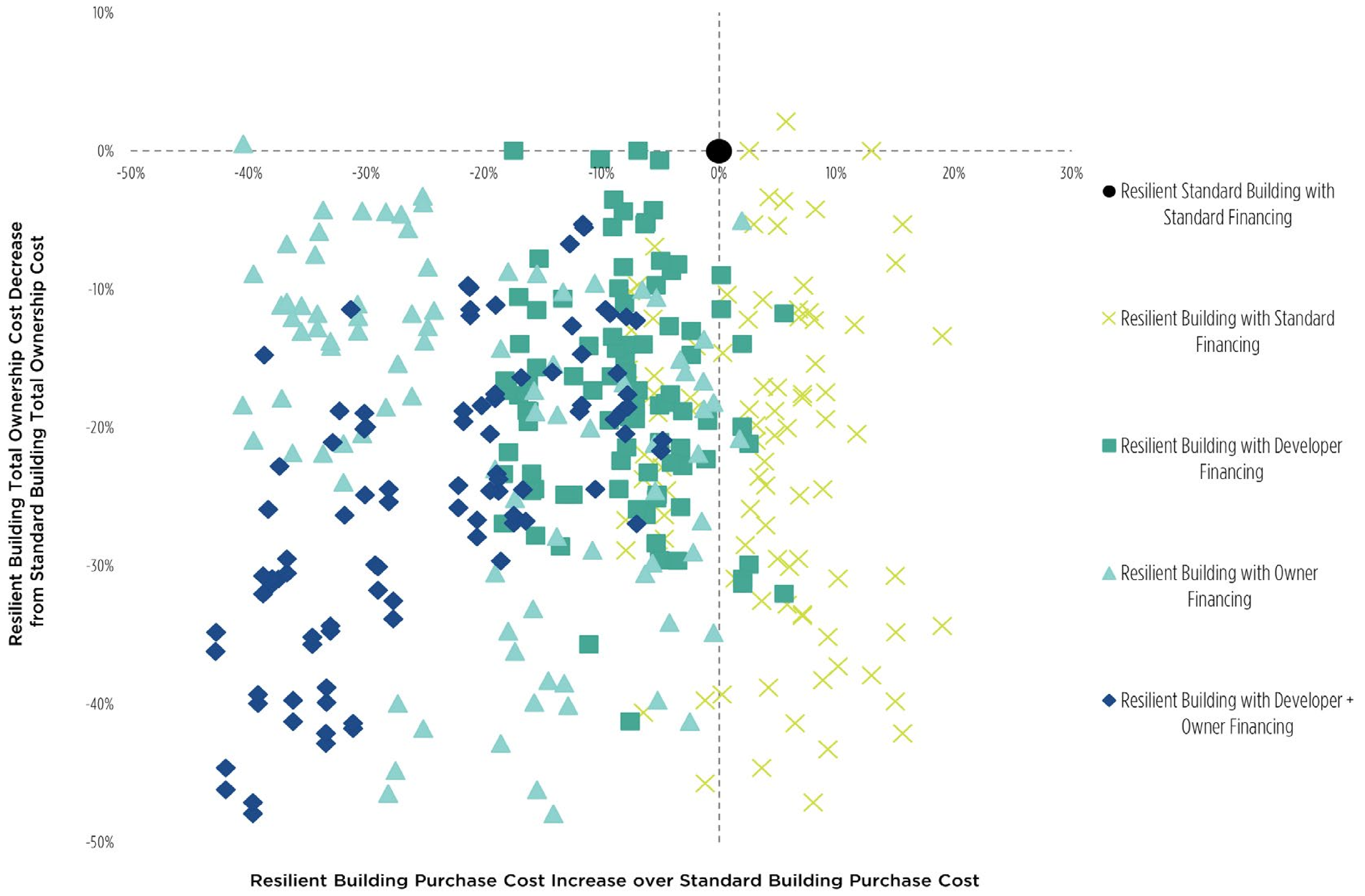
That is, the horizontal axis shows the increase in the purchase cost for a resilient building over the cost to purchase a standard version of each building category with standard financing. The vertical axis shows the decrease in total ownership cost over the life of the building for a resilient building below the total ownership cost for a standard version of each building category with standard financing.

The different data markers show the effect from the three financing subsidy options: subsidized developer finance, subsidized owner finance, and subsidized developer and owner finance.

The figure shows the impact of providing subsidized financing to the project developer, the building owner, or both, relative to standard financing options.

Figure 5.3 shows that providing subsidized finance to the project developer reduces the building purchase price below that of the BAU option for most of the analyzed resilient building options. Providing subsidized finance to the building owner would reduce the effective purchase price even further. Providing subsidized finance to both the developer and the building owner resulted in the greatest discount relative to the BAU cases, but did not provide a discount that was significantly greater than that of the subsidized owner finance alone.

Figure 5.3. Resilient building purchase costs and total ownership costs with different financing subsidies relative to a standard building with standard financing across all modeled combinations of building category, building material, and construction method.



This high level result suggests that providing subsidized financing to the building owner may be the most effective way to incentivize resilient construction practices among the three options that were considered (subsidized developer financing, subsidized owner financing, and both).. Providing subsidized finance to project developers can also reduce price barriers to building resilient structures, but does not have as great an impact on reducing the purchase price as subsidizing the mortgage for the owner.

Resilient Building Financing Subsidy	Resilient Building Purchase Cost Relative to Standard Building			Resilient Building Total Ownership Cost Relative to Standard Building		
	Min	Average	Max	Min	Average	Max
Standard Financing	-7.9%	3.8%	19.0%	-25.1%	-11.1%	2.6%
Subsidized Developer Financing	-18.3%	-7.9%	5.5%	-28.9%	-16.7%	-4.1%
Subsidized Owner Financing	-40.5%	-20.3%	1.9%	-46.5%	-23.4%	-3.3%
Subsidized Developer + Owner Financing	-42.8%	-24.5%	-4.8%	-47.9%	-25.2%	-5.3%

Source: Author calculations

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Social Infrastructure

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